Good phonetic errors in poor spellers are associated with righthandedness and possible weak utilisation of visuospatial abilities

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Abstract

Poor spellers in normal schools, who were not poor readers, were studied for handedness, visuospatial and other cognitive abilities in order to explore contrasts between poor spellers with and without good phonology. It was predicted by the right shift theory of handedness and cerebral dominance that those with good phonology would have strong bias to dextrality and relative weakness of the right hemisphere, while those without good phonology would have reduced bias to dextrality and relative weakness of the left hemisphere. Poor spellers with good phonetic equivalent spelling errors (GFEs) included fewer left-handers (2.4%) than poor spellers without GFEs (24.4%). Differences for hand skill were as predicted. Tests of visuospatial processing found no differences between the groups in levels of ability, but there was a marked difference in pattern of correlations between visuospatial test scores and homophonic word discrimination. Whereas good spellers and poor spellers without GFEs showed positive correlations between word discrimination and visuospatial ability, there were no significant correlations for poor spellers with GFEs. The differences for handedness and possibly for the utilization of visuospatial skills suggest that surface dyslexics differ from phonological dyslexics in cerebral specialisation and perhaps in the quality of inter-hemispheric relations. Keywords Dyslexia, surface dysgraphia, handedness, homophones, visuospatial abilities, right shift theory.

6/30/2008

These studies examined a population cohort of poor spellers in primary school, who were not poor or dyslexic readers, for the presence or absence of good phonetic equivalent (GFE) spelling errors. The aim was to investigate the distribution of handedness in the presence of good phonological awareness as shown by GFEs. The prediction was that in contrast to good spellers and to poor spellers with poor phonology, children giving GFEs are more often *right-handed*. The second aim was to explore the possibility that the spelling problem of children giving GFEs is associated with a deficit of right hemisphere functions, perhaps a weakness of visuospatial processing. The children of interest resemble those called 'dyseidetic' (Boder, 1973) or developmental 'surface' (Patterson et al., 1985) dyslexics.

Poor spelling, or dysgraphia, is part of a spectrum of literacy problems that can be considered under a general heading of 'dyslexia', poor literacy that cannot be ascribed to low intelligence or lack of opportunities to learn. The term 'dyslexia' is used here to include poor readers and spellers, both absolutely and relative to intellectual ability, on the understanding that children in normal schools should be able to acquire a reasonable standard of literacy, unless they have serious learning disabilities. Poor spelling may or may not be associated with difficulties in reading (Frith, 1980) and it frequently persists when former reading problems are resolved (Rutter et al., 2006). It may occur as an acquired dyslexia/dysgraphia following brain insult, or it may occur as a developmental problem. The present research examined poor spellers in normal schools after dyslexic readers and children with physical or mental handicaps were excluded from analysis. The question is whether poor spellers can be classified in subgroups that do or do not have

weakness in phonological processing, and whether these groups differ for handedness and for visuospatial abilities.

There is a huge literature on the acquired and developmental dyslexias and several models of the cognitive processes involved (reviews in Beaton, 2004; Snowling and Hulme, 2005). Weak phonology is found in many developmental dyslexics and it is the basis of the most widely accepted theory of dyslexia (Snowling 2000; Ramus et al., 2003). Weak phonology is associated with poor grasp of the relationships between letters and sounds, or between graphemes and phonemes, making it difficult to read new words or nonwords by 'building' words from their elements. There is also poor awareness of phonemic structure as when asked to repeat a word with a phoneme deleted (such as 'find' without the 'd' to give 'fine'). These weaknesses are agreed to characterize 'developmental phonological dyslexics' (Boder, 1973; Temple and Marshall, 1983; Olson et al., 1985). What is more controversial is whether there are other types of dyslexia (Barron, 1980; Castles and Coltheart, 1993) with different problems. Of particular interest here are cases in which grapheme-phoneme relationships are well understood but used inappropriately. The weakness appears to be in learning that many words in English have irregular spellings (such as 'pint', 'yacht') that do not follow the phonetic rules. The main features of this type of literacy problem are the regularisation of irregular words, and weakness in distinguishing homophonic words (such as 'route' and 'root', 'son' and 'sun'). The term 'surface' dyslexia was first applied to brain injured patients who made regularisation errors in reading (Marshall and Newcombe, 1973). Other terms for this pattern of disability are 'morphemic' dyslexia (Seymour and McGregor, 1984) and 'orthographic' dyslexia (Olson et al., 1985). It is controversial,

6/30/2008

however, whether developmental dyslexics who make regularisation errors and can read new words and nonwords (in contrast to phonological dyslexics) form a distinct subgroup (Snowling et al., 1998; Stanovich et al., 1997; Temple, 1985).

Evidence for the distinction between phonological and surface dyslexia has been found in two contrasting undergraduates (Hanley and Gard, 1995) and in numerous individual case studies (Campbell and Butterworth, 1985; Coltheart et al., 1983; Funnell and Davison, 1989; Goulandris and Snowling, 1991). A biological foundation for this distinction is suggested by evidence that phonological and surface dyslexias are independently heritable (Castles et al., 2006; Gayan and Olson, 2003). They also differ in EEG recordings while performing cognitive tasks (Flynn and Boder, 1991), but it is not clear that the pattern of differences fits expectations for Boder's theory (Flynn et al., 1992). Flynn and Deering (1989) found left temporo-parietal activity in dyseidetic dyslexics which suggested they over-use linguistic abilities (as hypothesized below for the RS + + genotype). Computational models of reading can be manipulated to produce errors resembling those of phonological or surface dyslexia (Coltheart, 2005; Harm and Seidenberg, 1999). The present research contributes to the evidence for a biologically based difference between phonological and surface dyslexics by showing that poor spellers with GFE errors differ from poor spellers without such errors for both handedness and the possible utilisation of visuospatial abilities.

The hypotheses which prompted the present research were suggested by the right shift (RS) theory of handedness and cerebral dominance (Annett, 1972, 1978). Annett (2002) reviewed the development of the RS theory, including its application to questions about dyslexia, along with proposed alternative theories. Critical reviews of Annett

5

(2002) were given by Corballis (2004), Crow (2004), Elias (2004) and McManus (2004) together with author's response (Annett, 2004). The RS theory suggests that handedness depends on a chance distribution of differences between the sides of bilateral organisms, but that in humans the normal distribution is displaced in a dextral direction by a gene (RS +) which gives a relative advantage to the left cerebral hemisphere. This advantage to the left hemisphere promotes the development of speech on that side. The mechanism of gene action is unknown, but findings for relative hand skill suggest that it is likely to involve a weakening of the left hand and right hemisphere (Annett, 1992a; Kilshaw and Annett, 1983) and poorer spatial abilities (Annett, 1992c).

The idea that an inherited factor might promote left hemisphere speech and incidentally bias handedness to the right suggested that if some individuals lacked this factor (RS - - genotypes) an explanation would be offered for Orton's (1925, 1937) observation that children with developmental language problems include many not strongly biased to the right hand. This hypothesis was followed up and supported in several studies (reviewed in Annett, 2002; Smythe, 2002). A surprising discovery, in the course of these investigations was that dyslexics attending a remedial centre included some who were *strongly biased to the right hand* for hand skill, in addition to the expected excess of left- and mixed-handers with reduced bias to the right. This suggested the possibility that there are risks to literacy at both sides of the laterality continuum. For RS - genotypes, at the left side of the continuum of right minus left (R-L) hand skill, there could be risk for speech based processes, while RS + + genotypes, at the right of the continuum, might over-rely on speech based processes. If this distinction maps onto the distinction between phonological and surface dyslexics, it would be consistent with the

6/30/2008

use of grapheme-phoneme rules by surface dyslexics when they are inappropriate. Irregular words and homophonic words must be learned by some other process independent of sound based rules. Reading and spelling irregular words must depend on visuospatial representations of combinations of letters. These representations might involve the right hemisphere. The hypothesis that the RS+ gene is associated with right hemisphere weakness is consistent with the idea that some people should have particular difficulty with the representation of letter combinations. Skilled readers appear to recognise words in their vocabulary by some very rapid process that allows them to go straight from orthography to speech. Such a process might depend on visual recognition and recall mechanisms in which the right hemisphere has a role.

This analysis of possible relations between handedness, cognitive weaknesses and dyslexia prompted research on samples of undergraduates and school children, looking for evidence of a dissociation between types of problem (phonological versus nonphonological) and hand preference (higher versus lower prevalence of nonright-handedness, respectively). Undergraduates were tested for phonological processing and for homophone discrimination and shown to differ as expected, relative weakness in phonology being more prevalent at the left of the laterality continuum while relative weakness for real word homophone discrimination was more prevalent at the right of the continuum (Annett, 1999). The present report depends on a population cohort of children in primary school that has been described for two previous analyses (Annett et al., 1996; Smythe and Annett, 2006). Annett et al. (1996) described the children who could be classified as poor or dyslexic readers. It was found that among those with weak phonology there were 29.4% left-handed writers, while among those without weak

6/30/2008

phonology there were no (0%) left-handers. Control children (who were neither poor readers nor poor spellers) were 9.7% left-handed. The second set of analyses (Smythe and Annett, 2006) examined phonological processing across the sample, and found this was particularly weak at the left side of the laterality continuum. Children poor for phonology (excluding poor readers, those with poor hand skills, and poor for other relevant variables) included 23-31% left-handed writers in three different analyses.

The present analyses focused on poor spellers, and looked for problems expected to be associated with the right side of the laterality continuum (Eglinton, 2005). Is there an excess of right-handers among those with poor literacy but good grasp of phonemegrapheme relationships? Is this associated with signs of right hemisphere weakness? Contrasts were made between poor spellers with and without weak phonology. The two types of poor speller were compared with the rest of the sample, some unselected and some matched for matrices percentile.

Method

Design and procedures

The present analyses describe aspects of the findings of a three year study of a cohort of children drawn from normal schools. The aim was to describe the whole sample for measures that could be made by group testing in class, and then to identify children with possible literacy problems for further individual examination. The children attended 9 schools, regarded as representative of the local education authority, including both town and country districts. In the first year of study all children in the 9-10 year age group were screened for laterality, literacy and cognitive abilities using short group tests.

Because spelling could be tested in class, the whole sample was screened for spelling in Year 1.

Tests requiring individual examination, including reading, were given in Year 2. The criterion for selection in Year 2 was any score on Year 1 tests that fell at or below one standard deviation below the mean for the sample. As many other children from the same classes were seen as time allowed, in order to increase the power of comparisons. Some 80% of the initial cohort was seen in Year 2. Children *not* seen in Year 2 were likely to be making normal progress in school. Absentees and children moving between schools were seen on subsequent visits if possible.

The Year 1 tests were administered by MA in the presence of a research assistant and usually the class teacher. The Year 2 children were collected from their classes in pairs and tested individually by two researchers using parallel forms of the tests. The physical arrangements for testing and the order of tests were planned so as to ensure the children were fully engaged with their own tests and that performances were independent. The tests described below are those relevant to this particular report. *Participants*

The total sample screened in year 1 included 479 children, 239 boys and 240 girls, mean age 121.4 months, SD 3.5 months. The children omitted from the present analyses include those whose first language was not English, those with physical or mental disabilities that precluded testing, and dyslexics/poor readers. (The latter were the poorest 10% for any of three criteria: British Ability Scale (BAS) (Elliott et al., 1978) reading test errors of 6+: reading quotient at or below 80 on the Schonell (Schonell and Schonell, 1952) graded word reading test given in year 3: standardized residual of 1.3z+ for BAS

reading errors regressed on Raven's (Raven et. al., 1984) matrices test score). Because poor readers were removed, the present poor spellers all read at a level above reading quotient 80.

After the exclusions described above, there were 414 children available for the spelling analyses in Year 1, of whom 324 were tested further in Year 2. All children available were included in the main analyses. For some purposes children were matched for Matrices percentile in order to control for levels of ability, in three groups of 30, as described below.

Laterality

A hole punching (Holes) group test of hand skill was devised for the present study. The test required holes to be punched through small circles printed on stiff paper, resting on a board with holes perforated beneath the circles, using a fine pointed biro pen (Annett, 1992b). After an initial practice trial by each hand, two 15 second trials were made by each hand in turn (order RLRL). A continuous measure of right minus left (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)% Holes = (((R-L)/(R+L))*100).

The Holes test can also be taken to define the discrete variable 'left-handedness' because Annett (1992b) found that the hand punching the greater number of holes was invariably the hand preferred for writing. Of the children observed writing in years 2 and 3 of the present study only one left- and one right-hander were discordant for hole punching performance. For the present purpose, the preferred hand means the hand punching more holes.

11

Literacy

Spelling: The main test of literacy in Year 1 was spelling from oral dictation. The 10 words of the year ten level of the Schonell graded word spelling test (Schonell and Schonell, 1952) were given. This test was relatively difficult for 9 – 10 year old children but was given with the intention of generating errors that could be classified for good phonetic equivalence. Each word was spoken twice by MA, first alone, and then embedded in a phrase or sentence to clarify the meaning (e.g. "Final, soccer cup final."). The spelling test was followed immediately by a list of nonwords (below). The instructions for the spelling and nonword spelling tests were to write down the word and if not sure of the spelling, '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'.

<u>Reading:</u> The BAS single word reading test, (lists C or D for the children tested in parallel) was given in Year 2.

<u>Homophonic word discrimination</u>: A list of 24 pairs of homophonic words (e.g. route, root; saw, sore) was given to each child as a group test in year 1. The task was to listen to a sentence spoken by MA and to underline or otherwise indicate the word that represented the meaning for that sentence (e.g. Our *route* was marked on a map). *Phonology*

<u>Nonword spelling</u>: The spelling test was followed immediately with 6 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).

<u>Phoneme deletion</u>: The task, given as an individual test in Year 2, was to listen to a word and repeat it with a sound missing (adapted from Bruce, 1964; Stuart, 1990). The phonemes to be deleted were in the initial position (as in fall – all), the final position (as in pint – pine) or the middle position (bind – bide) Some responses could be phonologically correct (pine or bide) or orthographically correct (pin, bid). Both were counted correct for the present purpose. The score was number of errors for 10 items. *Visuospatial abilities*

Drawing novel geometrical shapes: Four novel geometrical shapes were taken by special permission from a test under development by the National Foundation for Educational Research. Each figure was displayed for 5 seconds by overhead projector to the class in year 1. After 5 seconds delay, the children were asked to reproduce the shape from memory. The first shape was displayed a second time after the drawing was completed in order to point out salient features expected in reproduction. No further guidance was given. Marks were awarded for features such as the accuracy of angles and parallel lines. Raven's Coloured Matrices: The coloured matrices test (Raven et al., 1984) was given individually in year 2.

<u>Visual Shape Recognition</u>: This test, derived from Vellutino (1979), was given in year 2. The child was shown sets of geometric shapes (from one to four) for 5 seconds and then asked to find them in an array of 12 shapes.

The classification of spelling errors as good phonetic equivalents

The classification of spelling errors was made by EE, blind to other information about the participants. The judgement of phonetic equivalence was made independently by four judges (a teacher, two research assistants and a 12 year old schoolboy). Each judge was

6/30/2008

given a set of 10 envelopes, one for each word. The correct spelling was printed on the face of the envelope which contained slips of paper on which the incorrect spellings of that word had been typed. The judges were asked to read each slip in turn and select any that produced, in their opinion, a correct pronunciation of the word on the envelope. The spellings were confirmed as good phonetic equivalents (GFEs) only if all four judges agreed that the target word could be pronounced correctly from the misspelling.

The outcomes of this procedure differed slightly from the suggested GFEs of Boder and Jarrico (1982). 'Curcus' was judged a GFE for 'circus'. 'Encrease' was not judged a GFE for 'increase', nor were 'slippere' and 'police' for 'slippery' and 'policy' respectively. In 'lodge', the 'dg' could be substituted only by 'j'. Past tense and plural endings were not accepted if added or omitted from the words.

For the present purpose children making 8 or more spelling errors (out of 10) and giving at least 7 legible misspellings were classified for percentage of GFEs. Poor phonetic equivalent poor spellers (PPPS) were those making up to 50% GFEs (N = 45). Good phonetic equivalent poor spellers (GPPS) made 51% or more GFEs (N = 42). There were 327 good spellers (GS). Table 1 shows the sex and age composition as well as the spelling errors of these groups. The latter confirms that the two subgroups of poor spellers differed from good spellers, as expected, but did not differ from each other. The findings for reading quotient in Year 2 also show that poor spellers were poorer than good spellers, but not different from each other. Both GPPS and PPPS means were in the low normal range for reading, but all participants were above RQ 80, as explained above.

Table 1 about here

For some comparisons it was considered useful to match the groups for matrices percentile and for sex as far as possible. It was possible to make reasonable matches (within 5 percentile points) for 30 participants in each of the three groups. Characteristics of the matched groups are given in Table 2.

Table 2 about here

Statistical analyses were by SPSS 14.0. Contrasts included the Bonferroni correction for multiple comparisons.

Results

Laterality

The main prediction was that good phonetic equivalent poor spellers (GPPS) would be more often right handed than poor phonetic equivalent poor spellers (PPPS). Table 1 gives the percentages left-handed (by punching more holes with the left hand) for the three groups. The good spellers (GS, 8.3%), PPPS (24.4%) and GPPS (2.4%) differed significantly overall by chi square. GPPS differed significantly from PPPS as predicted and shown in the table.

Table I also compares the three groups for (R-L)% hand skill by anova, with contrast between GPPS and PPPS. The three groups differed overall and GPPS and PPPS differed as expected. GPPS was not significantly more dextral than GS but the trend was in the expected direction.

Examination of the number of holes punched by each hand suggests whether the differences between groups depend on the relative strength of the right hand or weakness of the left hand. GPPS did not punch significantly more holes than PPPS with the right hand but did punch significantly fewer with the left hand.

The validity of the GFE classification for phonological processing.

These analyses checked whether PPPS and GPPS differed on other tests of phonological processing as expected from the GFE classification. The findings for nonword spelling in Year 1 are shown in Table 1. There were significant differences over the three groups and also between GPPS and PPPS as expected. In year 2 the test of phoneme segmentation gave a similar confirmation of the difference between GPPS and PPPS.

Visuospatial abilities

The PPPS and GPPS spelling groups were compared for spatial drawing in year 1 and for Raven's matrices and visual recognition in Year 2. There were no significant differences between the two groups of poor spellers on any of these tests.

In comparison with good spellers both groups of poor spellers tended to have poorer visuospatial skills. In order to control for possible differences in general cognitive ability three groups (GS, PPPS, and GPPS) were matched for matrices percentile as described above. The findings for the main variables for the matched groups are given in Table 2. The outcomes for all variables in the matched groups are essentially the same as for the unmatched groups. The tests of shape drawing and visual recognition are of particular interest to check for differences in other aspects of visuospatial processing, given the comparable levels of matrices ability. There were no differences between the poor spellers and good spellers, nor between the two types of poor speller on any test of visuospatial ability.

Homophonic word discrimination and visuospatial abilities.

Tables 1 and 2 show that both groups of poor spellers were poorer than good spellers for word discrimination, as expected, but they did not differ from each other. Correlations

were calculated between errors for the word discrimination test and errors scores for each of the three tests of visuospatial ability (with scores adjusted for outliers). Table 3 shows the correlations for the matched groups. The pattern of findings gives a striking contrast between good spellers, for whom word discrimination was significantly correlated with all three tests of visuospatial ability, and GPPS for whom none of the tests were correlated. The correlations differed significantly (p = .026 2-tail) between GS and GPPS for word discrimination and matrices errors.

Table 3 about here

PPPS show a pattern intermediate between GS and GPPS. Matrices performance was significantly correlated with word discrimination but visual recognition was not. The finding for shape drawing (r = .275) was not statistically significant when N = 30 (for the matched groups) but over all available cases (N = 45) the correlation was significant (r = .318, p < .05).

Discussion

The findings for handedness in GFE groups supported the hypothesis that poor spellers differ according to the presence or absence of poor phonology. The difference between PPPS (24.4%) and GPPS (2.4%) left-handers was highly significant statistically. GPPS were not significantly different from GS (8.3%) but the trend was as predicted. In the literature on left- and nonright-handedness and dyslexia, the presence of an association between these variables has been highly controversial (Hallgren, 1950; Naidoo, 1972; Rutter et al., 1970; Satz and Fletcher, 1987). Bishop (1990) concluded that the association, if present, is so small as to be of negligible theoretical significance. If the present poor spellers had been treated as a group (not distinguished between PPPS and

GPPS) there would be 14.8% left-handers, not significantly different from good spellers (8.3%). However, the significant difference between poor spellers classified for poor phonology agrees with previous findings for dyslexics (Annett, et al., 1996) and undergraduates (Annett, 1999). Raised incidences for left-handedness are characteristic of groups with poor literacy *and* poor phonology, whereas poor literates without poor phonology tend to be less often left-handed than controls. One of the present GPPS was left-handed. This is not inconsistent with the RS theory because the genotype distributions are expected to overlap considerably. About 1% of the general population could be left-handers of RS + + genoptype.

Findings for the continuous measure of hand skill asymmetry ((R-L)%) were fully consistent with those for hand preference as described above. Analyses of the actual numbers of holes punched by each hand showed that the greater dextrality of GPPS was not due to punching more holes with the right hand but rather with punching fewer holes with the left hand. The difference was consistent with the hypothesis that strong dextrality is associated with relative weakness of the left hand rather than relative strength of the right hand.

Comparison of the GFE groups for other tests of phonology, nonword spelling and phoneme deletion, confirmed that GPPS were superior to PPPS for phonological processing. This was important to check the validity of the GFE classification of phonological awareness. It is sometimes argued that all dyslexics have a problem with phonology, and that over use of grapheme-phoneme rules by surface dyslexics is due to specific teaching of these rules in remedial classes, or as a stage in the maturational process (Snowling et al., 1998; Vellutino and Fletcher, 2005). The present sample was of

6/30/2008

poor spellers in normal schools who had not been identified as having problems (the problem children having been removed from the present analyses). There is no evidence, in the present findings, that the children with a high proportion of GFEs had an underlying problem with phonology.

Is there a visual weakness specifically associated with 'surface-type' dyslexia? Reading and spelling must involve vision at several levels of processing. Visual difficulties were the chief suspect in early accounts of 'congenital word blindness' (Hinshelwood, 1917). The nature of this 'blindness' has proved difficult to identify (reviews in Willows et al., 1993). Deficits in the magnocellular visual system have been suggested (Breitmeyer, 1993; Lovegrove et al., 1986; Stein and Talcott, 1999) but are unlikely to be characteristic of most cases (Hulme, 1988; Ramus et al., 2003). Goulandris and Snowling (1991) found visual memory deficits in a case of specific spelling difficulty but this was not replicated in other similar cases (Castles and Coltheart, 1996; Hanley et al,. 1992). Romani et al. (1999) found dissociation between good visual memory and poor ability to encode serial order in visually presented items in an intelligent dysgraphic.

Individual differences among dyslexics, of the type captured by the distinction between phonological and surface cases, make it difficult to evaluate the findings of studies that have sought general rules for all dyslexics. It was for this reason that it was considered worthwhile in the present study to look again for visuospatial processing deficits in poor spellers with good phonology. Over the total sample, both groups of poor spellers were relatively poorer than good spellers for shape drawing and matrices percentile but the two groups of poor spellers did not differ from each other. There was no evidence of weakness specific to GPPS. Matching groups for matrices percentile

6/30/2008

(Table 2) allowed evidence for relative weakness to be examined when overall ability was controlled. There was no evidence that GPPS was weaker in spatial drawing or visual recognition than the other two groups.

The unexpected finding with respect to visuospatial processing was that scores on these tests correlated with homophone discrimination in good spellers and to a lesser extent in PPPS, but not in GPPS. This suggests that although GPPS have no problem with visuospatial processing itself, they may have difficulty in applying these skills to the task of learning to spell. Exactly where the difficulty might lie can only be a matter for speculation at present. However, it may be suggested that there is some dissociation between mechanisms of visual representation and the processes of learning and memory for words. The RS theory has led to the idea that the RS+ gene weakens the right hemisphere in comparison with the left, so that in RS+ + genotypes there might be a considerable imbalance between the two sides in favour of the left hemisphere. The present findings suggest not an absolute weakness of visuospatial processes, but rather a dissociation between these skills and their application to learning and memory as required for literacy.

What are the overall implications of these findings? First, the longstanding and sterile debate about the relevance of atypical laterality for dyslexia needs to be reformulated in terms of *poor phonology* and atypical laterality. Given this re-reformulation, it may be suggested that poor phonology is associated with a weakness of left hemisphere specialisation for speech and language, consistent with difficulty in representing speech sounds 'in the head', as needed for normal progress in learning to read and spell. Second, not all dyslexics have phonological difficulties. Some dyslexics

6/30/2008

have other problems in representing the visual patterns of words, not because they have weak visuospatial processes in general but because they fail to apply these skills to literacy learning. Third, this analysis of the problem depended on classifications of children drawn from continuous distributions in the normal school population. When such distributions are searched for extreme cases, likely to be identifiable by clinical criteria, relatively few may be found (Snowling et al., 1998). How far poor reading and spelling represent extremes of normal continua, and how far dyslexia depends on distinct pathology will probably be clarified in time by genetic studies (Pennington and Olson, 2005; Plomin et al., 2001). However, in the meantime, it is necessary to recognise that there are individual differences among dyslexics (Seymour, 1986; Stanovich, 1992).

Further implications of these findings concern the RS hypothesis that there is a genetic balanced polymorphism with heterozygote advantage for the RS+ gene (Annett, 1995). The findings support the idea that there are risks at both sides of the laterality continuum, poor phonology at the left and a weakness related to visuospatial processing at the right. Challenges to the RS theory include doubts about whether there is a genetic component involved (Bishop, 2001; Laland et al., 1995; McKeever et al., 2000). Others have reported failures to find evidence of heterozygote advantage for cognitive abilities (Cerone and McKeever, 1999; Crow et al., 1998; Klipcera and Gasteiger-Klipcera, 1994; Natsopoulos et al., 2002; Palmer and Corballis, 1996; Resch et al., 1997). Findings interpreted as supportive of the RS theory were described by Casey (1995) and Kopiez et al. (2006). The present report offers new opportunities for tests of the replicability of findings associated with the RS theory.

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6/30/2008

Table 1 Good spellers and poor spellers with and without good phonology: descriptive statistics, means (SDs): scores for cognitive variables are errors: total sample minus poor readers and other exclusions (see text).

	Good spellers	Poor phonology poor spellers	Good phonology poor spellers	Statistical comparisons for three groups (p)	Contrasts between PPPS and GPPS (p)
Year 1 N	327	45	42		
Male %	46	47	57		
Age in months	122 (3.5)	121 (3.4)	121 (3.3)		
Spelling errors	3.4 (2.0)	9.1 (0.9)	9.0 (0.8)	< .001	ns
Left-handers	8.3	24.4	2.4	= .001	=.003
R-L Hole%	17.8 (15.0)	9.3 (20.5)	19.9 (10.4)	= .001	= .001
Holes right	53.9 (10.7))	48.5 (10.7)	52.9 (8.8)	= .006	ns
Holes left	37.8 (9.9)	40.8 (12.1)	35.6 (8.2)	=.046	=.015
Nonword	1.0 (1.2)	2.5 (1.5)	1.6 (1.3)	<.001	= .005
Word Discrimination	3.2 (2.4)	6.1 (3.1)	6.7 (2.9)	< .001	ns
Shape drawing	5.7 (2.6)	6.9 (2.0)	6.8 (2.7)	= .002	ns
Year 2 N	265	39	30		
Male %	46	46	50		
<i>Reading</i>	100.9 (12.9)	86.4 (11.8)	88.5 (11.3)	< .001	ns
Phoneme segmentation	0.3 (0.7)	1.4 (1.2)	0.8 (1.1)	< .001	= .001
Visual	3.5 (1.7)	4.2 (2.0)	3.6 (1.6)	ns	ns
Matrices percentile	46.8 (27.8)	35.5 (24.3)	39.6 (29.0)	= .034	ns

Table 2. Good spellers and poor spellers with and without good phonology: descriptive
statistics, means (SDs): scores for cognitive variables are errors: groups matched for
matrices percentile

	Good spellers	Poor phonology poor spallers	Good phonology poor spallars	Statistical comparisons over three arouns (p)	Contrasts between PPPS and CPPS (n)
Ν	30	30	30	groups (p)	OTTS(p)
Male %	50	43	50		
Year 2 Age in months	134 (3.4)	134 (3.5)	136 (3.0)		
Left-handers %	13.3	30.0	3.3	= .016	= .006
Reading Ouotient	98.7 (14.8)	86.1 (11.2)	88.5 (11.3)	<.001	ns
word discrimination	3.8 (2.9)	6.0 (2.9)	6.5 (2.7)	<.001	ns
Phoneme segmentation	0.5 (0.8)	1.6 (1.2)	0.8 (1.1)	= .001	= .005
Shape drawing	6.0 (2.5)	6.3 (2.6)	6.6 (2.6)	ns	ns
Visual recognition	5.1 (1.3)	4.8 (1.3)	5.0 (1.1)	ns	ns
Matrices percentile	39.7 (28.8)	38.7 (26.0)	39.6 (28.9)	ns	ns

Table 3. Correlations between homophonic word discrimination and three tests of visuospatial ability in three spelling groups matched for matrices: all scores are errors.

	Good spellers	Poor phonology	Good phonology	
		poor spellers	poor spellers	
Shape drawing	.457*	.275	.126	
Visual recognition	.497**	046	065	
Raven's matrices	.592**	.413*	.075	