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Developmental Surface Dysgraphia: What Is the Underlying Cognitive Impairment?

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The purpose of this study was to investigate the cognitive causes underlying spelling difficulties in a case of developmental surface dysgraphia, AW. Our results do not support a number of possibilities that could be the cause of AW's poor orthographic lexicon, including difficulties in phonological processing, phonological short-term memory, configurational visual memory, and lexical semantic memory. We have found instead that AW performs poorly in tasks that involve detection of the order of adjacent letters in a word or the order of adjacent units in strings of consonants or symbols. Finally, he performs poorly in tasks that involve reconstructing the order of a series of complex visual characters (Japanese and Hindi characters) especially when these are presented sequentially. We advance the hypothesis that AW's poor spelling and good reading skills stem from an underlying pattern of cognitive abilities where a very good visual configurational memory is coupled with a poor ability to encode serial order. This may have resulted in a holistic word-based reading strategy, which, together with the original problem of encoding order, may have had detrimental effects for the acquisition of spelling.

A variety of different impairments have been suggested as the underlying cause of developmental dyslexia/dysgraphia. The one that has received most support is an impairment of phonological awareness or phonological processing. According to this hypothesis, dyslexic children fail to learn to read and write because they are unable to segment a word into the corresponding sequence of phonemes (e.g. Bruck, 1993; Bryant & Bradley, 1985; Stanovich, 1988; for reviews see Adams, 1990; Wagner & Torgesen, 1987). As a result, they are unable to learn sublexical conversion rules (phoneme–to–grapheme and grapheme–to–phoneme)—the first step towards proficient reading and writing. An alternative hypothesis is that an impairment of phonological short-term memory causes a failure to learn sublexical conversion rules: There are not enough memory resources to keep in mind the results of phoneme–to–grapheme conversions before they can be blended into the corresponding words (Baddeley, 1979; Campbell & Butterworth, 1985).

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These phonological impairments can explain the characterstics of the majority of the developmental dyslexics reported in the literature who show a pattern that—based on the acquired dyslexia literature—can be labelled *phonological dyslexia/ dysgraphia* (Campbell & Butterworth, 1985; Funnel & Davison, 1989; Snowling, Stackhouse & Rack, 1986; Temple, 1986; Temple & Marshall, 1983). Like the acquired cases, the developmental phonological dyslexics (and dysgraphics) show better performance with words than with nonwords, a frequency effect, and no regularity effect; they show few phonologically plausible errors, but instead show visual and lexicalization errors. All of these characteristics suggest a reliance on lexical representations and poor sublexical conversion rules.

Recently, however, a number of dyslexic cases have been reported whose problems seem to lie not so much in the acquisition of phoneme–grapheme conversion rules, but in the acquisition of orthographic lexical representations (Castle & Coltheart, 1996; Coltheart, Masterson, Byng, Prior, & Riddoch, 1983; Goulandris & Snowling, 1991; Hanley & Gard, 1995; Hanley, Hastie, & Kay, 1992; Holmes, 1973; Seymour, 1986; Seymour & Evans, 1993; Temple, 1985). These developmental cases show the same characteristics as acquired cases of *surface dyslexia/ dysgraphia*. That is, they show a regularity effect: They make fewer errors on regular than irregular words, perform relatively well with nonwords compared to words, and make a high proportion of phonologically plausible errors. In contrast with the characteristics of phonological dyslexics/ dysgraphics, all these characteristics indicate good reliance on phoneme–to–grapheme conversion rules but poor knowledge of the idiosyncratic properties of words—that is, poor lexical representations.

Given these different patterns, an important question is whether different cognitive impairments underlie them. Goulandris and Snowling (1991) have suggested that while poor phonological awareness can cause poor acquisition of phoneme–grapheme conversion rules, poor visual memory could cause poor acquisition of orthographic representations. They reported the case of JAS who showed spelling problems with a surface pattern but fairly good reading ability. Goulandris and Snowling showed that JAS had problems not only remembering word spellings but also in remembering geometric shapes. They made the inference that a single problem with visual memory was the basis of both difficulties.

Hanley et al. (1992), however, described a developmental case—called Allan—whose pattern of cognitive abilities did not support Goulandris and Snowling's hypothesis. Allan's difficulties were also mainly with spelling, and, like JAS, he showed good phoneme–grapheme conversion rules but poor orthographic lexical representations. Unlike JAS, however, Allan's visual memory was very good. Since Allan also had a normal span and showed no evidence of impairment in tasks involving phonological awareness and phonological processing, it seems that he suffered from no other cognitive impairment than a problem in acquiring orthographic lexical representations.

Another recent case reported by Castles and Coltheart (1996) also aimed to identify the cognitive correlates of developmental surface dyslexia, but failed to find any. MI had reading as well as writing difficulties and showed a surface pattern in both. Again, Castles and Coltheart not only failed to find any problems of phonological awareness but also failed to find any problems of visual memory. This was in spite of the fact that they attempted to test recall of visual sequences as well as recall of visual configurations. Hanley et al. (1992) tested Allan only on memory for single visual shapes and it can be argued that reading and writing do not depend on processing and remembering a single visuo-spatial configuration but a *sequence* of visual units. MI, however, performed well even on a task tapping this last skill.

One possibility is that Allan shows no cognitive problems in addition to his spelling difficulties because he does not have any. He was 22 years old at the time of the study. He may have suffered from a developmental lag—that is, he may have suffered from a cognitive impairment at the time he was taught to read and write, but he may not suffer from this problem any more. With time, he may have developed all the "normal" skills, but his reading and writing may still be impaired because they could not take full advantage of formal education when it was offered. The hypothesis of a developmental gap, however, is less plausible in the case of MI who was only 10 years old at the time of the study.

Given what has been discussed above, the underlying cause of developmental surface dyslexia is, at present, quite elusive. There are no logical problems in assuming that acquired brain damage may selectively impair existing representations or processes underlying reading or writing and spare all other cognitive abilities. This is, in fact, the assumption of most cognitive neuropsychological studies. It is more difficult, however, to think of a developmental impairment that selectively affects orthographic representations and has no other cognitive consequences. The acquisition of literacy is such a recent event in our phylogenesis that one cannot imagine neurological resources selectively dedicated to the learning of orthography. Thus, individuals with developmental difficulties in reading or writing *must* have a deficiency in some other more basic skills that nature has bestowed on us for more general purposes (see Ellis, 1981). The identification of these skills is important for an understanding of the processes involved in skilled reading and in writing, and it is crucial for an understanding of the nature of developmental dyslexia.

In the present study, we report the case of a young man, AW, whose characteristics of spelling performance are very similar to those of JAS and MI and strikingly similar to those of Allan. Our purpose is to attempt to find out which underlying cognitive deficit is the basis of AW's orthographic difficulties.

CASE STUDY

AW is a 22-year-old A-level student who was referred to us because of spelling difficulties. He does not report any problems with reading. AW's cognitive development had been uneventful until the emergence of spelling problems during scholastic education. AW has never suffered from any neurological, behavioural, or emotional problems. He does not report any particular problems in learning to read. By the age of 10 years, because of his spelling difficulties he was assessed by a clinical psychologist. He was found to be a child of above-average intelligence and was diagnosed as suffering from a developmental impairment of the dyslexic type. Current, standardized tests of intelligence also reveal above-average scores (WAIS full = 128; verbal = 122; performance = 132; Standard Progressive Matrices: 95th percentile).

AW is a pleasant person and an avid reader, and he has many interests and hobbies. Currently, he is working successfully as a supervisor in a home for delinquent children, and is planning a career as a social worker. AW's problem has a familial history, because his father and one of his cousins apparently suffer from similar difficulties.

SPELLING

AW has a spelling age corresponding to 9.0 years when tested with the Wechsler Objective Reading Dimension Scale (Rust, Golombok, & Trickey, 1993) and a spelling score corresponding to the 2nd percentile when tested with the Wide Range Achievement Test (Jastak, Bijon, & Jastak, 1978).

AW was assessed with the Johns Hopkins Dysgraphia Battery (Goodman & Caramazza, 1985). All results are presented in terms of percentages of errors. He showed no significant effects of:

1. concreteness (concrete words: 6/21 = 29%; abstract words: 7/21 = 33%);
2. frequency (high-frequency words: 5/14 = 36%; low-frequency words: 5/14 = 36%);
3. part of speech (nouns: 9/28 = 32%; verbs: 10/28 = 36%; adjectives: 14/28 = 50%; functors: 6/20 = 30%).

However, he showed significant effects of:

1. word length (4–5 letters: 5/28 = 18%; 6–7 letters: 11/28 = 39%; 8 letters: 9/14 = 50%; $\chi^2 = 9.0$; $p < .05$);
2. lexicality: He showed an "inverse effect", misspelling real words more often than made-up words (words: 37/104 = 35%; nonwords: 5/34 = 14%: $\chi^2 = 4.3$; $p < .05$).

Finally, in an initial assessment with the Johns Hopkins Dysgraphia Battery, AW did not show a significant effect of regularity. He made 2/30 (7%) errors on regular words—words whose spelling could be derived by applying the most common phoneme–grapheme conversion options—and 16/80 (20%) errors on irregular words—words containing more unusual graphemic options, $\chi^2 = 1.9$; $p = .16$. This lack of significance, however, is probably the result of a ceiling effect. An effect of regularity was assessed again with a list that contrasted 76 regular and 76 irregular words matched one to one for frequency and letter length. For each condition, half of the words were of low frequency (between 0 and 40 according to Carrol, Davies, & Richman, 1971) and half were of higher frequency (higher than 50). The letters of the regular words were all common realizations of the corresponding phonemes, occurring at least 30% of the time (according to Hanna, Hanna, Hodges, & Rudolf, 1966). The irregular words, instead, contained at least one uncommon graphemic realization (occurring 10% of times or less for the corresponding phoneme).

This time the effect of regularity was significant. AW made 8% errors (6/76) on the regular words and 24% errors (18.76) on the irregular words, $\chi^2 = 6.0$; $p < .05$. A frequency effect was significant with the irregular words (4/38 = 10% vs. 14/38 = 37%; $\chi^2 = 5.9$; $p < .05$), but failed to reach significance with regular words (high frequency: 1/38 = 3% vs. low frequency: 5/38 = 13%; $\chi^2 = 1.6$; n.s.).

Analysis of Error Types

Overall, AW was given 1,005 words to spell to dictation and made 32% errors (321/ 1005). As phonological plausibility may vary along a continuum (depending on how common the orthographic rendition of the target sounds is), we asked three different judges to rate AW's errors for phonological plausibility, 91%, 88%, and 82% were rated as phonologically plausible by each of the three judges, respectively. Together with AW's good writing of nonwords and his better performance with regular than irregular words, these results indicate a fair ability to apply phoneme–to–grapheme conversion rules.

Of the misspelled words, 247 (77%) contained a single error, 41 (13%) contained two separate errors, and 33 (10%) contained multiple errors. Only occasionally did AW misspell a word with another word (12/ 332 = 3.7; e.g. "comb" → "come"), and many of these could reflect phonological approximations. A breakdown of AW's individual errors by type is shown in Table 1. Multiple errors are not included because they cannot be classified unambiguously.

All the most common errors made by AW reflect underspecified orthographic lexical representations. The most common error of all involves vowels, which are notoriously difficult to spell in English because of the variety of phonologically plausible graphemic realizations. Thus, in most cases, they can only be spelled correctly by consulting the lexicon. The second most common error involves the omission or the insertion of the letter "e" at the end of a word. In this context, in English, "e" is usually silent and signals the lengthening of the preceding vowel. This is one of the most difficult orthographic rules to learn, partly because it is constrained by context and partly because there are many exceptions. Thus, AW's problem with final "e"s shows both that his lexical representations are poor and that he has not mastered this complex rule (the same, however,

TABLE 1
AW's Type of Spelling Errors (over 329 Individual Errors)

	Type of Error	*n*	*%*	*Example*	*Other Statistics*
Phon.–graph. conversions	vowel options	112	34	jerk → jeark	
	consonant options	9	3	profile → prophile	
	mixed cons/ vowel options	9	3	severe → seveare	
	finale "e"	68	21	mug → muge	59 insertions
				carve → carv	9 deletions
	double consonants	51	15	pity → pitty	24 insertions
				inner → iner	27 deletions
Others	substitutions	9	3	putting → pudding	
				damn → damb	4 silent letters
	deletions	34	10	fact → fat	
				witch → wich	31 silent letters
	insertions	16	5	want → whant	8 silent letters
				broad → broard	5 perseverations
	transpositions	21	6	grief → greif	

Note: Errors were classified in the categories under phoneme–to–grapheme options first; if this was not possible then they were classified otherwise.

could be true for many "average spellers"). The third most common error involves double consonants. As in English double consonants have no phonological realization, again they can be spelled correctly only by consulting the lexicon. Of the remaining errors, many involve deletions, insertions, and substitutions of letters that have no phonological realization (silent letters). This again indicates that AW's spelling relies, at least partially, on phoneme–to–grapheme conversion.

Although most of AW's errors reflect lack of lexical knowledge, not all do. Some reflect partial knowledge because they contain letters that have no phonological realization (n = 31; e.g. "colonel" → "colnel"; "budget" → "budgette"; "sovereign" → "sogverin"). It is likely, therefore, that AW's spelling is based on a combination of partial lexical orthographic knowledge supplemented by the use of phoneme–to–grapheme conversion rules. All these characteristics of performance that suggest good phoneme–to–grapheme conversion and underspecified lexical representations identify AW as a surface dysgraphic.

READING

Reading of Words

AW made no errors reading on paper the stimuli of the Johns Hopkins Dyslexia Battery (Goodman & Caramazza, 1986), which contrasts words of various lengths, frequency, grammatical class, and concreteness. He was also asked to read as fast and accurately as possible words from Seidenberg, Waters, Barnes, & Tanenhaus (1984, Experiments 3 and 4). Words were presented one at a time on a computer screen as in those experiments. Experiment 3 contrasted high- and low-frequency regular and exceptional words (N = 13 for each category); Experiment 4 contrasted high- and low-frequency regular consistent, regular inconsistent, and strange words (N = 15 for each category).[1]

Results are reported in Table 2. AW's reading performance is consistently better than the average performance of the college students tested by Seidenberg et al. (1984) in terms of both reaction times (RTs) and error rates. This holds true for each category of words in both experiments. Moreover, in contrast to spelling, results do not suggest over-reliance on phoneme–grapheme conversion, because (a) responses seem too fast for this to be the case, and (b) AW does not show an enhanced effect of regularity.

Reading and Spelling of Homophones

AW was given two tasks in which he was asked to define written homophones. The first included 38 homophones. He made 4 errors: He defined "morn" as "mourne", "serge" as "surge", and "boarder" as "border", and he failed to define "vale". A group of 10 undergraduates made on average 3.4 errors (range 1–5). A second task included 40 homophones

[1] Consistent and inconsistent words differ in terms of the presence in the language of visually close neighbours with a different phonological realization. For example, "save" is a regular word because the most common grapheme–to–phoneme option requires a vowel to be lengthened before a final "e". However, "save" is an inconsistent word because of the presence in the language of the word "have", where the same orthographic sequence "have" has a different phonological realization (e.g. / hev/). Strange words are words like "aisle" or "fuel" with unusual spelling patterns.

TABLE 2
RTs and Percentages of Errors in Speeded Word Reading Tasks for AW and a Group of Undergraduate Controls

			AW		*Controls*	
Experiment	*Type of Words*		*RTs*	*Errors*	*RTs*	*Errors*
3	*High-frequency*	Regular	446	0	588	1
		Exceptional	457	7.7	590	0.5
3	*Low-frequency*	Regular	484	0	610	0.5
		Exceptional	458	0	639	9.6
4	*High-frequency*	Regular consistent	488	0	603	2.2
		Regular inconsistent	500	0	608	3.0
		Strange	498	0	590	1.3
4	*Low-frequency*	Regular consistent	540	0	608	3
		Regular inconsistent	483	0	638	5.3
		Strange	588	20	680	27

Note: Experiments, experiments 3 and 4 lists, and control data from Seidenberg et al., 1984.

(10 regular pairs, e.g., "cell–sell"; and 10 irregular pairs, e.g. "dough–doe"). AW made 4 errors, whereas the control group of 10 undergraduates made on average 3.1 errors (range 1–6). In this task, therefore, AW performed well within the normal range. He did, however, make homophone errors in writing (e.g. from his corpus of errors, "poll → pole"; "aunt → ant"; "pear → pair"). This, again, shows that different strategies are used by AW in reading and writing. Reading is orthographically and lexically based and, thus, homophony creates no problems. Writing is, at least in part, phonologically based. Thus, a word can sometimes be spelled as another word having the same phonology.

Reading of Nonwords

AW's performance was very fluent and was errorless in reading, on paper, 68 monosyllabic and bisyllabic nonwords from the Johns Hopkins Dyslexia Battery. Given his problems with the rule of final "e" in spelling, however, we also expect that he would not consistently apply this rule in reading nonwords where he could not rely on lexical knowledge. He was asked to read 85 further nonwords ranging in length from 3 to 8 letters (average length = 5.6). Of these nonwords, 26 had a final "e" that suggested vowel lengthening and 26 did not have a final "e". This time AW made 4 errors, and 3 involved failing to lengthen the preceding vowel in the presence of a final "e". These results, therefore, confirm that AW has a poor mastery of this rule.

In order to assess the different strategies that he may use when reading words versus nonwords, AW was given two computer tasks that involved reading words mixed with nonwords as fast and as accurately as possible. The first task used materials from a study by McCann and Besner (1987). It included words (e.g. "tracks"), pseudohomophones (nonwords that sound like real words, e.g. "trax"), and control nonwords (e.g. "prax"). Nonwords were derived from matched words (not included in the experiment) by changing one or two letters. All stimuli were monosyllabic. The second task used lists from PALPA (Kay, Lesser, & Coltheart, 1992) that contrasted 80 words (40 of high frequency and 40 of low frequency) with an equal number of nonwords, which were derived from words in the lists. Words and the corresponding nonwords were monosyllabic (*n* = 23), bisyllabic (*n* = 41), and trisyllabic (*n* = 16). Length ranged from 3 to 9 letters (average = 5.8). Control subjects for the two tasks were, respectively, 9 and 11 students at the University of Birmingham.

Results are reported in Table 3. AW made only one error. This time, however, RTs are consistently longer than average. In fact, in the second task where there is a high similarity between the words and the nonwords in the lists, AW's RTs are outside the normal range for both low-frequency words and nonwords.

Discussion

AW shows a striking dissociation between a severe spelling impairment and very good single-word reading. In fact, we do not know any other case reported in the literature with an equally striking dissociation. Allan, reported by Hanley et al. (1992), had previously shown the strongest dissociation. Even in this case, however, reading of words from PALPA without time constraints was only about 95% correct, which placed him in the lower normal range.

Not only is word reading unimpaired compared to spelling, but it seems to rely on different processing strategies. Whereas spelling relies on sublexical conversion procedures, reading seems to be based on lexical orthographic knowledge: There is no enhanced regularity effect, and written homophones are defined correctly. Moreover, although AW is very good at reading words, he is not as good when they are mixed with nonwords. This suggests again that word reading is based on processing partial orthographic information. A word can be distinguished from other possible words on the basis of just a few letters, and by taking into account word features such as word length and word shape. For a nonword, instead, even considering orthographic constraints, it is very difficult to guess a letter in any position. Thus, mixing words with

TABLE 3
RTs and Percentages of Errors in Speeded Word/Nonword Reading Tasks for AW and Groups of Undergraduate Controls

		AW		*Controls*		
Lists		*RTs*	*Errors*	*RTs*	*Range*	*Errors*
McCann & Besner, 1987	words	559	0	552	473–660	0
	pseudo-homophones	677	0	578	494–702	0.4
	control nonwords	700	0	594	503–710	0.4
PALPA—Kay et al., 1992	high-freq. words	621	0	549	492–667	0.2
	low-freq. words	706	0	562	500–673	0.2
	nonwords	866	1.2	636	572–791	2.4

nonwords forces a more exhaustive analysis of both the words and the nonwords, because there is no way to know beforehand whether each stimulus is a word or nonword (e.g. it could be "elephant" but also "eliphant"). This explains why with mixed lists AW performs more poorly with both kinds of stimuli.

Reading and spelling abilities may dissociate because of the different requirements of the two tasks (Frith, 1985; Hanley et al., 1992; Seymour & MacGregor, 1984). Sublexical conversion procedures are likely to be more successful with reading than with spelling. This is because there are more diverse ways to convert a sound into letters than vice versa (e.g. the sound /k/ can be realized by either the letter "c" or the letter "k", but the letter "k" always corresponds to the sound /k/); it is also because in reading, sublexical conversion procedures may be helped by phonological lexical knowledge. For example, given a word like "fountain", the bigram "ou" is more likely to be read as /au/ than as /o/ because one has heard of /fauntəns/, but not of /fontəns/. Reading and spelling, however, may also dissociate because reading can be carried out on the basis of partial lexical knowledge. Thus, AW may have underspecified lexical knowledge that is sufficient for efficient reading but not for correct spelling. One possibility that will be substantiated in the rest of the paper is that AW's efficient reading strategy has, in fact, turned out to be a liability for spelling, which requires more detailed orthographic representations. Before presenting further evidence on this point, however, we will examine other possible causes of AW's spelling difficulties.

PHONOLOGICAL PROCESSING

As mentioned in the introduction, the most common explanation offered for developmental dyslexia is a phonological deficit: This may be either a problem with phonological short-term memory (Baddeley, 1979; Campbell & Butterworth, 1985; Jorm, 1979) or an inability to segment speech sounds (Bryant & Bradley, 1985). Impairments of phonological processing, in fact, have been consistently reported in the case of phonological dyslexics (e.g. Campbell & Butterworth, 1985; Funnell & Davison, 1989; Snowling et al., 1986), but they have not been found in the case of surface dyslexics (Hanley et al., 1992). Given AW's fairly good ability to apply phoneme–to–grapheme conversion rules, we have an early indication that he may have no problem with phonological short-term memory or with phonological segmentation.

Phonological Short-term Memory

AW has a digit span of 6–7 items (tested with the WAIS). He was also asked to repeat series of 4, 5, 6, and 7 words and series of 2 and 3 nonwords. All the words were monosyllabic nouns of medium/high frequency. All the nonwords respected phonotactic constraints of English. No word or nonword was repeated across the series. Nonword lists contained contrasting stimuli ranging from one to three syllables. Results for AW and for control groups of college students are presented in Table 4.

AW's performance was within normal range in all conditions. Performance with 6 words seemed unusual in the sense that there was a large decrement from 5 to 6 words (only 2/19 controls showed an equal or bigger drop). Similarly, performance seemed to

TABLE 4
Percentage of Items Correct in Repeating Lists of Words and Nonwords for AW and Groups of Undergraduate Controls

List Types		*n*	*AW*	*Controls*		
				Mean	*Range*	*n of subjects*
4 words		10	100	96	85–100	19
5 words		10	96	86	36–100	"
6 words		5	67	81	52–93	"
6 words		10	85	81	60–100	15
7 words		10	77	70	47–89	"
2 nonwords	1 syllable	10	100	98	95–100	10
	2 syllables	10	90	94	90–100	"
	3 syllables	10	85	86	70–95	"
3 nonwords	1 syllable	10	97	91	80–100	"
	2 syllables	10	90	80	53–93	"
	3 syllables	10	50	60	23–80	"

drop with the longest lists of nonwords (however, 2/ 12 subjects showed an equal or bigger drop). To check whether performance remained normal even with longer lists, we gave AW new lists of 4, 5, 6, and 7 words. This time, performance with 6 words was better than average, as was performance with 7 words. Taken together, therefore, these results do not suggest any impairment of phonological short-term memory.

Phonological Segmentation

Identification of Initial/ Final Sounds. AW made no errors (0/ 68) in a task where he had to identify the initial or final sound of a given word (e.g. experimenter: "bread" → AW: / b/).

Counting Phonemes. AW was given a task from Perin (1983), which involved counting how many phonemes there were in an auditorily presented word ($n = 32$) or nonword ($n = 16$) (length 2–5). Of the real words, 16 had the same number of phonemes as letters (e.g. "mud"), the other 16 had a discrepant number of letters and phonemes (e.g. "knock"). AW was overall 94% correct. The subjects tested by Perin were 14–15-year-olds who had varying levels of reading/ spelling abilities ($n = 17$ in each group). The good readers/ good spellers were 70% correct; the good readers/ poor spellers were 56% correct, and the poor readers/ poor spellers were 60% correct. We also tested 10 age-matched controls who were, on average, 79% correct (range 52–90; $SD = 13$). AW's performance was the best in the group. Therefore, contrary to what was suggested by Perin (1983) and by Goulandris and Snowling (1991), our results show that a lexical impairment of AW's severity does not hinder performance on a phoneme counting task.

Rhyming Judgements. Two words were presented to AW in the spoken modality, and he had to decide whether or not they rhymed. We used the test from PALPA, which includes 60 pairs of words: 30 rhyming, 30 non-rhyming; for each category, half the pairs have the same spelling pattern ("hive–dive"; "cheat–sweat"), and the other half have a different spelling pattern ("ghost–roast"; "sort–part"). AW was 100% (60/60) correct.

Spoonerisms. AW was given a task involving the creation of a spoonerism from a pair of words ($n = 85$). The spoonerisms could result in two new words ("sock rent" → "rock sent"; $n = 45$); in two nonwords ("dare night" → "nare dight"; $n = 20$), or in a word and a nonword ("mint tea" → "tint mea"; $n = 20$). The task was also given to 10 undergraduate students. AW's performance was good in all conditions. With spoonerisms resulting in two words, he was 96% correct (controls 95%; range 94–100); with spoonerisms resulting in two nonwords, he was 95% correct (controls 96%; range 90–100); finally, with spoonerisms resulting in one word and in one nonword, he was 100% correct (controls 93%; range 80–100).

AW was also given a second task from Perin (1983), which involved realizing spoonerisms with names of famous musicians (e.g. "Bob Dylan" → "Dob Bylan"). He was 100% correct (18/18).

Sound Blending. AW was given the sound-blending subtest of the Illinois Scale for Psycholinguistic Abilities, which involves pronouncing in a staccato way the individual phonemes making up a word (e.g. b - oa - t) and asking the subject to identify the word. The test included 17 words ranging from 3 to 8 phonemes and 8 nonwords ranging from 3 to 6 phonemes. He made no errors with words but two errors with nonwords. A group of 8 control students at the University of Birmingham made on average 1.25 errors with words (range 0–4) and 1.63 errors with nonwords (range 1–3).

Discussion

AW had no problems in the tasks described in this section. This is consistent with his pattern of spelling performance since successful application of phoneme–to–grapheme procedures entails phonological segmentation and the use of phonological short-term memory resources. These results constitute a replication of Hanley et al.'s (1992) findings and do not support the view that problems with phonological processing are a *necessary* correlate of developmental difficulties of the dyslexic type (see Snowling, 1987; Wilding, 1989, 1990). At the very least, they do not always occur in cases like AW and Allan where spelling is the predominant problem and where a poor acquisition of orthographic lexical representations is accompanied by good acquisition of phoneme–to–grapheme conversion procedures.

VISUAL MEMORY

It is possible that a poor visual memory is a more likely candidate as the source of AW's spelling difficulties, as suggested by Goulandris and Snowling (1991). Their case, JAS, presented characteristics similar to AW: Her problems were mainly with spelling, and she showed the pattern of surface dysgraphia. Contrary to AW, JAS was impaired in a number of tasks manipulating phonology, such as rhyming judgements, phoneme counting, and spoonerisms. Goulandris and Snowling, however, argued that it was JAS's poor visual memory that caused her poor development of the orthographic lexicon. JAS performed poorly on two types of task:

1. She did poorly on tasks that require recognition or recall of a visual configuration—for example, tasks involving drawing a meaningless geometric shape from memory, or recognizing a geometric shape among distractors (e.g. the tests of visual recall and recognition of the British Ability Scale); we will call the skills underlying the first kind of task *configurational visual memory.*
2. JAS also had trouble with tasks that involve remembering a number of visual shapes in the correct order. For example, she was presented with sequences of 2–4 Greek letters. After she examined each sequence for 10 sec, she had to select the right letters from a limited set of alternatives and arrange them in the correct order. Following Castles and Coltheart (1996), we will call the skills underlying this task *sequential visual memory.*

In this section, we describe AW's performance on a number of tasks that tap long-term configurational visual memory. AW's performance on tasks tapping sequential visual memory will be described later.

Iconic Span. AW has a normal iconic span. In an array of 3 × 3 letters presented for 50 msec, he recalled, on average, 5.1 letters. Control subjects (from Sperling, 1960) recalled, on average, 4.3 letters (range 3.8–5.2).

British Ability Scale (Elliot, Murray & Pearson, 1983). AW was given the "recall of designs" subtest, which involves the immediate reproduction of 19 geometric shapes, each studied for 5 sec. AW's performance corresponded to the 93rd percentile when compared to a group of 17.5-year-olds. Normative data for older subjects are not available, but there is no reason to think that visual memory would significantly improve after this age.

He was also given the "visual recognition" subtest, which involves the consecutive presentation of eight geometric shapes, each studied for 5 sec. Each shape then has to be chosen from among 6–8 alternatives. Recognition is attempted once again, without further presentation of the shapes, after about 20 min of intervening activity. AW's performance corresponded to the 99th percentile in the immediate condition and to the 92nd percentile in the delayed condition when compared to 17.5-year-olds.

Wechsler Memory Scale (Wechsler, 1987). AW was given the visual reproduction subtests, which involve drawing from memory four meaningless shapes. Reproduction is attempted immediately after presentation of each shape and then again after 20 min of intervening activity. Adult normative data are available for this battery. Again, AW's performance was excellent. In the immediate condition, it corresponded to the 94th percentile (raw score = 37); in the delayed condition, to the 95th percentile (raw score = 39).

Discussion

AW performed extremely well on tasks involving visual memory. Our results parallel a number of other results from group studies, which have found retarded readers to be unimpaired in tasks requiring recall of visual configurations (for paired association tasks see Goyen & Lyle, 1971; Vellutino, Harding, Phillips, & Steger, 1975; Vellutino, Steger, & Pruzek, 1973; for a task involving recognition, see Vellutino, Steger, Desetto, & Phillips, 1975). As far as single case studies are concerned, AW's good performance on tasks tapping visual memory contrasts with the poor performance of JAS (Goulandris & Snowling, 1991) and parallels the good performance of Allan (Hanley et al., 1992) and MI (Castles & Coltheart, 1996). Since both Allan and AW have a lower spelling age than JAS, severity of impairment cannot account for these differences. It is surely possible that an impairment of visual memory determines or contributes to JAS's spelling difficulties. It is not, however, the basis of the spelling difficulties of all developmental cases of surface dysgraphia.

LEXICAL/SEMANTIC MEMORY

Finally, we wanted to assess the possibility that AW's poor storage of orthographic representations stems from a more general problem in the long-term storage of verbal information.

In the story recall subtest of the Wechsler Memory Scale, a brief story is read aloud, and recall is attempted immediately after presentation and again after 30 min of intervening activity. AW's performance was excellent. In the immediate condition, it corresponded to the 84th percentile (raw score = 33); in the delayed condition, it corresponded to the 83rd percentile (raw score = 30).

In the word paired associates subtest of the Wechsler Memory Scale, eight pairs of words are presented to the subject. Given one member of the pair, the task is to recall the other. The eight prompts are presented three times (feedback is provided after each time) and a fourth time after 20 min of intervening activity. AW's performance was at ceiling in both the immediate and the delayed recall conditions (23/24 and 8/8, respectively). This result, together with that of the previous story recall subtest, shows that AW's poor acquisition of orthographic representations cannot be attributed to a general problem in the storage/retention of verbal information.

INTERIM DISCUSSION

We found AW's performance to be normal on all of the tasks described so far. At this point, one may wonder whether AW's poor orthographic lexical knowledge is caused by a problem that no longer exists, and he is now completely normal on the whole spectrum of cognitive abilities. AW's discrepant performance between reading words and nonwords, however, already gives some indication that he processes orthographic information in an unusual way. In Romani and Stringer (1994), moreover, it was found that AW is still very poor in learning new written (and spoken) words.

AW's reading performance suggests a preference to process words on the basis of whole-word features, such as length, shape, and particular groups of letters. It is likely that skilled reading does not entail an exhaustive serial analysis of the letters in a word. AW, however, seems to engage in serial analysis less and less easily than do our control readers because his performance is disrupted when he has to carry out a more careful analysis of the individual letters making up the word. AW's excellent ability to process and retain visual–configurational information strengthens the hypothesis of an unusual cognitive profile where poor serial analytic skills are coupled with excellent parallel configurational skills. The rest of the paper, therefore, explores the possibility that it is AW's idiosyncratic processing of orthographic information that causes a problem with spelling. First of all, we want to show that he has a problem with encoding and remembering the order of adjacent visual units. Second, we want to show that this problem is the cause and not the consequence of poor lexical representations.

LEXICAL DECISION TASK—ORDER VERSUS IDENTITY

One way to explore AW's processing of orthographic information further is to use lexical decision tasks. By manipulating the way in which nonwords are derived from words, one can have a better idea of which parts, if any, of an orthographic representation AW has trouble attending to. If AW has a problem with the analytic processing of orthographic representations we would expect him to perform poorly in a lexical decision task. In particular, he should have trouble detecting nonwords created from words by changing letter order.

We gave AW a preliminary lexical decision experiment with stimuli from Holmes and Ng (1993), which included high- and low-frequency regular words, low-frequency idiosyncratic words, and nonwords derived from them by changing one or two letters. AW's performance was intermediate between the performances of Holmes and Ng's groups of good and poor spellers. Mean RTs were: poor spellers = 777; AW = 766; good spellers = 728. Error rates were: poor spellers = 8.8; AW = 4.0; good spellers = 2.8. As argued by Holmes and Ng, however, this task could still be carried out by sampling orthographic visual information in a parallel fashion and disregarding letter order. Holmes and Ng showed that their group of poor spellers had particular trouble in a second lexical decision task where nonwords were derived from words by changing not the identity but the ordinal position of two adjacent letters. AW was also given a similar task.

Method

The lexical decision task used by Holmes and Ng (1993) included only nonwords created by changing the position of two adjacent letters in a word. In our task, we wanted to compare more directly processing of nonwords derived by changing letter identities with processing of nonwords created by letter transpositions. A total of 64 eight-letter words were mixed with an equal number of nonwords. Half of the nonwords were created from the words by changing letter identities (identity condition) and the other half by changing letter order (order condition). For each of the two nonword conditions, letters were changed either at the beginning ($n = 8$), at the end ($n = 8$), or in the middle of the word ($n = 16$). In each condition, half of the changes produced a legal letter sequence and the other half an illegal letter sequence.

The experiment was run using an Apple Macintosh computer running Psychlab 0.85 software. Following fixation, the stimuli appeared at the centre of a computer screen in lower-case letters and disappeared as soon as the subject made a response by pressing one of two keys.

The task was also given to a control group of 20 college students. Everyone was instructed to complete the task as accurately and as fast as possible. One subject was excluded for not complying with the task (performance was almost at chance and RTs were extremely fast).

Results

RTs that were three standard deviations above or below average were eliminated both for AW and for the controls. AW's performance on words was fair: RTs were just out of the normal range (AW = 1195; controls = 810; range 580–1175; *SD* = 223); and error rate was about average (AW = 3.1; controls = 2.9; range 0–13; *SD* = 2.9). Results for nonwords are reported in Table 5.

AW showed a normal effect of legality, responding faster to the illegal nonwords (legal = 1297 msec vs. illegal = 1115 msec). Since legality did not interact with any other factor, results have been collapsed for legal and illegal nonwords. In the identity condition, AW's performance was normal in terms of both RTs and errors. It was poor, however, in the order condition. When the change was in the middle of the word, both errors and RTs were out of the normal range. Errors were also out of the normal range in the "end" condition and barely within range in the "beginning" condition. Finally, although most of the control subjects showed worse performance with the "order" than with the "identity" nonwords, AW showed a significantly larger drop in performance. In terms of errors, AW showed a difference in performance of 52.2, whereas the controls showed an average difference of 7.5, $z(18) = 4.9$, $p < .001$. In terms of RTs, there was no significant difference between AW and the controls: AW showed a difference of 340 msec, and the controls showed an average difference of 150 msec, $z(18) = 2.18$, $p < .05$.

AW was given a paper and pencil version of the same task about a year later. This time he was instructed to take his time, but to complete the task as accurately as possible. He

TABLE 5
RTs and Error Rates for AW and Undergraduate Controls in a Lexical Decision Task involving Identity-change and Order-change Nonwords

		Identity-Change Nonwords			*Order-Change Nonwords*		
			Controls			*Controls*	
		AW	*Mean*	SD	*AW*	*Mean*	SD
RTs	beginning	1184	882	399	957	933	465
	middle	1205	984	499	1995	1133	531
	end	1079	798	366	1084	1047	789
Errors	beginning	0	5.5	7.8	12.5	3.4	5.8
	middle	0	3.7	4.9	73.3	18.0	16.5
	end	0	1.3	3.9	50.0	5.3	8.7

made 6/ 64 errors overall. Again, most of the errors were made with nonwords and in the order condition (4 vs. 1 in the identity condition).

Discussion

The results confirm that AW processes orthographic information in an unusual way. In particular, he has difficulty when the task requires processing information about the order of letters within a word. A similar problem was found by Holmes and Ng (1993) with their group of good readers/ poor spellers. These results, however, do not address whether it is AW's processing style that has caused his poor orthographic representations or whether it is the poor lexical representations that cause trouble in this and other tasks. The next section addresses this issue more directly.

MATCHING TASKS—ORDER VERSUS IDENTITY

Matching tasks involving same–different judgements for pairs of words, sequences of consonants, and sequences of symbols were constructed. Again, these were modified versions of tasks used by Holmes and Ng (1993). We added a condition where differences were based on changes of identity to a condition where differences were based on changes of order. This had the purpose of allowing a more direct comparison between the skills involved in detecting identity and order changes. Although word matching may well involve lexical retrieval (Chambers & Forster, 1975), matching sequences of letters and symbols does not. A comparison across these different matching tasks, therefore, allows us to establish whether AW has a problem when the task does not require lexical retrieval or even processing of orthographic information.

Word Matching Tasks

Method

A total of 64 identical pairs (32 words, 32 nonwords) were contrasted with 64 "different" pairs (32 word–nonword; 32 nonword–word). Each word/ nonword was eight letters long. The nonwords were created by changing the order of two adjacent letters in the order task and their identity in the identity task. In each task, the change could occur either at the beginning ($n = 8$ for each condition), at the end ($n = 8$ for each condition), or in the middle of the word ($n = 16$ for each condition). Only "middle" changes came from words matched for frequency and, therefore, only these were considered for analysis. The other items served as fillers to prevent subjects from attending to just the middle of the words. Half of the nonwords in the middle-change condition were orthographically legal; the other half were orthographically illegal. Following fixation, the two stimuli of a pair appeared side by side in the middle of a computer screen. They disappeared as soon as a response was made by pressing one of two response keys.

Results and Discussion

RTs three standard deviations above or below average were eliminated. Results are presented in Table 6. AW's RTs were well within the normal range for both the identity and the order condition. Error rates, instead, showed a strong contrast: They were within range in the identity condition but well outside the range in the order condition. In terms of errors, moreover, AW's difference in performance between the order and the identity condition was much stronger than that shown by the controls (AW = 36.3; controls = 7.3; $z(19) = p < .01$). In terms of RTs, AW and the controls showed a similar difference (AW = 333; controls = 301; $z(19) = 0.1$; ns). Together with the results of the lexical decision tasks, these results suggest that AW has a particular problem in processing the order/ structure of orthographic representations.

A word matching task has a strong short-term memory component: The letters of the first stimulus of a pair must be kept in mind while they are compared to those of the second stimulus. One could wonder why AW does not rely on his good phonological short-term memory to perform the task. Although we have shown that AW has a normal span, there are some indications that aspects of his phonological memory are not entirely normal. For example, he is poor at learning the association of new phonological representations with pictures (see Romani & Stringer, 1994). Moreover, he shows a large discrepancy between the forward and the backward digit span sub-tests of the Wechsler Memory Scale: Performance is normal forward (52nd percentile) but poor backward (26th percentile). It is possible that AW performs normally only when the task requires immediate, rote recollection but not when it requires a more "active encoding" of information because the task requires either long-term learning or a more explicit encoding of order information. In forward span, retention of order is a by-product of verbatim recall. In backward span or in the word matching task, however, order information must be encoded more explicitly so that it can be used in a more flexible way.

Although it seems difficult to attribute poor detection of letter transpositions completely to a lexical problem, one could wonder about the contributions of lexical retrieval to this task. The experiments presented in the next section eliminate possible effects of lexical retrieval or even orthographic processing by using stimuli that have no orthographic structure.

TABLE 6
RTs and Error Rates in the Matching Tasks; 20 Undergraduate Controls Participated in the Word Tasks, 10 in the Consonants and Symbols Tasks

		Identity Task				*Order Task*			
			Controls				*Controls*		
		AW	*Mean*	*Range*	*SD*	*AW*	*Mean*	*Range*	*SD*
Words	RTs	1500	1136	652–2903	469	1833	1436	807–2165	347
	Errors	4.7	5.3	0–32	7	41	12.6	2–36	8.9
Consonants	RTs	1978	2231	1335–2835	517	3312	2809	2213–3673	518
	Errors	9.0	7.2	4–9	4.7	18.8	15.1	7–20	4.6
Symbols	RTs	2111	2572	1600–3342	597	3500	3143	2677–3733	406
	Errors	14.4	8.3	3–21	6.2	16.2	11.9	5–25	5.5

Consonants and Symbols Matching Tasks

Method

The *consonant matching task* involved deciding whether two sequences of eight consonants were identical or not. The two sequences were presented side by side in the centre of a computer screen and disappeared as soon as a response was made. A total of 56 "same" and 56 "different" pairs were used. The *order task* used the consonantrs "cdjpfslv" in various combinations. The different pairs were constructed by reversing the order of two adjacent consonants in one of the two otherwise identical strings (e.g. cdjpfslv cdjfpslv). Consonants were reversed in each of the seven possible adjacent positions in the string, resulting in eight stimuli for each position. The *identity task* was analogous to the order task except that all the 21 English consonants were used and the different pairs were constructed by changing the identity of two adjacent consonants (e.g. cdjpfslv cdjhmslv).

The materials and the procedure in the *symbols matching task* were identical to those of the previous task, except that instead of consonants, the *order task* used the following eight symbols: \ # &!*@<%; the *identity task* used the following twenty symbols: ¶, $, Δ, ∞, Σ, %, @ (, √, ~, !, &, #, ¥, π, ≠, £, •, *, ¢.

Results and Discussion

Results are presented in Table 6. An inspection of this table reveals that, although AW performed within normal range in all conditions, he showed an unusual drop in performance in the order conditions compared to the identity conditions. With both consonants and symbols, his RTs were faster than average in the identity condition but slower than average in the order condition. Thus, although all subjects showed faster RTs in the identity than in the order condition, with both consonants (range of differences 196–879 msec) and symbols (range of differences 119–1078 msec), AW showed a difference much larger than that of any other subject (1384 msec with consonants and 1389 msec with symbols). For AW, the RT difference between the order and the identity condition was significantly larger than control differences with both consonants, $z(9) = 3.8$; $p < .01$, and symbols, $z(9) = 2.9$; $p < .05$. (Order–identity differences were not equally marked in terms of error rates, for both AW and the controls: with consonants, AW = 10, controls = 7.2, z (9) = 0.3, n.s.; with symbols, AW = 2, controls = 3.1, $z(9) = 0.2$, n.s.) These results, therefore, suggest that AW has a particular weakness in processing order information compared to his ability to process identity information, even in tasks that do not involve orthographic processing.

It is interesting to note that Holmes and Ng (1993), in a similar way to us, found that their group of poor spellers/ good readers performed poorly with words but within the normal range with consonants and symbols. Given these results, they concluded that the poor spellers' difficulties with encoding order were limited to linguistic stimuli. Holmes and Ng, however, did not have an identity condition to compare with an order condition. If they had, they may have found that their group of poor spellers also showed an unusual decrement of performance between the identity and the order condition.

CONCLUSIONS

The results of the matching tasks, like those of the lexical decision tasks, showed that AW is good at processing letter identity but not letter order. In addition, the results of the consonant and symbol matching tasks suggest that the problem with order is not a consequence of poor lexical representations (since these tasks do not involve lexical representations at all), although it may well be their cause. Moreover, AW's weakness in processing order is not as evident when assessed by itself as it is when compared to his processing of identity information. Results from the next section provide additional evidence on this point.

SORTING VERSUS RECOGNITION

In this section we want to see whether the same contrast between processing order and identity is found with a different paradigm and, especially, with different kinds of visual units. The new paradigm contrasts *recognition tasks*, where the identity of a number of stimuli has to be recalled independently from their order of presentation, and *sorting tasks*, where the order of a number of stimuli has to be recalled independently of their identities (which are provided). The lexical decision and matching tasks required processing high-spatial frequency information because the stimuli were made up of small and closely spaced units (either letters or symbols). The sorting and recognition tasks used fewer, bigger, and more complex units which minimized the contribution of low-level perceptual difficulties. The sorting tasks, moreover, were more similar to the tasks used by Castles and Coltheart (1996) to tap visual sequential memory and thus allowed a more direct comparison with the performance of another developmental case. Finally, we wanted to carry out the same tasks with words as with visual stimuli to see whether the same contrasts were obtained.

Method

Hindi Characters. Series of 4 and 5 characters from the Hindi alphabet were used as visual units. They were, for all purposes, equivalent to visual configurations because AW, like our controls, was unfamiliar with this alphabet. Twenty control subjects participated in the first session with series of 4 characters; 14 came back for the second session with sequences of 5. An example of a series of these characters is presented in Figure 1.

The Hindi characters appeared individually on the centre of the screen of a Macintosh computer. Each character remained on the screen for 100 msec with an interstimulus interval of 300 msec. After the end of the series, the subject was given a set of tiles with the corresponding characters to arrange in the correct order (*sorting task*). Ten series of 4 and 10 series of 5 characters were presented. After five trials, *all* the characters presented were mixed together with an equivalent number of new tiles. The task was to say whether each character was old or new (*recognition task*). Therefore, with series of 4 characters, 20 out of 40 stimuli had to be recognized; with series of 5 characters, 25 out of 50 characters had to be recognized.

Words. Ten series of 7 words were presented one at the time on the computer screen (words were taken from a pool of 50 words so that 10 words were presented twice). The procedure was identical to that used with the Hindi characters. At the end of each series, the subjects were given

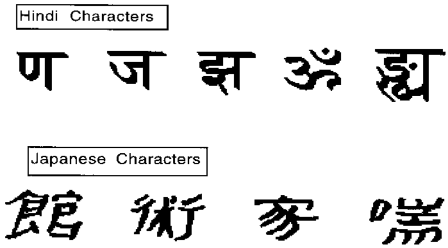

FIG. 1. Examples of the characters used in the tasks contrasting sorting vs. recognition (Hindi characters) and in the tasks contrasting sequential vs. simultaneous presentation (Japanese characters).

the 7 words, printed on cards, to arrange in the correct order. When the sorting trials were completed the subjects were asked to distinguish the 50 words presented in the sorting trials from 50 new words.

Results

Results for AW and a group of 13 college students are presented in Table 7.

Hindi Characters. With series of 4 characters, results are what we expected. AW performed well in the recognition task. His performance, in fact, was better than the average of the controls. It was poor, however, in the sorting task. Only one subject out of 20 performed worse than he did. With series of 5 characters, however, AW's performance was good in both the recognition and the sorting task (it was the second best and the fourth best, respectively). A probable reason for this improvement is that AW started to use a verbal recoding strategy. He himself stated that he found a way to perform the task by remembering the number of "legs" sticking out of each character. Performance, therefore, is likely to be good because five digits are well within his span. If this hypothesis is correct, AW should again perform poorly when the number of units in the list is more than his span.

Words. The sorting tasks involved series of 7 words—a number which exceeded his span. AW, therefore, should perform poorly and this is what happened. Table 7 shows that AW's performance was the worst out of a group of 13 subjects. It was well within the normal range, however, in the recognition task.

Discussion

AW performed well on all three of the recognition tasks, but very poorly on two out of three of the sorting tasks. A learned strategy is the most likely explanation of the odd good result. Thus, again, AW performed well when the task required processing/

TABLE 7
Percentage Correct for AW and a Group of Undergraduate Controls in Sorting and Recognition Tasks

			Controls		
		AW	*Mean*	*Range*	*AW's Ranking*
Recognition	Hindi characters (20/ 40)	78.8	72.5	60–86	5th in 21
	Hindi characters (25/ 50)	84	74.8	56–86	2nd in 15
	Words (50/ 100)	94	94.5	89–100	6th in 14
	Total	85.6	80.6		
Sorting	4 Hindi characters	67.5	84	65–95	20th in 21
	5 Hindi characters	88	77	60–96	4th in 15
	7 Words	58.6	81.4	64–97	14th in 14
	Total	71.4	80.8		

remembering the identity of a number of visual units, but poorly when the task involved processing/ remembering their order. An alternative possibility is that performance was good on the recognition tasks because these were easy tasks. However, the controls' performance was far from ceiling in two out of three of the recognition tasks and, overall, the controls' performance was no different between the two kinds of tasks. The fact that a dissociation in processing identity and order was found even with large and quite distinctive visual units makes an explanation in terms of a low-level perceptual difficulty unlikely. Finally, these results confirm that AW's processing style is not limited to lexical representations.

SEQUENTIAL VERSUS SIMULTANEOUS PRESENTATION

The results of the previous section confirm that AW has a problem processing order, but are at odds with the fact that he performed very well on a task involving learning some Russian words in association with a picture (described in Romani & Stringer, 1994) because this task also involved remembering the order of a number of visual units (cyrillic characters). A crucial difference, however, may be the fact that the Russian words involved a limited number of characters (never more than four), which were simultaneously presented, whereas the characters of the sorting tasks were always presented serially one at a time. AW may be able to exploit well his excellent visual memory only in the first condition. To test this hypothesis directly, we decided to compare serial versus simultaneous presentation of visual units within the same sorting task.

Method

Given AW's ability to develop coding strategies, a new set of characters was used. They were taken from the Japanese alphabet and were unfamiliar to both AW and our control subjects. An example of a series of these characters is presented in Figure 1.

Series of 4, 5, and 6 characters were presented. In the *simultaneous condition*, the characters appeared in a row in the middle of the computer screen, each separated from the other by a space. They remained on the screen for 2000 msec. In the *sequential condition*, they appeared one after the other as in the previous experiment: A character appeared in the middle of the screen; it stayed on for 100 msec; there was a blank of 300 msec, and the next character appeared in the same position.

In both conditions, the task was to sort into the correct order tiles with the characters just presented. In addition to AW, 20 undergraduates participated as controls.

Results

Results are presented in Table 8. With 4 characters, AW's performance was well within the normal range, both in the simultaneous and in the sequential condition—it was, in fact, better than average in both conditions. With 5 and 6 characters, AW presented the dissociation we expected with 5 characters. Performance was better than average in the simultaneous condition, but barely within the normal range in the sequential condition. With 6 characters, AW's performance was still within range in the simultaneous condition, but completely out of range in the sequential condition. These results suggest that, with 5 simultaneous characters, AW is still able to use his excellent visual (configurational) memory to encode the sequence, whereas with 6 characters complete compensation for poor retention of order is no longer possible.

Most important, with 5 characters, AW's difference in performance between the simultaneous and sequential condition (-8) was significantly smaller than the average difference shown by the control subjects ($+18$), who found the simultaneous condition harder than the sequential condition, $z(19) = 2.2$; $p < .05$. With 6 characters, again, AW's difference in performance between conditions (-3) was significantly smaller than the average difference shown by the control subjects ($+25$), $z(19) = 2.1$; $p < .05$. AW's difference in performance between the two presentation conditions is even more striking if one considers that he is the only subject to perform better in the simultaneous than in the sequential condition with both 5 and 6 characters. With 6 characters, all 20 of the control subjects showed an advantage in the *opposite* direction (range 2–62). With 5 characters, again all but one control showed better performance with the sequential condition (range 0–44).

TABLE 8
Percentages Correct in Recalling Sequences of Japanese Characters for AW and a Group of Undergraduate Controls

	Simultaneous Condition			*Sequential Condition*		
	AW	*Controls*		*AW*	*Controls*	
Characters		*Mean*	*Range*		*Mean*	*Range*
4	75	66	43–90	90	81	50–100
5	64	56	36–80	56	74	54–92
6	27	42	27–58	23	68	47–90

Discussion

AW shows a striking dissociation between his ability to process a series of characters when they are sequentially versus simultaneously presented. This dissociation is very likely to stem from the fact that, whatever mechanism is necessary to encode order, it is taxed more when the units are presented one at a time and, therefore, are more likely to be coded individually, than when they are presented all together and, therefore, are more likely to be integrated into larger visual configurations. This dissociation echoes another: that between AW's good word reading (which entails processing simultaneously presented strings of letters) and his poor spelling (which entails retrieval of an ordered sequence of letters). In fact, *all* of the results presented so far can be well explained by a dissociation between good ability to process and remember visuo-spatial configurations and poor ability to encode serial order when immediate memory span is exceeded.

Our hypothesis, therefore, is that it is a problem with encoding order that has caused AW to develop orthographic lexical representations that are good enough to support reading (which can be based on partial information), but not good enough to support spelling (which requires an exact recall of letter order). Given this hypothesis, one should consider whether other developmental surface dyslexics reported in the literature also show evidence of a problem with order. The cases reported in the literature who have spelling difficulties very similar to AW are: JAS (Goulandris & Snowling, 1991), Allan (Hanley et al., 1992), and MI (Castles & Coltheart, 1996). Superficially, they show quite different cognitive characteristics: JAS has a problem with configurational memory, but Allan, MI, and AW do not; AW and Allan have problems with tasks tapping visual sequential memory, but MI does not. For our hypothesis, however, the only troublesome result is MI's good performance on a task involving sequential visual memory (the ITPA; Kirk, McCarthy, & Kirk, 1968). This task, however, involves *simultaneous* presentation of the sequence of symbols to be remembered and we have seen that AW shows a clear advantage for this modality of presentation. It is interesting, in fact, that AW was given the same task when he was 10 years old and he was also found unimpaired. It could be, therefore, that both MI and AW show no deficit with the ITPA test because they can compensate through a configurational memory that is exceptionally good in both of them.

GENERAL DISCUSSION

Dyslexic children have been found to be impaired on a wide variety of cognitive skills. Restricting ourselves to impairments for which there is considerable empirical support, groups of dyslexics have shown on the visual front evidence of low-level perceptual deficits (Breitmeyer, 1993; DiLollo, Hansen, & McIntyre, 1983; Lovegrove, Martin, & Slaghuis, 1986; Stanley & Hall, 1973); on the verbal front, they have shown evidence of deficits of phonological coding (Shankweiler, Liberman, Mark, Fower, & Fisher, 1979), phonological segmentation (Bryant & Bradley, 1985), phonological short-term memory (e.g. Baddeley, 1979; Jorm, 1979; Thomson & Wilsher, 1979), word retrieval (Denckla & Rudel, 1976; Murphy, Pollatsek, & Well, 1988; Wolf, 1984), learning of new phonological representations (paired associate tasks with nonsense syllables, e.g. Done & Miles, 1978; Gascon & Goodglass, 1970; Vellutino, Steger, Harding, & Phillips, 1975; learning new words, e.g. Done & Miles, 1978; Gascon & Goodglass, 1970), and verbal coding (Ellis, 1981; Ellis & Miles, 1979; Hicks, 1980; Snowling, 1980). A number of group studies have also found that poor readers/ spellers are impaired on tasks requiring the encoding/ retention of serial information: the ability that we claim is impaired in AW (Bakker, 1972; Bryden, 1972; Done & Miles, 1978; Holmes & McKeever, 1979; Holmes & Ng, 1993; Mason, 1980; Mason, Katz, & Wicklund, 1975; Mason, Pilkington, & Brandau, 1981; Noelker & Schumsky, 1973).

Variety has also been well documented on the side of the reading/ writing difficulties. At least two different patterns have been reported: one stemming from an inability to acquire phoneme–grapheme conversion rules and the other from an inability to acquire lexical representations. Thus, Frith (1980, 1985) has talked of dyslexics arrested at the alphabetic phase, who can read/ write words only through a piecemeal conversion of letters into phonemes, and of dyslexics arrested at the logographic phase, who can treat words only as visual patterns. Boder (1973) has talked of dysphonetic dyslexics, who have a problem with phonic skills, and dyseidetic dyslexics, who have a problem recognizing words as visual patterns. Mitterer (1982) has talked of recoding poor readers and whole-word poor readers. Finally, with reference to the literature on acquired disorders, many authors have used the labels *phonological* and *surface* developmental dyslexia/ dysgraphia to refer to a distinction very similar to those endorsed by the authors cited above (e.g. Temple, 1986).

Perhaps the most important task for current research is not that of documenting yet another impairment in the population of dyslexic children, nor that of documenting different patterns of reading and writing difficulties (to an extent these tasks have already been accomplished). The real challenge is that of linking a particular pattern of reading/ writing difficulties with a particular underlying cognitive problem.[2] In this framework, a particular problem is posed by the underlying cause of surface dyslexia/ dysgraphia. This is because, while phonological dyslexia/ dysgraphia has been linked to an impairment of phonological processing, there is, currently, no viable hypothesis on the causes of developmental surface dyslexia/ dysgraphia (see Castles & Coltheart, 1996; Hanley et al., 1992). The suggestion of our study is that surface dysgraphia may be linked to a problem of order encoding. We will first review AW's pattern of spared and impaired abilities and exclude as unlikely a number of possible alternative causes. Then, we will detail our hypothesis that it is a problem with encoding order that is causing AW's difficulties and place this problem in a developmental framework. Finally, we will discuss some variations of this hypothesis and directions for future research.

AW performs normally, or above the norm, on an impressive variety of tasks. Our results show that he has: (a) good *phonological awareness*, as shown by performance on

[2] Bryant and Impey (1986) have concluded that the distinctive patterns associated with phonological and surface dyslexia not only cannot be the cause of the dyslexic difficulties by themselves, but are, in fact, totally extraneous to them. This conclusion stems from the observation that these patterns are not uniquely associated with acquired or developmental impairments, but can also be found among normal children learning to read (e.g. Baron, 1979; Bryant & Impey, 1986; Treiman 1984). We find this conclusion puzzling. For the purpose of finding out what cognitive weaknesses dyslexic children may suffer from, the patterns of performance in reading and writing should be at least as informative as those exhibited in any other tasks.

phoneme counting, rhyming judgements, spoonerisms, and phoneme blending; (b) good *phonological short-term memory*, as shown by repetition of lists of digits, words, and non-words; (c) good *visual short-term memory*, as shown by recall of a matrix of digits; (d) good *spatial/ configurational visual memory*, as shown by reproduction of designs and recognition of meaningless shapes, and (e) good *episodic/ lexical memory*, as shown by story recall, and paired associates.

All the tasks on which AW performs poorly involve encoding/processing of serial order. Perhaps most interestingly, AW shows an unusual difference in the relative strengths of his abilities, even when performance is overall normal: He performs systematically better when the task can be based on processing the identity versus the order of some visual units (identity versus order condition of lexical decision and matching tasks). Moreover, in contrast to our controls, he shows much better performance when he can deal with a single visual configuration than when he has to process a number of separately presented visual units (simultaneous vs. sequential presentation of sorting tasks). We believe that this particular pattern of cognitive skills—weak processing of serial order and good processing/memory of visuo-spatial configurations—has to be put in direct relation to AW's pattern of reading and writing skills. Before exploring this possibility more extensively, however, it is important to discuss why we believe alternative possibilities are unlikely.

One could still argue that even if, presently, AW does not show any problems in the cognitive domains listed above, a difficulty at the time of learning may still have been at the root of his spelling difficulties. Let us examine a number of possibilities in turn. Hanley et al. (1992) have argued that current good performance on tests of phonological short-term memory or phonological processing does not rule out the possibility that problems at a younger age may have hindered the acquisition of phoneme–to–grapheme rules and this, in turn, may have led to an under-development of the orthographic lexicon. Phoneme–to–grapheme rules, in fact, allow meaning to be derived from novel words that can then be stored in the lexicon more easily. This hypothesis can clearly be rejected in the case of AW. In contrast to Allan, we know that AW *currently* has a problem in the acquisition of new orthographic representations (Romani & Stringer, 1994), whereas he has little problem with phoneme–to–grapheme conversions, short-term memory, and phonological processing.

Another, perhaps more likely possibility is to assume that original difficulties in phonological processing have led to a strong preference for a holistic word-based strategy in reading which, in turn, has caused problems with spelling. Equally one can assume that an original peripheral visual problem may have caused reliance on a holistic-word strategy. The first problem with these and similar hypotheses is that there is no evidence at all of the presumed impairments (in fact, AW's performance is generally *better* than the controls). A second problem is that they treat AW's problem in tasks tapping order as totally coincidental. In fact, although one can imagine that the habit of using a holistic word-based strategy in reading would lead to poor performance on tasks requiring detection of letter order, there is no reason to assume that this strategy would lead to poor performance in tasks involving sequencing of complex visual characters. Nor is it easy to see how such a strategy would lead to the development of an exceptional visual memory. Simplicity of explanation suggests instead that it is the pattern of strengths and weaknesses *currently* displayed by AW that caused his difficulties, especially as this pattern is fully consistent with his reading and writing performance.

The main characteristic of AW's performance in the orthographic domain is a striking contrast between good word reading and poor spelling, which is accompanied by evidence of different strategies adopted in the two domains. In spelling, AW shows evidence of underspecified lexical knowledge and reliance on phoneme–to–grapheme conversion procedures. In reading, he shows no evidence of the application of sublexical conversion procedures, but, instead, evidence of relying on the lexical properties of words. These different characteristics are well accounted for by the hypothesis that AW has a problem with encoding order. This problem would lead to underspecified orthographic representations and re-enforce a reading strategy based on partial word features. Reading will be generally both fast and correct. This is because orthographic information is quite redundant: Several features distinguish a word from other possible words in the language and, in connected text, context helps with disambiguation. Reading words mixed with nonwords will be more problematic, but this is an artificial task. More seriously, spelling will be poor since it requires not only retrieval of all the individual letters in a word, but also retrieval in the correct order.

Frith (1980, 1985) has also reported dissociations of performance between good reading and poor spelling. In her well-known developmental model, the acquisition of literacy involves three stages—logographic, alphabetic and orthographic[3]—but progress does not need to occur in parallel for reading and writing. Alphabetic skills are most congenial to spelling and are applied there first. The opposite occurs for orthographic skills. Thus, those whom Frith calls type-B poor spellers are good at reading but not at spelling because they have reached the orthographic stage in one task but not the other. Evidence comes from the fact that performance is better with words than nonwords in reading, whereas the opposite is true for spelling. Equally, the ability to discriminate homophones is good in reading but poor in spelling.

AW shows the same characteristics of type-B spellers described above. As already suggested, it is possible that a deficit of order encoding may lead to particular difficulties in entering the orthographic phase of spelling. AW's reading, however, also shows features such as "insensitivity to order changes", which Frith describes as a sign of logographic processing. It remains to be seen, therefore, whether there are different kinds of type-B spellers. Some of them, for example, may read in a totally normal fashion, whereas others could over-rely on a holistic word-based strategy. At any rate, we believe that Frith's description and our hypothesis are not conflicting, but that they complement one another. She has provided evidence that there are different stages in the learning of orthography and that development can be arrested at any of these stages. We have provided a hypoth-

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[3] In the logographic stage, processing is accomplished on the basis of a word's visual characteristics (e.g. a word like "doll" may be recognized or written on the basis of being a short word with two ascending letters); in the alphabetic stage, the relation between letters and sounds begins to be appreciated so that reading and writing are carried out on the basis of sublexical conversion procedures; finally, in the orthographic stage, features from the two preceding stages are combined. Words are processed on the basis of their visual characteristics, but linguistic constraints are appreciated so that both syllabic and morphological contexts are taken into account.

esis for the causes of arrest at a given stage. We have argued that AW's failures to develop an adequate lexicon can be linked to problems in encoding order. Other causes, however, may be identified in different subtypes of type-B spellers.

A Problem with Order: A Better Characterization?

We have characterized AW's problem as one of encoding and not of retention of order because he shows difficulties even in tasks that do not have a strong memory component, such as lexical decision and matching tasks. However, one could move the chain of explanation further and ask: What is causing AW's problem with encoding order? One possibility is that AW has a problem with a general mechanism involved in encoding order in different modalities (see next section); another is that a problem with order is the consequence of a processing style that favours parallel/configurational processing over serial/analytic processing. This second class of explanation capitalizes on the fact that AW is not only poor on tasks which require encoding of order, but is exceptionally good on tasks based on parallel configurational visual processing.

It seems likely that serial processing is better suited than parallel processing to the encoding of order. In this modality, in fact, attention is allocated to a number of visual units, one at a time, in a given order. Serial processing, however, is not a precondition for encoding of order. For example, some order information must be processed in reading and lexical decision tasks, although it is likely that most processing occurs in parallel (e.g. Frederiksen & Kroll, 1976). It is possible, however, that even in these tasks serial processing becomes more important in conditions that stress encoding of order—as in reading words mixed with nonwords—or in the order lexical decision task (the conditions that AW finds problematic). That there is an affinity between serial processing and encoding of order is shown by the fact that in our sorting tasks, our control subjects, but not AW, showed a strong preference for a serial/sequential modality of presentation.

Partly overlapping with the parallel/serial dichotomy is the configurational/analytic dichotomy. Again, processing order certainly entails analytic processing: Attention has to be deployed to individual letters to encode their order. Seymour and MacGregor (1984) have suggested that there are two kinds of visual processing difficulties in developmental dyslexics who do not have phonological impairments: a problem in holistic processing (morphemic dyslexia) or a problem in analytic processing (analytic dyslexia). In the first case, there would be a difficulty in treating "multiple letters strings as units"; in the second case, there would be a difficulty in focusing "on individual segments of a letter array". They predict that analytic problems should result in a surface pattern in spelling (as the consequence of poor lexical representations), no problems in reading words but slow reading of nonwords, and difficulties in matching tasks involving arrays of letters. The same characteristics are found in Frith's type-B spellers and in AW. However, although certain features of AW's performance are best described in terms of a problem in focusing on individual letters (e.g. his decrement in performance when words are mixed with nonwords), others are best described in terms of a problem in encoding order (e.g. worse performance in the order than in the identity conditions).

At present, we do not have enough evidence to disentangle these different possibilities. However, whether AW's problem directly involves the encoding of order, or is the consequence of a processing strategy that, in turn, causes problems with order, his pattern of results suggests that the ability to remember item identities must be distinguished from the ability to remember their order. Results from the "normal literature" have already shown that different variables affect retention of order and item information. Thus, semantic similarity impairs recall of order but improves recall of individual items (Murdock & von Saal, 1967). Similarly, phonological similarity results in a selective increase of order errors (Wickelgren, 1965). Finally, bow-shaped serial position curves are obtained when the task requires retention of order, but flat curves are obtained when the task requires only retentions of the items (Healy, 1974; see Bjork & Healy, 1974 for results relative to order errors). Some models of memory find it difficult to account for these dissociations. Models where recall is based on gradient of activation (Burgess & Hitch, 1996; Houghton, Glasspool, & Shallice, 1994), on chain of associations (Lewandowsky & Murdock, 1989), or on retrieving items in different positional slots (Conrad, 1965; McClelland & Rumelhart, 1981; Plaut & Shallice, 1993) do not allow items to be recalled independently from position. Our results, however, support models that use different computational devices for the representation of order and item information and that, therefore, allow a selective impairment of order information. Examples of models of this type include those of Estes, Brown, and their collaborators (Brown, Preece, & Hulme, 1997; Estes, 1997; Lee & Estes, 1981). Estes' model represents order through a set of hierarchical control units. The implemented model of Brown et al. (1997; Brown & Vousolen, 1998) represents order through a context vector, which is defined by oscillators that vary sinusoidally over time at different speeds, thus enabling any episode to be linked to a particular state of the context vector. Finally, models that distinguish representation of order from representation of identity have also been proposed in a different domain: that of theoretical phonology. Here evidence suggests that the content of phonemes and their order are represented at different levels, which can be selectively engaged by phonological rules (Clements & Keyser, 1983; Goldsmith, 1990).

A Problem with Order: How General?

Parents, clinicians, and teachers have noted that children with dyslexic-type symptoms have problems in remembering spoken sequences such as the days of the week or the months of the year (e.g. Miles, 1983). This last problem was also noted in AW when he was 10 years old. It would be interesting, therefore, to know whether AW's problem with order involves not only visual but also auditory units. An early indication that AW's problem may be supramodal is his poor performance in tasks requiring learning of both new orthographic and phonological representations (Romani & Stringer, 1994). Although AW's everyday problem is with spelling and not with speech, this may be attributed to the fact that spoken language is practised more extensively and must be processed sequentially, and that articulatory constraints may help in keeping phonemes in the correct order. On the other hand, a general rule of the cognitive system seems to be that processing, mnestic, and storage resources are distinct for different modalities and cognitive components (see Romani & Martin, in press), and this argues against a single over-arching mechanism involved in the representation of order. In terms of a model like that of Brown et al. (1997), asking whether order impairments are or are not supra-modal is equivalent to asking whether distinct context vectors are used by different modalities. The answer would clearly have far-reaching implications.

In conclusion, we have shown that detailed single-case studies of developmental patterns can be informative in a variety of ways. AW confirms that developmental spelling difficulties are not all of the same kind. They can exist, as in this case, in the face of excellent visual and phonological capacities. We have argued, moreover, that AW has problems with spelling as a consequence of a more general difficulty encoding serial order. If this is correct, our account may provide a way to tie together the data from several previous studies with conflicting features. In addition, it fits well with the expectation that developmental difficulties will not selectively affect specific and non-universal aspects of language. Although very specific problems may be noted, they will have more general origins. This potential to trace the sources of developmental difficulties and to uncover implications regarding the maturation and overall architecture of the cognitive system makes developmental studies of this type especially valuable for both cognitive and clinical research.

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