

**Phonology and handedness in primary school: Predictions of the Right Shift**

**Theory**

Pamela Smythe and Marian Annett

School of Psychology, University of Leicester.

*Address:* School of Psychology, University of Leicester, University Road, Leicester,

UK LE1 7RH

*Running title:* Phonology and handedness

Word Count: 6552

**Abstract**

**Background:** The right shift (RS) theory of handedness suggests that poor phonology may occur in the general population as a risk associated with absence of an agent of left cerebral speech, the hypothesised RS + gene. The theory predicts that poor

phonology is associated with reduced bias to right-handedness. **Methods:** A representative cohort of primary school children was assessed on tests of phonology, nonverbal ability, literacy, and handedness. There were three types of analysis; for discrete variables, poor phonology and left hand preference; for continuous variables, phonology factor scores and hand skill; for 'cases' of specifically poor phonology.

**Results:** Reduced bias to dextrality was found in those with poor phonology for all types of analysis. Trends were similar for both sexes but stronger in males than females. Poor phonology was associated with a raised proportion of left-handed brothers. There was a strong association between poor phonology and poor literacy, but not all those with specifically poor phonology were poor readers or spellers.

Among children with poor phonology but not poor for other variables, some 23 - 31% were left-handed writers. **Conclusions:** Poor phonological processing is associated

with reduced bias to the right hand, consistent with absence of an agent of left

hemisphere advantage. **Key words:** Phonology, handedness, right shift theory, sex

differences, genetics. **Abbreviations:** AHPQ: Annett Hand Preference Questionnaire;

RS: right shift.

The aim of this research was to test the hypothesis that primary school children with poor phonological processing have reduced bias to right-handedness. The hypothesis follows from the theory that a substantial minority of the general population lack an agent that gives an advantage to the left cerebral hemisphere for speech production and incidentally increases the probability of right-handedness, the right shift (RS) theory (Annett, 1972, review 2002). These typical asymmetries for hemisphere specialisation and handedness are associated but not directly linked. Among atypical cases, about two-thirds of people with right hemisphere speech are right-handed, and about two-thirds of left-handers have left hemisphere speech. The RS explanation of these associations (Annett, 1975; Annett & Alexander, 1996) depends on the theory that hand preference depends on a continuous, accidental, normal distribution of asymmetry for hand skill, but that the distribution is displaced in a dextral direction by an agent of left hemisphere advantage (hypothesised RS + gene). Contrary to some accounts, the RS + gene does not cause right-handedness directly. It shifts the distribution of asymmetry by about 1 standard deviation so that some gene carriers remain below the threshold for right-handedness. Some people are hypothesised to lack the RS + gene (RS - - genotypes). In these cases cerebral specialisation and handedness depend on chance, and chances that are independent of each other. The mean difference between the hands in this group is expected to be zero, and hand preferences are likely to be evenly divided between left and right, with a majority mixed-handed. The first main support of the theory was found in families of two left-handed parents (Annett, 1974) where the children were about equally divided for greater skill in the left or right hand. In an enlarged sample, one-third were left-handed writers (Annett, 1983). Further developments of the model showed that the

literature on handedness in families is predictable if the shift depends on a single gene (Annett, 1978, 1999a; see Annett 2002 for a review of evidence and tests by segregation analysis).

Annett (1972) suggested that this theory might throw light on the raised proportion of mixed and left-handers among those with specific difficulties of speech and literacy (Orton, 1937). If some people lack an agent of left hemisphere speech, they should also lack group bias to dextrality. The hypothesised RS + gene gives a nudge toward left hemisphere specialisation and thereby aids speech acquisition. Some 18% of the population lack this aid, according to the RS genetic model, so it cannot be a major determinant of speech, language or literacy. However, aspects of speech learning and the cerebral representation of speech are likely to be at risk in the absence of RS. Studies of laterality and literacy have given rise to a large literature. The statistical significance of findings tend to be weak, leading to doubts about theoretical significance (Bishop, 1990). This is not surprising if, by analogy with signal detection theory, presence or absence of the signal (agent of left cerebral speech) has to be detected against the noise of a chance distribution of handedness. Meta-analysis of studies selected from the literature by Bishop (1990) revealed a small but significant excess of non-right-handers among those with poor literacy (Eglinton & Annett, 1994).

Research on dyslexics (poor readers and spellers with otherwise good abilities and educational opportunities) found the predicted excess of non-right-handers but also that some were strongly biased to the right for hand skill (Annett & Kilshaw, 1984). Annett and Manning (1990) found in a general school sample an excess of poor readers at both the left and right of the hand skill continuum. These findings

were consistent with expected risks for RS -- genotypes, but they suggested unexpected risks for RS ++ genotypes. The former were likely to have poor speech based processing but the latter might rely on speech based strategies to the detriment of other word recognition skills. This distinction could map onto the subtype classification of developmental dyslexics as phonological versus dyseidetic (Boder, 1973) or surface (Patterson, Marshall & Coltheart, 1985). Phonological dyslexics, on this analysis, should have reduced bias to dextrality while dyseidetic or surface dyslexics should be strongly biased to dextrality. The contrast was supported by a study of undergraduates with poor literacy skills (Annett, 1999b).

The present sample was collected mainly to investigate the hypothesised distinction between phonological and non-phonological dyslexics (Annett, Eglinton & Smythe, 1996). Poor readers were identified by scores at least 1.3 S.D below the mean (poorest 10%) for any of three criteria (BAS reading test 6+ errors, reading quotient at or below 80 on Schonell GWR, or standardized residual of 1.3z for BAS reading errors regressed on matrices score). Most children met more than one criterion. The poor readers were then classified as poor or not poor for phonology. Poor readers with poor phonology included 29% left writers while those without poor phonology included no left-handers. The present analyses extend the study of phonology in this sample, looking for weakness as a population characteristic, including some analyses when poor readers are excluded.

The studies described here were part of an investigation of literacy (reading and spelling), laterality (hand preference and hand skill) and cognitive abilities (phonological and visuospatial) in a representative cohort of nearly 500 children. The overall aims were to identify children who have specific literacy problems and then

look for differences for laterality and cognitive abilities. The research questions required the initial screening of a complete cohort, followed up by individual testing of children likely to be at risk, together with controls from the same classes. The present report describes findings from the initial screening by short group tests (year 1) and the individual follow up of a substantial number of children (year 2). The Annett Hand Preference Questionnaire (AHPQ, Annett, 1970) was distributed in year 3 to the families of all children in the classes of the initial cohort. The question was whether relatives of children with poor phonology were more often left-handed, as expected if this weakness was associated with an RS - - genotype.

Phonology and handedness were examined in three main ways, as discrete variables, as continuous variables, and for 'cases' of specifically poor phonology. The discrete approach, typical of the literature, involves looking for associations between two variables that are both defined by cut-offs at the extremes of their respective distributions, poor phonology and left-handedness. This requires a large initial sample and not too strict a criterion of poor phonology in order to have Ns large enough to compare percentages of left-handers. The data are presented in terms of odds ratios as these are unaffected by sample size and unequal groups (Howell, 1992, p 148). Statistical significance is assessed by the chi square test. Phonological processing and handedness were examined over the whole sample, and also at several levels of selection in order to remove children with identified problems, poor reading, slow hand speeds and low vocabulary test scores. Selections for good abilities were made to counter the argument that raised incidences of non-right-handedness might be due to developmental pathologies. Exclusion of poor readers from some analyses was particularly important because it had already been shown that poor readers with poor

phonology included an excess of left-handers (Annett et al., 1996). The question was whether the finding was true of not poor readers also. By excluding children with poor hand skills and poor vocabulary, effects of developmental pathologies should be reduced and effects of natural variation enhanced.

The continuous variable approach allowed the distribution of phonological skill to be examined over the continuum of relative hand skill in the whole sample. This was achieved by deriving a phonology factor score, by contrast with a nonverbal factor score. The distribution was investigated over groups classified for differences between the hands for tests of hand skill. The prediction was that phonology is poorer toward the left hand side of the asymmetry continuum.

The third analysis identified children with poor phonology factor scores but not poor nonverbal factor scores. The question was whether a group of cases with specifically poor phonology has an asymmetry distribution as expected for RS - - genotypes. The predictions were that children with specifically poor phonology have hand skills distributed about zero and hand preference mainly mixed.

There is considerable evidence that girls learn to talk slightly earlier than boys and are less prone to developmental speech and reading disorders (Halpern, 1986; Rutter et al, 2004). There is female superiority for speech production although not for verbal ability (Hyde & Linn, 1988). Females tend to be more often right-handed than males and they are more strongly shifted to the right for hand skill (Annett & Kilshaw, 1983). These observations are consistent with the idea that the hypothesised agent of left hemisphere advantage is expressed more strongly in girls than boys. The key questions for the present study were whether poor phonology is associated with

reduced bias to dextrality in participants and their relatives, and whether this applies to both sexes.

## METHOD

### *Design and Procedures*

The overall design of the study and procedures were described by Annett et al. (1996) and the present tests by Smythe (2002). A cross-sectional cohort of 9-10 year old children in 9 schools representative of a single local authority, covering both town and country, was screened for literacy, laterality and cognitive abilities. The initial screening was constrained by the need to assess children by group tests in class, and by the time available in a double class period. The screening was intended to identify all children who might have literacy problems, so that they could be followed up individually. The criterion of selection in Year 2 was a score at or less than one standard deviation below the mean on any of the year 1 tests. As many other children as time allowed were also seen in Year 2, so as to maximise the power of the comparisons to be made.

*Laterality tests.* The group test in Year 1 was hole punching (Holes, Annett, 1992b). Holes were punched through small circles printed on stiff paper, resting on a board with perforations beneath the printed circles, using a fine pointed red biro pen. After an initial practise trial by each hand, two 15 second test trials were made by each hand. A continuous measure of R-L hand skill was derived by subtracting the number of holes punched by the left hand from the number punched by the right hand and taking the difference as a proportion of the total ( $R-L\% \text{ Holes} = ((R - L)/(R+L)) * 100$ ). The Holes test can also be used to define 'left-handedness' because Annett (1992b) found that the hand punching the greater number of holes was



invariably the hand preferred for writing. This was true for 99.5% of 427 children observed for writing in the present sample (one left- and one right-handed writer were discordant for hole punching).

Individual testing in Year 2 allowed observation of hand use for the twelve items of the AHPQ. This permitted classification in hand preference subgroups (Annett, 1970, 1985), as listed in Table 3. Hand skill was measured by a peg moving task (Pegs, Annett, 1970, 1992b). A continuous measure of hand skill was obtained by subtracting the time taken by the right hand from that taken by the left hand, as a proportion of total time ( $R-L\% \text{ Pegs} = ((L-R)/(R+L))*100$ ). (The subtraction is R-L for Holes because more holes are usually punched by the right hand, but L-R for Pegs because the left hand typically takes longer.)

### *Tests of Phonology*

The initial screening for phonological processing in Year 1 was by a brief group test. Children were asked to spell six nonwords, made by changing one phoneme of words expected to be well known to the age group (gouse (house), doney (money), charch (church), fape (cape), toble (table), nater (later)). The words were presented at the end of a spelling test with instructions as follows: "If you are not sure how to spell the words it doesn't matter. Just do the best you can. Some of them will be pretend words so they cannot be right or wrong. I would like you to show me how you think they could be spelled." The nonwords were spoken twice, as clearly as possible by MA. Nonword spellings were scored by PS, blind to information on other tasks. Nonword spellings were allowed if they sounded like the target when pronounced (e.g. "gouss" and "gaus" were accepted for "gouse" but not "gose", "gawbs" or "gouth", see Smythe (2002, Appendix G) for a list of accepted nonword spellings).

Another group test of phonology was given in Year 1, a word order test (Annett, 1992a), which was included in the factor analysis but is not examined further here. The task was to listen to 4 unrelated words spoken via tape recorder and then indicate the order they were spoken on a printed sheet that listed the sets of words in a different order. Half of the sets were rhyming words and therefore easily confusable (sun, gun, fun, nun) and half were non-confusable (cap, lot, den, tun). This test was scored for confusable and non-confusable sets separately.

The individual test in Year 2 was a 10 item *phoneme segmentation* task adapted from Bruce (1964) and Stuart (1990). The task was to listen to a word and repeat it with a specified sound missing. The phonemes to be deleted were in the initial position ('fall - all'), the final position ('pint - pine') or a middle position ('bind-bide'). Responses to some words could be phonologically correct (as in pine or bide) or orthographically correct (as in pin or bid). Both were counted correct here.

#### *Further tests of cognitive abilities*

There were three tests of nonverbal ability. In year 1, spatial memory was assessed for drawing novel geometrical shapes. In year 2, the Coloured Progressive Matrices Test (Raven, 1963) and a test of visual shape recognition derived from Vellutino (1979) were given.

Educational achievement had been assessed by teachers at seven schools, using the Richmond tests (Heironymus, Lindquist & Fraser, 1975). Scores for the Vocabulary test (a multiple choice test offering four alternatives from which the child must select the correct meaning for a given word) were used to select for ability below. For the present sample (N = 384) the Vocabulary test mean was 104, SD 14.

#### *Family handedness*

In Year 3 of the research programme, sets of AHPQ were given to all children in the classes of the original cohort, with a letter to be taken home requesting completion by parents and siblings. Numbered envelopes were provided so that the forms could be returned to school anonymously. Returns were received from 58% of families. First degree relatives of the sample children were counted, including all full siblings of 6 years plus (but omitting younger children and half-sibs).

### *The sample*

The year 1 cohort included 479 children, 239 boys and 240 girls, mean age 121.4 months, SD 3.5 months. The second year follow-up sample included 397 children, 192 boys and 199 girls, mean age 134.7 months, SD 3.6 months. Children *not seen* in Year 2 were intended to be those without problems on any of the Year 1 tests. Children not seen in Year 2 were distributed across the laterality continuum fairly evenly (in groups distinguished for R-L% Holes below).

In the initial cohort there were 12 children whose first language was not English and 8 with physical or mental disabilities that made their performance on some of the tests unreliable. These 20 children were excluded from further analyses. There were also 4 children with missing data for Holes. Children described as 'poor readers' were all of 40 children identified by Annett et al. (1996), as described above.

## **RESULTS**

### **Phonology and left-handedness as discrete variables**

#### *Nonword spelling in Year 1*

Most children (79%) could produce 4 or more (from 6) acceptable nonword spellings and only 13 (2.8%) produced none. The mean was 1.3 , SD 1.5 errors, with a highly skewed distribution. The criterion of poor performance was 4 plus errors (N = 59,

13%) in order to have a reasonable number for statistical comparisons. Handedness was classified by the hand punching more holes, or by observed writing hand for those with missing Holes data.

Table 1 about here

Table 1 first compares the groups for the whole sample (top line). Good nonword spellers included 9.3% and poor nonword spellers 13.6% left-handers. The difference was in the direction predicted but not statistically significant by chi square test (odds ratio = 1.54;  $X^2(1, n = 459) = 1.08, p = .299$ ). Table 1 then shows successive selections for ability on other measures. The second line shows the effect of removing the 40 children previously identified as poor readers. Most of the poor readers (27) were in the group of poor nonword spellers as expected, giving a large association between reading and nonword spelling groups ( $X^2(1, n = 459) = 116.812, p < .001$ ). The question here was whether effects for handedness and poor phonology were removed with the poor readers, or did they persist among not poor readers? The latter with good nonword spelling were 9.0% and those with poor nonword spelling 15.6% left-handed (odds ratio = 1.86).

Table 1 then shows the not poor readers with poor performance on the Holes test excluded, to remove children whose poor hand skills might indicate pathology. The difference for hand preference was enhanced in the remaining children (8.9% versus 19.2%, odds ratio = 2.43). The next row of Table 1 removed further children with vocabulary test scores below 70. The contrast for handedness was between 9.0% and 20.8% for good versus poor nonword spellers respectively (odds ratio = 2.67). The contrast was stronger when the vocabulary criterion was 90 plus, 9.3% versus

31.3% left-handers with good versus poor phonology respectively (odds ratio 4.46,  $X^2$  (1, N = 299) = 7.8386,  $p = .005$ ).

#### *Phoneme segmentation*

Table 2 about here

Table 2 contrasts those good at phoneme segmentation (not more than 1 error) and those who were poor (2 or more errors). For the whole sample (top line) there were 8.6% left-handers among the good and 16.0% among the poor respectively (odds ratio = 2.02). When poor readers were removed, there were 8.9% versus 15.6% among good versus poor groups respectively. Table 2 then shows the contrasts when children were removed because they had slow peg moving times (mean time greater than 13.0s for either hand) and low vocabulary test scores. For children with good hand skill and vocabulary score 90 plus, there were 8.9% versus 23.3% left-handers among those with good versus poor phonology respectively (odds ratio 3.13;  $X^2$  (1, N = 267) = 5.942,  $p = .015$ ).

#### *Sex differences and family handedness*

The analyses of Tables 1 and 2 were repeated for sexes separately in the whole sample. Three of the four analyses found non-significant trends in the expected direction, but numbers were now small. Handedness of fathers, mothers, brothers and sisters did not differ between children classified for good versus poor nonword spelling. Relatives of children classified for phoneme segmentation included more left-handed brothers in those who were poor (44% of N = 16) versus not poor (18% of N = 105) (odds ratio 3.52,  $p = .020$ ).

#### **Phonology and handedness as continuous variables**

Factor scores were derived by principal component analysis with varimax rotation for the 377 participants completing the relevant tests of phonology and nonverbal ability. The four measures of phonological processing (confusable and non-confusable word order, nonword spelling and phoneme segmentation) had loadings greater than 0.7, while the three nonverbal tests had loading less than 0.3 on the first factor. For the second factor, there was the reverse pattern of loadings. The first factor was called 'phonology' and the second 'nonverbal ability'.

Do factor scores vary with relative hand skill? The sample was divided into four groups as evenly as possible for R-L% Holes, and also into four groups for R-L% Pegs. The groups can be broadly described from left to right as having absent, mild, moderate and strong bias to dextrality. The findings were similar for both analyses, and will be described further here for Pegs only (Ns 95, 101, 94, 87 in the 4 groups respectively).

Analyses of variance were run for phonology factor scores by R-L% Pegs group (4) and sex (2). The analysis found a significant effect overall ( $F(7,369) = 2.360, p = .023$ ), a significant effect for group ( $F(1,369) = 3.240, p = .022$ ) and also for sex ( $F(1,369) = 3.966, p = .047$ ). There was no interaction. The effect sizes were small to medium (partial eta squared = 0.026) for R-L% groups and small (0.011) for sex.

Figure 1 about here

Mean phonology factor scores in R-L% Pegs groups are shown for each sex in Figure 1. A trend to lower scores in the left-most group was evident for both sexes but particularly clear for males. Female means were higher than male means in all groups. Tests for trend in the sexes combined found a significant linear ( $p = .028$ ) and also

quadratic ( $p = .035$ ) trend. Further analyses for each sex separately found for males a significant linear trend ( $p = .014$ ) and also a tendency to quadratic trend ( $p = .080$ ).

Contrasts with Bonferroni correction between R-L% groups found that group 1 differed from group 3. There were no significant trends or contrasts for females.

### **Cases of specifically poor phonology**

Factor scores were used to identify children with particularly poor performance.

Taking a score of  $-1.5z$  and below as the criterion, 30 children were poor for phonology and 27 poor for nonverbal ability. No child was poor on both. Children of particular interest were those poor for phonology but with good nonverbal ability.

Taking a phonology factor score not greater than  $-1.5z$ , and a difference between phonology and nonverbal factors scores of at least  $1.5z$ , identified a group specifically poor on phonology but not nonverbal ability. There were 21 children, 15 males and 6 females (sex ratio 2.50:1), 66% previously identified as poor readers. The hand preference distribution was well spread across the 7 hand preference subgroups listed in Table 3 a. The subgroup distribution is also shown for children with phonology factor scores greater than  $-1.5z$ . The distributions differed significantly ( $X^2(6, n = 368) = 12.874, p < .045$ ). Among children with specifically poor phonology there were 81% non-right-handers including 29% left-handed writers. Among the not poor children there were 54% non-right-handers including 10% left-handed writers.

Table 3 about here

The groups were compared for peg moving hand skill using the R-L% measure and also the raw difference (L-R peg moving time) (Table 3 b). Variances were greater for children with specifically poor phonology than for those without poor phonology. Taking unequal variances into account, contrasts were significant.

Examination of peg moving asymmetry in children not poor for phonology reveals that the mean differences were to the right of zero by about 1 standard deviation, as expected. For children with poor phonology both means were close to zero, indicating no significant dextral shift.

### **Discussion**

The prediction that poor phonology in primary school children is associated with reduced bias to dextrality was examined in three ways. For the discrete variables, poor phonology and left-handedness, trends were in the predicted direction but not statistically significant for the sample as a whole. This analysis and the non-significant finding, parallel many others in the literature. However, when children were selected for good performance on other measures (reading, hand skills and vocabulary score) there was increased left-handedness in those with poor phonological processing (Tables 1 & 2). The enhanced effect for left handedness when children with poor performance on other tasks were excluded strengthens the argument that there is natural variation in the population, independent of any effects due to pathology. Children poor for hand skill and other abilities are more likely to have been affected by adverse influences on growth that might have influenced both handedness and phonology.

Comparisons for left-handed relatives relied on the 58% of families who returned questionnaires. This is a reasonable return rate for a survey of handedness, but the lower Ns required that all children be considered, without exclusions for ability. Relatives of children poor for nonword spelling did not differ for handedness but for children poor at phoneme segmentation, there was an excess of left-handed brothers. This finding is consistent with the theory that poor phonology and increased



left-handedness are associated with absence of the RS + gene but independent replication is needed.

The second type of analysis was for continuous variables, phonology factor scores and two measures of hand skill asymmetry, considered over the whole sample. The factor scores were derived by varimax rotation. (Other rotations gave essentially similar findings.) Analyses for hand skill found significant differences between R-L% groups and marginally significant differences between the sexes. This was true of both the Holes and Pegs tests, but only peg moving was described further because previous studies of hand skill in families, with which the present findings could be compared, depended on peg moving. Girls were superior to boys for phonology at all levels of relative hand skill, and differences between hand skill groups were less marked for girls (Figure 1). However, the pattern of association was similar for both sexes. The poorest performers were the left-most group, and performance improved with increasing bias to the right hand. A small decline at the extreme right gave a quadratic trend. The sex difference here is consistent with evidence that females are at lower risk than males for poor performance on speech based tasks (Hyde and Linn, 1988).

The third type of analysis examined 'cases' of specifically poor phonology. The 21 cases included 15 (71%) males and 14 (67%) poor readers. The question of interest was whether children with specifically poor phonology were distributed for handedness as expected for the RS - - genotype. They were well distributed across hand preference subgroups, including 29% left writers and 81% non-right-handers (Table 3a). Was the mean for hand skill asymmetry close to zero? The L-R difference between the hands for peg moving time was not significantly above zero, as found for

the children of two left-handed parents (Annett, 1974). The difference was identical to that found in a second sample of such children (Annett, 1983, Table 1). For R-L% also, the mean was not significantly above zero. The hand preference and hand skill findings are consistent with predictions for a group of predominantly RS - - genotype.

The key contrast sought and found in the present study was between a main group with a typical directional bias and a minor group without bias to either side. This pattern of results has been found in many studies of speech related cerebral cortex in dyslexics (reviews Beaton, 1997; Habib, 2000; Grigorenko, 2001; Toga & Thompson, 2003). Rae et al. (2002) found significant asymmetry in the volumes of cerebellar grey matter, larger in the right than left cerebellum in controls but symmetrical in dyslexics. Rae et al. (2002) also assessed peg moving skill and found times similar to those here for children with and without poor phonology. The interpretation of reduced asymmetries has generally been cautious, and often negative because of lack of statistical significance. Weak statistical effects are not surprising if the true difference between sides for atypical groups is zero, and the effect of the bias to asymmetry relatively small (about 1 z). However, the pattern of findings throughout the literature is consistent with predictions of the RS theory.

Genome wide scans of peg moving asymmetry have found strong evidence of linkage to a locus on chromosome 2p, and another suggestive locus on 17p (Francks et al., 2002, 2003). Insofar as the peg moving task is detecting the presence or absence of the shift to dextrality, these findings might give a clue as to the location of the putative RS + gene. However, the most important clues are likely to be found in searches based on measures of phonology.

What are the wider implications? The most important implication is that there is natural variation in the general population for cerebral dominance, contrary to the assumption that atypical asymmetries are pathological, as implied by terms such as 'anomalous' (Geschwind & Galaburda, 1985) or 'alinormal' (Halpern & Coren, 1990). Cerebral speech asymmetry in healthy samples is continuously distributed with negative skew (Knecht et al., 2002), resembling the distribution of asymmetry for hand skill. Atypical cerebral dominance occurs naturally without the need to postulate pathological influences on development, either genetic or environmental (Knecht et al., 2003). If some people lack cerebral dominance on either side, as surmised by Brain (1945), it is not surprising if there are risks to literacy. Reading and spelling problems are associated with weak phonological processing (Frith, 1985; Snowling, 1992) and the phonological deficit theory of dyslexia has strong support (Ramus et al., 2003). Is poor phonology to be interpreted as a pathological phenomenon, or as a risk associated with natural variation for cerebral dominance? This was the main question for the present research, in seeking an association between poor phonology and increased non-right-handedness in an epidemiological sample. We found evidence for this link in several analyses. An important problem for future research will be to distinguish the range of normal variation from that of specific disorders of speech (Enard et al., 2002) and literacy (Schulte-Körne, 2001) due to identified genetic anomalies. Progress in mapping the human genome, however, will probably require frequent review of the distinction between natural and abnormal variation.

*Acknowledgements:* This research was supported by a grant to M. Annett from the Wellcome Trust. We are grateful to the schools and families that participated.

*Corresponding author:* Dr. Marian Annett, Emeritus Reader, School of Psychology, University of Leicester, University Road, Leicester LE1 7RH. Email [doc@le.ac.uk](mailto:doc@le.ac.uk)

### References

- Annett, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology*, 61, 303-321.
- Annett, M. (1972). The distribution of manual asymmetry. *British Journal of Psychology*, 63 343-358.
- Annett, M. (1974). Handedness in the children of two left-handed parents. *British Journal of Psychology*, 65, 129-131.
- Annett, M. (1975). Hand preference and the laterality of cerebral speech. *Cortex*, 11, 305-328.
- Annett, M. (1978). *A single gene explanation of right and left handedness*. Coventry: Lanchester Polytechnic.
- Annett, M. (1983). Hand preference and skill in 115 children of two left-handed parents. *British Journal of Psychology*, 74, 17-32.
- Annett, M. (1985). *Left, right, hand and brain: The right shift theory*. London, Lawrence Erlbaum Associates Ltd.
- Annett, M. (1992a). Phonological processing and right minus left hand skill. *The Quarterly Journal of Experimental Psychology*, 44A, 33-46.
- Annett, M. (1992b). Five tests of hand skill. *Cortex*, 28, 583-600.
- Annett, M. (1999a). Left-handedness as a function of sex, maternal versus paternal inheritance and report bias. *Behavior Genetics*, 29, 103-114
- Annett, M. (1999b). Handedness and lexical skills in undergraduates. *Cortex*, 35, 357-372.
- Annett, M. (2002). *Handedness and brain asymmetry: The right shift theory*. Hove, East Sussex: Psychology Press.

- Annett, M. & Alexander, M.P. (1996). Atypical cerebral dominance: Predictions and tests of the right shift theory. *Neuropsychologia*, 34, 1215-1227.
- Annett, M., Eglington, E., & Smythe, P. (1996). Types of dyslexia and the shift to dextrality. *Journal of Child Psychology and Psychiatry*, 37, 167-180.
- Annett, M. & Kilshaw, D. (1983). Right- and left-hand skill II: Estimating the parameters of the L-R difference in males and females. *British Journal of Psychology*, 74, 269-283.
- Annett, M., & Kilshaw, D. (1984). Lateral preference and skill in dyslexics: Implications of the right shift theory. *Journal of Child Psychology and Psychiatry*, 25, 357-377.
- Annett, M., & Manning, M. (1990). Reading and a balanced polymorphism for laterality and ability. *Journal of Child Psychology and Psychiatry*, 31, 511-529 (see corrigendum, Annett & Manning 1994).
- Beaton, A. (1997). The relation of planum temporale asymmetry and morphology of the corpus callosum to handedness, gender and dyslexia: A review of evidence. *Brain and Language*, 60, 255-322.
- Bishop, D.V.M. (1990). *Handedness and developmental disorder*. Oxford: Blackwell.
- Boder, E. (1973). Developmental dyslexia: A diagnostic approach based on three atypical reading-spelling patterns. *Developmental Medicine and Child Neurology*, 15, 663-687.
- Brain, W.R. (1945). Speech and handedness. *Lancet*, 249, 837-841.
- Bruce, D.J. (1964). The analysis of word sounds. *British Journal of Educational Psychology*, 34, 158-170.

- Eglinton, E., & Annett, M. (1994). Handedness and dyslexia: A meta-analysis. *Perceptual and Motor Skills*, 79, 1611-1616.
- Enard, W., Przeworski, M., Fisher, S.E., Lai, C.S.L., Wiebe, V., Kitano, T., Monaco, A.P. & Paabo, S. (2002). Molecular evolution of FOXP2, a gene involved in speech and language. *Nature*, 418, 869-872.
- Francks, C., DeLisi, L.E., Fisher, S.E., Laval, S.H., Rue, J.E., Stein, J.F., & Monaco, A.P. (2003). 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, I.L., Richardson, A.J., Marlow, A.J., Stein, J.F., & Monaco, A.P. (2002). A genomewide linkage screen for relative hand skill in siblings pairs. *American Journal of Human Genetics*, 70, 800-805.
- Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.) *Surface dyslexia*. (pp. 301-330). London: Routledge & Kegan Paul.
- Geschwind, N., & Galaburda, A. M. (1985). Cerebral lateralization. Biological mechanisms, associations and pathology I: A hypothesis and a program for research. *Archives of Neurology*, 42, 428-458.
- Grigorenko, E.L. (2001). Developmental dyslexia: An update on genes, brains and environments. *Journal of Child Psychology and Psychiatry*, 42, 91-125.
- Habib, M. (2000). The neurological basis of developmental dyslexia: An overview and working hypothesis. *Brain*, 123, 2373-2399.
- Halpern, D. F. (1986). *Sex differences in cognitive abilities*. Hillsdale, NJ: Erlbaum.

- Halpern, D. F., & Coren, S. (1990). Laterality and longevity: Is left-handedness associated with a younger age at death? In S. Coren (Ed.) *Left-handedness: behavioral implications and anomalies*. (pp. 509-545). Amsterdam: Elsevier.
- Heironymus, A.N., Lindquist, E.F., & Fraser, I. (1975) *Richmond tests of basic skills*. Windsor: NFER-Nelson.
- Howell, D.C. (1992). *Statistical methods for psychology*, 3<sup>rd</sup> ed. Belmont, CA: Duxbury Press.
- Hyde, J. S. & Linn, M. C. (1988). Gender differences in verbal ability: A meta-analysis. *Psychological Bulletin*, 104, 53-69.
- Knecht, S., Flöel, A., Dräger, B. Breitenstein, C., Sommer, J., Henningsen, H., Ringelstein, E. B., & Pascual-Leone, A. (2002). Degree of language lateralization determines susceptibility to unilateral brain lesions. *Nature Neuroscience*, 5, 695-699.
- Knecht, S., Jansen, A., Frank, A., van Randenborgh, J., Sommer, J., Kanowski, A. & Heinze, J. (2003). How atypical is atypical language dominance? *Neuroimage*, 18, 917-927.
- Orton, S.T. (1937). *Reading, writing and speech problems in children: A presentation of certain types of disorders in the development of language*. London: Chapman and Hall.
- Patterson, K. E., Marshall, J. C., & Coltheart, M. (1985). *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading*. London: Lawrence Erlbaum Associates.
- Rae, C., Harasty, J.A., Dzendrowskyj, T.E., Talcott, J.B., Simpson, J.M., Blamire, A.M., Dixon, R.M., Lee, M.A., Thompson, C.H., Styles, P., Richardson, A.J.,



- & Stein, J.F. (2002). Cerebellar morphology in developmental dyslexia. *Neuropsychologia*, 40, 1285-1292.
- Ramus, F., Rosen, S., Dakin, S. C., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: insights from a multiple case study of dyslexic adults. *Brain*, 126, 841-865.
- Raven, J.C. (1963). *Guide to using the coloured progressive matrices*. London: H.K. Lewis.
- Rutter, M., Caspi, A., Fergusson, D., Horwood, L. J., Goodman, R., Maughan, B., Moffit, T. E., Meltzer, H., & Carroll, J. (2004). Sex differences in developmental reading disability: New findings from 4 epidemiological studies. *Journal of the American Medical Association*, 291, 2007-2012.
- Schulte-Körne, G. (2001). Annotation: Genetics of reading and spelling disorder. *Child Psychology and Psychiatry*, 42, 985-997.
- Smythe, P. (2002). *Aspects of phonological processing in subgroups of left and right handedness*. Unpublished PhD thesis, University of Leicester.
- Snowling, M. (1992). *Dyslexia: a cognitive developmental perspective*. Oxford: Blackwell.
- Stuart, M. (1990). Processing strategies in a phoneme deletion task. *The Quarterly Journal of Experimental Psychology*, 42A, 305-327.
- Toga, A. W., & Thompson, P. M. (2003). Mapping brain asymmetry. *Nature Reviews Neuroscience*, 4, 37-48,
- Vellutino, F. (1979). *Dyslexia, theory and research*. London: MIT Press.

**Table 1 Left-handedness in children classified for non-word spelling: All cases and cumulative selection for abilities.**

	Non-word spelling						
	N	Good Left- handed %	N	Poor Left- handed %	odds ratio	lower & upper bounds	p 2-tail
Total sample	400	9.3	59	13.6	1.539	.679-3.489	.299
Not poor readers	387	9.0	32	15.6	1.862	.675-5.142	.223
Holes >25 both hands	358	8.9	26	19.2	2.426	.857-6.867	.086
Vocabulary 70+	301	9.0	24	20.8	2.671	.924-7.720	.060
Vocabulary 90+	281	9.3	16	31.3	4.458	1.438-3.822	.005

**Table 2 Left-handedness in children classified for phoneme deletion: All cases and cumulative selection for abilities.**

	Phoneme deletion				odds ratio	lower & upper bounds	p 2-tail
	N	Good Left-handed %	N	Poor Left-handed %			
Total sample	302	8.6	75	16.0	2.022	.968-4.224	.057
Not poor readers	292	8.9	45	15.6	1.885	.765-4.641	.162
Peg time <= 13.0 both hands	287	9.1	44	15.9	1.889	.770-4.684	.158
Vocabulary 70+	251	9.2	38	18.4	2.238	.887-5.648	.081
Vocabulary 90+	237	8.9	30	23.3	3.130	1.202-8.154	.015

**Table 3 Cases of specifically poor phonology compared with not poor cases.***(a) Subgroup hand preference compared by chi square*

	Phonology		p
	Poor	Not poor	
N	21	347	
Subgroup hand preference	Percent	Percent	
1. Right consistent	19	46	
2 Right weak left	14	10	
3 Right moderate left	14	19	
4 Right strong left	24	15	
5 Left strong right	5	3	
6 Left weak right	10	3	
7 Left consistent	14	4	
			.045

*(b) Hand skill asymmetries compared by t-test*

	Mean (SD)	Mean (SD)	p for unequal variances
L-R Peg time (sec.)	0.2 (1.2)	0.8 (0.9)*	.031
R-L% Pegs	0.7 (5.7)	3.9 (4.3)*	.019
* variances differ			

**Figure Legend**

Phonology factor scores in R-L% peg moving quartiles for males and females.

