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Effects of spelling-sound consistency on the reading and spelling of skilled and dyslexic developing readers

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Abstract

We investigated the effects of rime consistency on reading and spelling among dyslexic children and a control group who were skilled readers, matched by reading-age. Under a factorial design, we manipulated the consistency of orthography-to-phonology (OP) mappings together with the consistency of mappings from phonology to orthography (PO) mappings. We examined feedback as well as feedforward effects of consistency in both reading and spelling. In reading, feedforward consistency is OP consistency, feedback consistency is PO consistency. In spelling, feedforward consistency is PO consistency, feedback consistency is OP consistency. We found feedforward consistency effects in the reading and spelling of dyslexic and control children. Dyslexic but not control children demonstrated feedback (PO) consistency effects in reading. Both dyslexic and control children demonstrated feedback (OP) consistency effects in spelling. Our results challenge accounts of reading or spelling skill that assume feedforward consistency effects alone are important. We consider the implications of these results in relation to theories in which children may assess candidate responses for goodness of fit to prior expectations. We discuss the wider implications of our results for the assessment and remediation of dyslexia.

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Introduction

A literate individual is able to read or spell by translating between the orthography (spelling) and the phonology (sound) of words. The lexicon in English includes words that vary in the predictability of their spelling or sound. That is, given what one knows about other words that share graphemes or phonemes e.g. “dish, fish” or “have, cave”, for some words it is possible to predict correctly their spelling or sound (“dish” given “fish”) but for others it is not (“have” given “cave”). A long tradition of research shows that the varying predictability of a word is a fundamental aspect of the learning challenge for the developing reader-writer.

A word’s spelling or pronunciation can be predicted depending on factors that include the correspondences that exist at a grapheme-phoneme level, as well as the intra-lexical context in which a grapheme or phoneme appears (Kessler & Treiman, 2001). The influence of intra-lexical context on the predictability of spelling-sound (or sound-spelling) mappings can be captured in relation to rime consistency. We report a study focused on a significant gap in our knowledge about the effects of rime consistency on the reading and spelling of developing normal or impaired readers.

Monosyllabic words in English (for example, “street”), can be divided into sublexical units including the onset (“str…“), the initial consonant or consonants, and the rime (“…eet”), the vowel or vowel combination plus the final consonant or consonant cluster. Rimes exhibit two forms of feedforward consistency. (We use the term "feedforward" to refer to mappings from input to output in a task, e.g. from spelling to sound in reading.) A word is consistent in its orthography to phonology (OP) mapping if there is only one pronunciation of its orthographic rime e.g. "gang". A word that is inconsistent in its OP mapping shares its orthographic rime with other words that may be pronounced differently e.g. "scarf, dwarf". A word that is consistent in its phonology-to-orthography (PO) mapping has a rime that is spelled in only one way e.g. "song". A word that is PO inconsistent has a rime that may be spelled differently in different words e.g. "lung, young". We know that OP inconsistent words are more difficult to read than OP consistent words (see Metsala, Stanovich, & Brown (1998) for a quantitative meta-analysis of the extensive set of relevant findings) and that PO inconsistent words are more difficult to spell than PO consistent words (Barry & Seymour, 1988; Brown & Loosemore, 1994; Holmes & Ng, 1993; Kreiner & Gough, 1990; Waters, Bruck & Seidenberg, 1985). Little is known about whether feedback inconsistency influences normal or impaired reading or spelling. We report an experimental investigation designed to address this gap.

We use the term feedback consistency to refer to the mappings between the (potential or actual) output and the input of a task (see Stone, Vanhoy & Van Orden, 1997). Feedback consistency in reading is the consistency of the mappings from the sound to the spelling of words. Feedback consistency in spelling is the consistency of the mappings from the spelling to the sound of words. The possibility of feedback effects is significant for both methodological and theoretical reasons. Words may be inconsistent in both feedforward and feedback mappings, thus if feedback effects are observed one can question the validity of findings stemming from previous investigations of (feedforward) consistency that have failed to control for feedback consistency (Stone et al., 1997). Current models of reading and spelling (e.g. Brown & Loosemore, 1994; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; Houghton & Zorzi, 2003; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989) allow but do not address feedback consistency effects, so that the observation of such effects would serve to improve the constraints on theoretical accounts of literacy skills. Feedback consistency effects implicate modes of compensatory processing that reading impaired children may employ to achieve success in reading or spelling.

Several accounts of the development of reading and spelling (for example, Frith, 1985) assume that growth in one skill is inextricably linked to growth in the other (though the influences on growth may be distinct in the early stages of development). Thus feedback links (PO links in reading, OP links in spelling) may be established as part of the normal process of literacy acquisition. There is some support for this position in the findings of recent longitudinal studies. Caravolas, Hulme and Snowling (2001) report that during the first one and a half years of schooling phonemic awareness and letter-sound knowledge predict the ability of children to produce phonologically plausible spellings, that is, spellings that if decoded sound like the target word. They also found that for slightly older children, phonological spelling ability, phoneme isolation skills, and letter-sound knowledge predict success in conventional spelling. By the third year of schooling, however, only reading ability and conventional spelling predict the level of a child’s spelling proficiency. In comparison, later reading proficiency is predicted by earlier reading proficiency but, in the early stages of school, phonological spelling ability and letter name knowledge were also found to be important factors. We interpret these and other findings (Bruck & Waters, 1988, 1990; Cataldo & Ellis, 1988; Ehri, 1997; Ellis & Cataldo, 1990;

Juel, Griffith & Gough, 1986) as signifying the interactive character of development in reading and spelling, an interactivity over time which may underlie a functional interactivity observable as the influence of feedback consistency on developing reading and spelling.

We submit that, in the course of development, at test, a child may check spelling attempts through phonological recoding and that such verification (implicitly or explicitly asking, 'Does this spelling sound like it should, like the word I may recently have heard said?') fosters the participation in spelling of orthography-to-phonology feedback mappings or of a spelling-sound verification mechanism. We further note that it has been suggested by Share (1995) that phonological recoding of printed words supports self-teaching of orthographic knowledge. There may thus be multiple causes for the development of the use in spelling of information about feedback orthography-to-phonology mappings. We consider that growth in print exposure over time could fuel the development of an awareness of variation across words in sound-spelling predictability which would, in turn, invite verification of spellings. Such verification may be routine in the early phases of development or for individuals presenting specific impairment in spelling development.

Similarly, in reading, slow or uncertain spelling-sound mappings can be verified before output by checking that the spelling of the candidate pronunciation matches up with the stimulus orthography (a verification test that may ask, implicitly or explicitly, 'Is the phonological word, the sound I wish to utter in response to the written word in front of me, capable of being spelled in the way that I see that the word is spelled?'). Where reading aloud must be performed at a forced in pace or, where the process of reading is highly efficient, there may be no time for such a test of a candidate pronunciation. (Paap, Newsome, McDonald, and Schvaneveldt, 1982, discuss a model of word recognition in which verification may be truncated by very short presentation intervals or by the backward masking of words).

The findings from Caravolas et al. (2001) provide strong support for the view that feedback mappings support normal reading and spelling development. However, their study was not motivated by the question of feedback effects and their data are relevant to phonemic awareness and to letter-sound knowledge, rather than to rime knowledge per se. Thus it is an open question whether feedback consistency of the rime has any impact on children's reading and spelling performance. Yet there is a clear case for examining these effects.

Substantial evidence indicates the importance of the rime level to success in reading and spelling. Kessler and Treiman (2001; p.611) argue that although mappings that serve reading or spelling "…may fundamentally operate at the phoneme level…", there is evidence that their successful operation can profit by "…[taking] into account the context in which each phoneme is found". In an analysis of data furnished by large scale studies of reading, Treiman, Mullennix, Bijeljac-Babic, and Richmond-Welty (1995) report that OP rime consistency accounted for variation in speed or accuracy of both developing and adult reading, above and beyond any contribution due to consistency at the grapheme-phoneme level. Further, Goswami (1986, 1988, 1993) has reported that children are able to successfully read new words by exploiting analogies with similarly spelled rimes that exist in the lexicon. (It is important to note in this context the finding by Treiman and Zukowski (1988) that adult read and also spell nonwords by analogy to lexical rime neighbours.)

Feedback consistency effects in reading and spelling have recently been the target of investigation. A number of observations concerning such effects have nevertheless been reported. English and French adults have been found to respond to PO (feedback) consistent words faster than to PO inconsistent words in reading aloud (Ziegler, Montant & Jacobs, 1997, in French; La Cruz & Folk, 2002, in English), and in lexical decision (in English, Perry, 2003; Stone et al., 1997; in French, Ziegler et al., 1997). Such feedback influence is likewise suggested by observations of the effect of homophony on word recognition (Ferrand & Grainger, 2003; Pexman, Lupker & Jared, 2001; Pexman, Lupker & Reggia, 2002). We find only one extant report in the literature of OP (feedback) consistency effects in spelling. Laxon et al. (1988) report the results of a logistic regression analysis which suggested that OP regularity significantly influenced children's accuracy in a test of spelling (see, also, Stuart & Masterson, 1992).

Of particular relevance to our study is the comparison reported by Swan and Goswami (1997a) of the phonological awareness presented by dyslexic and reading-age matched children (of age-average ability). These authors examined phonological awareness in relation to items that had been successfully used by both groups in a confrontation naming task. They found that whereas both dyslexic and reading-age-matched individuals showed equivalent phonological awareness at the onset-rime level, the dyslexic children presented an impairment in their awareness at the level of the phoneme in comparison to the control group. After suggestions by a number of authors (Fowler, 1991; Hulme and Snowling, 1992; McDougall, Hulme, Ellis, & Monk, 1994; Snowling & Hulme, 1989) the phonemic awareness impairment presented by the dyslexic children study may reflect the inadequacy, perhaps through imprecise specification, of phoneme-level (but not rime-level) phonological representations in the reading-impaired group (see, also, Griffiths &

Snowling, 2002). It would therefore seem sensible to begin the investigation of feedback consistency effects in developing reading and spelling with a study of rime-level effects.

What prediction can we derive about feedback effects on reading and spelling for children who have dyslexia? In common with many researchers, we view the basis of dyslexia in terms of the phonological-core variable-difference model (Stanovich, 1988), which holds that dyslexia stems from a specific deficit of word recognition, linked to an impairment in phonological processing. Support for this view rests on findings that dyslexic individuals perform poorly, in comparison with control group children, on phonological awareness tasks and on tests of verbal short-term memory or of rapid automatic naming (see Vellutino, Fletcher, Snowling, & Scanlon, 2004, for a recent review of relevant findings). Further, related, reports have concluded that dyslexic children also present deficits in nonword reading (Rack, Snowling & Olson, 1992; Ijzendoorn & Bus, 1994) and in confrontation naming (Swan & Goswami, 1997b).

One theoretical implication of the assumption of a phonological processing deficit is entailed in the form of the delayed phonology hypothesis. It has been known for two decades that reading ability can interact with feedforward consistency in reading and spelling. Waters and Seidenberg (1985) made the first set of predictions about interactions between reading ability and OP consistency effects in children's reading, based on a time-course model of phonological processing in visual word recognition developed by Seidenberg (1985; see also Brown & Loosemore, 1994 for a similar account of phonological processing in spelling). In this model, phonological activation is the source of OP consistency effects on reading, and phonological activation lags behind visual processing, so that, to quote Waters and Seidenberg (1985, p. 557): "…phonological effects will occur whenever the duration of processing exceeds the latency of phonological code activation. Thus, consistency effects are expected for lower frequency words *and for poorer readers*, because the recognition process is relatively slow…" (our italics). The delayed phonology hypothesis has some empirical support but it is not a viable explanation of reading problems in dyslexia because a meta-analysis of relevant studies finds equivalent effects of OP consistency for children with dyslexia and ability-matched children with age-average ability (Metsala et al., 1998).

An alternative set of expectations can be derived from the examination of the consequences for learning to read of a phonological processing deficit. In this alternative account, the first supposition is that "If [the constituent] sounds [of speech] are poorly represented, stored or retrieved, the learning of grapheme-phoneme correspondences…will be affected." (Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003; p. 842). Not only grapheme-phoneme correspondences, we submit, but also the rime-level mappings between orthography and phonology that account for the use of analogies in reading (Goswami, 1993) and also in spelling (Treiman & Zukoswki, 1988).

Contrasting expectations arise from the assumption that a phonological processing deficit may affect the learning and use of rime-level mappings between spelling and sound. The first is implied by Goswami (1993; p.471) in the suggestion that: "The possible establishment of orthographic recognition units that lack even onset-rime coding will… inhibit the use of analogies in reading, resulting in each word having to learned independently of its orthographic neighbour." If each word is learned independently of its rime-level neighbours then we might have no reason to expect a difference in the relative success with which dyslexic children read or spell consistent or inconsistent words. Thus, one expectation would be that dyslexic children will present smaller or null effects of consistency, irrespective of the direction of consistency (feedforward or feedback), in reading or spelling. As noted, the substantial majority of relevant studies indicates no difference in the extent of feedforward consistency effects on reading in comparisons of dyslexic and reading-age matched controls (Metsala et al., 1998). It is an open empirical question, however, whether the same would be true of feedforward effects in spelling, and in feedback effects in both reading and spelling.

In contrast, there are grounds for expecting that dyslexic children may be more prone to exploit feedback rime consistency to help them in reading, at least. (We will treat reading before going on to consider spelling.) The notion that dyslexic children may present an impairment of phonological processing does not preclude the possibility of reading or spelling through the use of analogies at the level of the orthographic rime. Indeed, Goswami (1993) points out that dyslexic children can benefit from training in the use of rime-based analogies (citing a study reported by Gaskins, Downer, Anderson, Cunningham, Gaskins, & Schommer, 1988). Our expectation of greater effects of feedback consistency in reading derive from the implications of the computational modeling reported by Harm and Seidenberg (1999) of reading in the normal and in dyslexic cases.

Harm and Seidenberg (1999) simulated dyslexia by examining the consequences of an impairment of phonological representation imposed prior to learning to read. They showed that if such impairment is effected (in their terms, to a 'mild' extent), in their simulation through the imposition of weight decay in the phonological attractor mechanism, the result is a deficit in nonword reading together with a normal level of accuracy in reading OP consistent compared to OP inconsistent words; these results mirror the empirical findings reviewed by Metsala et al. (1998) and by Rack et al. (1992). The attractor mechanism in Harm and Seidenberg's (1999) model of reading is designed to ensure correct mappings even where phonological mappings may be incomplete or noisy. Imposing weight decay on the connections of the attractor mechanism means that the model with impaired phonological representations must learn more word-specific mappings to attain successful reading performance. In Harm and Seidenberg's (1999; p.512) words, "…the model is biased to become a whole-word reader…" and this is why it presents a deficit in nonword reading. Generalising from the model to human dyslexic readers, a greater tendency to whole-word mappings between spelling and sound entails that such readers may be more sensitive to orthographic structure (Rack, 1985).

A bias towards reading cued by orthographic structure is more likely to reveal feedback consistency effects, or likely to reveal greater feedback consistency effects in comparison to readers of age-average ability. For if one asks whether a candidate pronunciation is spelled in the same way as the word printed on the page (in an attempt to verify a pronunciation while reading aloud), one is more vulnerable to inconsistencies among PO mappings between phonological rime neighbours e.g. "chief, beef". Feedback consistency may have no effect for the readers of normal ability because the preserved coding of phonology supports accurate OP mappings so that there is no time for the influence of PO mappings, or so that there is less pressure to be sensitive to variation in the orthography of phonological rime neighbours.

Spelling involves a greater degree of unpredictability than reading in relation to mappings between orthography and phonology (Barry & Seymour, 1988; Kessler & Treiman, 2001; Stone et al., 1997). If there is greater inconsistency among mappings the learner reader-speller must devote more resources to establishing the correct PO mappings. In these circumstances, developing spellers might rely on the information provided by OP feedback mappings to complete correct spellings. Moreover, the extent to which PO inconsistency is the case for words in English can be expected to delay the point at which, in normal development, reliance on OP feedback mappings may cease. It is plausible, therefore, that both a reading impaired and a reading-age matched control group of children will present effects of feedback consistency in their spelling performance.

The primary goal of this experiment was to investigate PO consistency effects on reading in children with dyslexia, however. We did this for methodological and conceptual reasons. Tests of the effect of feedback consistency, or of possible interactions between feedback and feedforward consistency effects, would have substantial implications for understanding extant reports of feedforward consistency effects. Stone et al. (1997) report that 72% of OP consistent English words are PO inconsistent. Yet PO consistency is not routinely controlled in studies of OP consistency effects. Thus existing reports of equivalent OP consistency effects on reading in dyslexia and RA controls may be unreliable. More widely, observations of feedback consistency effects, and of possible interaction effects, are important to our understanding of how literacy develops (Perfetti, 1992). If the effects of feedforward or feedback consistency on reading and spelling are different for dyslexic readers and RA controls this may be revealing in terms of understanding the impairments in dyslexia. In particular, the observation of feedback consistency effects in reading and in spelling may reflect propensity for the use of compensatory processing to achieve correct mappings between spelling and sound, processing we have described in terms of verification mechanisms.

We tested feedforward and feedback consistency effects on reading and spelling by manipulating factorially different types of words in English: 1) words with OP consistent/PO consistent (OPC/POC) rimes e.g., /Ish/ -> fish; 2) words with OP consistent/PO inconsistent (OPC/POI) rimes e.g., /ot/ -> boat, bote; 3) words with OP inconsistent/PO consistent (OPI/POC) rimes e.g., /aYv/ -> live, hive; and 4) words with OP inconsistent/PO inconsistent (OPI/POI) rimes e.g., /Ul/ -> wool, tool, pull. We predicted a larger effect of feedback PO consistency on reading by children with dyslexia compared to reading-age-matched controls because the imprecision of phonological representations associated with dyslexia is expected to induce in reading impaired children a greater or more prolonged reliance on orthographic information. We predicted an effect of feedback OP consistency on spelling for both groups because the mappings employed in spelling are less consistent and more difficult to master, even for the child of age-average ability, and because such difficulty may require the use of feedback mappings for the control group as for the dyslexic children. We also expected an effect of feedforward consistency on reading and spelling for both groups but given the many methodological problems in previous studies we had no strong prediction about group differences.

The experiment

We investigated feedback as well as feedforward consistency effects in a factorial design experiment. We have suggested that feedback effects challenge reports of feedforward consistency effects because feedback consistency has not been controlled in previous studies. However, some studies reporting feedback consistency effects have themselves been subject to methodological criticisms (Peereman, Content, & Bonin, 1998).

This is because variables that moderate feedforward consistency effects, for example, orthographic neighbourhood size and lexical familiarity, have not hitherto been controlled. In the present study, we took care to ensure that these variables were controlled to exclude the possibility of such confounds.

Method

Participants

20 dyslexic children (17 males, 3 females) were recruited for the study from East Court School in Ramsgate, Kent. These children were between 109 mths. (9 yrs., 1 mth.) and 148 mths. (12 yrs., 4 mths.) old at the time of testing (mean of 133 mths.), and were tested in their first year at the school. The reading ages (RA) of the dyslexic group (tested using the Schonell Graded Word Reading Test (Schonell & Goodacre, 1971)) were 40.6 months less than their chronological ages (CA), on average; the difference between CA and RA ranged between 26 months and 63 months. All children included in the study presented full intelligence quotient scores of not less than 90 (WISC-R or WISC-III scores). The children were reported not to present behavioural, emotional or neurological problems.

20 more children were recruited from a primary school in Kent to form an R.A.-matched control group (10 males, 10 females). None were reported to present behavioural, emotional or neurological problems. The control children were of better than age-average reading ability. These children were between 65 mths. (5 yrs., 5 mths.) and 108 mths. (9 yrs.) old at the time of testing (group average CA of 88 mths., or 7 yrs., 4 mths.) Their reading ages were measured using the Schonell Graded Word Reading Test (Schonell & Goodachre, 1971). Reading ages in the group ranged between 75 mths. (6 yrs., 3 mths.) and

110 mths. (9 yrs., 2 mths.), with a group average of 97 mths. (8 yrs., 1 mth.) A paired samples t-test indicated that the reading ages of the dyslexic and the RA-matched control group were not significantly different at the .05 significance level ($t\ (19\ d.f.) = -1.449$, $p > .05$). (Please see subject details in Table 1, below).

Table 1. The chronological and reading ages of the dyslexic and control group children

Table 1 here

Materials

The stimulus set consisted of 48 monosyllabic English words assigned in groups of 12 to each of four categories (guided by the statistics derived by Ziegler, Stone & Jacobs, 1997): orthography-to-phonology consistent, phonology-to-orthography consistent (OPC/POC); orthography-to-phonology consistent, phonology-to-orthography inconsistent (OPC/POI); orthography-to-phonology inconsistent, phonology-to-orthography consistent (OPI/POC); orthography-to-phonology inconsistent, phonology-to-orthography inconsistent (OPI/POIC). All but one of the words ("lost") were pronounced using the type majority OP rime mapping.

We selected stimuli that were familiar to seven-year old children, according to data from the Harrison (1980) corpus of words used by British children. The stimuli were matched across conditions for psycholinguistic variables, including word length in letters and frequency, both Kucera and Francis (1967) frequency estimates and CELEX log10 combined spoken and written frequency per million (Baayen, Piepenbrock, & van Rijn, 1993). Stimuli were matched also for orthographic neighbourhood size, for which we used two measures, ALLON and NODUPON (Buchanan & Westbury, 2000), that are counts of the total number of entries in the dictionary which are at most one letter different, by substitution only, from the target word; ALLON includes the target word itself, as well as orthographic neighbours which appear more than once in the dictionary whereas NODUPON collapses identical entries. In a series of 1-way ANOVAs, words in the four conditions were found not to differ significantly, see Table 2 for a summary of item values, see the Appendix for a list of items used in the study.

Table 2. Item mean values of length, frequency and orthographic neighbourhood size.

Table 2 here

Apparatus

In the oral reading task, stimuli were presented by means of a Macintosh laptop computer (Macintosh Powerbook 180) using the Psychlab application (v.08; Gum & Bub, 1988). For the reading task, the stimulus words were presented in Geneva bold 24-point lowercase font. Reading accuracy was recorded by the experimenter, who sat with participants during testing. Children's spelling responses were written on standardised answer sheets.

Procedure

Participants were asked to perform the reading and spelling tasks within the same test session. The order in which participants were required to read and to spell was counterbalanced across participants. In the administration of each task, stimuli were presented in one of seven different random orders. The children were instructed that they were participating in an exercise or game. They were assured that the test was not a test of intelligence, and that they could respond "pass" or leave no spelling if they did not know a word. Before testing, the experimenter answered any questions the children had in relation to the purpose or the character of the tests.

In the reading test, children were asked to read aloud words shown on the computer screen as quickly and as accurately as they could. Words were presented one at a time. The reading task took up to 10 minutes in total for each participant.

In the spelling test, children were asked to spell words dictated by the experimenter. Participants were told they could ask for a word to be repeated if they were unsure that they had heard it correctly. Words were dictated at an even pace and in an even tone and volume. The children were asked to attempt spellings if they knew the word even if they had not spelt it before.

Results

The experiment was an investigation of the effects on oral reading accuracy of the factors reading group (dyslexic, reading-age matched skilled readers), OP consistency (consistent/inconsistent) and PO consistency (consistent/inconsistent). An omnibus ANOVA was conducted to test the significance of the main and interaction effects of these factors. The ANOVA consisted of an analysis of by-subjects data. We also tested the significance of effects of group, PO and OP consistency separately for each task. We do not report by-items analyses due to the greater risk of Type II errors in such analyses when items are matched for critical psycholinguistic variables (Raajmakers, Schinemakers & Gremmen, 1999). We elucidated interaction effects through selected simple effects analyses; reported results are significant at the .01 level unless otherwise noted.

Table 3. Accuracy of oral reading and spelling to dictation: Percentage correct responses

Table 3 here

Reading Results

We observed significant main effects of OP consistency $F(1,38) = 12.5, p = .001$ and of PO consistency $F(1,38) = 15.7, p < .001$ children read words more accurately if they were OP or PO consistent. We also observed a main effect of reading group $F(1,38) = 6, p = .01$ the control group read words more accurately than the dyslexic children. There was a significant interaction of PO consistency and group effects $F(1,38) = 5.7, p = .022$ stemming from the fact that dyslexic but not control children demonstrated the simple effect of PO consistency. There was a significant interaction of OP and PO consistency effects $F(1,38) = 11.5, p = .002$.

Spelling Results

We observed significant main effects of OP consistency $F(1,38) = 29.2, p < .001$ and of PO consistency $F(1,38) = 76.7, p < .001$ children spell words more accurately if they are OP or PO consistent. We also observed a main effect of reading group $F (1,38) = 4.2, p = .047$ the control group spelled words more accurately than the dyslexic children. There was a significant interaction of OP and PO consistency effects $F(1,38) = 33.3, p = .002$. Finally, there was a significant interaction between OP consistency, PO consistency and group $F(1,38) = 6.7, p = .014$.

Omnibus Analysis

We observed significant main effects of task, with pronunciations produced more accurately than spellings $F (1,38) = 11.1, p = .002$. We observed a main effect of reading group, control group children were more accurate overall than dyslexic children $F (1,38) = 9.4, p = .004$. We observed a main effect of OP consistency, OP consistent words elicited more accurate responses than inconsistent words $F (1,38) = 37.3, p < .001$. We observed, also, a main effect of PO consistency, PO consistent words elicited more accurate responses $F = (1,38) = 74.5, p < .001$. We found a significant interaction between task and PO consistency $F (1,38) = 32.8, p < .001$. The simple effect of PO consistency was significant in both reading and spelling. There was a significant interaction between the effects of PO consistency and of group $F (1,38) = 6.8, p = .013$. The simple effect of PO consistency significantly affected the performance of both dyslexic and RA children, moreover, the effect of PO consistency was found to be greater in the case of dyslexic reading and spelling. We found a significant interaction between the effects of OP and of PO consistency $F(1,38) = 34.9, p < .001$. We also found that there was a significant three-way interaction between task, OP consistency and PO consistency $F(1,38) = 5, p = .032$. Finally, we observed a significant three-way interaction between group, OP consistency and PO consistency $F(1,38) = 6, MSe = 112, p = .022$.

We note, finally, that there are two or three items in each condition with complex onsets or codas, but that there is no systematic skew, and that the greater number of words words with complex codas are in the OPC/POC condition. Thus any potential confound between the occurrence of words with complex forms and task difficulty would tend to make more conservative a test of the hypothesis that inconsistent words are harder to use accurately. A regression analysis indicated that there is no effect of number of letters in onset or coda (ranging from 1-3) on spelling for either participant group.

<u>Summary and conclusions</u>

We observed that both OP and PO consistency affected the accuracy of participants' reading responses. In this circumstance, a PO consistency effect can be termed a feedback effect. We also observed effects of both OP and PO consistency on spelling accuracy. Here, the OP consistency effect can be termed the feedback effect. The feedforward effect of OP consistency on reading was shown by both dyslexic and control children. Likewise, the feedforward effect of PO consistency on spelling was demonstrated by all children although dyslexic children presented a greater PO consistency effect than control group children. Importantly, PO (feedback) consistency affected the reading performance of dyslexic children but not of control group children. The effect on spelling of OP (feedback) consistency was demonstrated in both dyslexic and control group children. The effects of OP and of PO consistency were observed to interact, under all analyses.

The observation of feedforward consistency effects adds to previous reports that OP predictability affects reading and PO consistency affects spelling. Children are less accurate at reading OP inconsistent (exception) words compared to OP consistent words and are less accurate when spelling PO inconsistent words compared with PO consistent words. Such feedforward consistency effects are readily explained by current models of reading and spelling. Our results are congruent with the expectations that can be drawn from both dual-route (Coltheart et al., 2001; Houghton & Zorzi, 2003) and connectionist (Brown & Loosemore, 1994; Harm & Seidenberg, 1999; Plaut et al., 1996; Seidenberg & McClelland, 1989) accounts. In principle, the effect of feedforward consistency is the consequence of cross-talk between inconsistent spelling-sound mappings: for inconsistent words there is delay while competition or conflict between alternate mappings must be resolved; for consistent words there is an advantage since no such resolution is required (Stone et al., 1997; Van Orden, Pennington & Stone, 1990).

The effect of OP consistency on reading was not found to differ for dyslexic and skilled readers, a finding congruent with the conclusions of Metsala et al. (1998). We submit, therefore, that our findings add to the view that OP consistency effects are demonstrated in a similar fashion in the reading of groups of more or less skilled readers. There is little extant research concerning the possible interaction between PO consistency and reading ability in spelling. What research is available presents a mixed answer to what kind of interaction may be observed. Dyslexic children in our study were more affected by PO consistency in spelling than were the R.A.-matched control group children. This is consistent with the observation by Laxon et al. (1988) that less able readers were more affected (in their reading and spelling) by orthographic neighbourhood size than good readers. Our finding contrasts with the observation by Waters et al. (1985) that children who were good readers or spellers demonstrated a PO consistency effect in spelling but that poor readers or spellers did not. It contrasts, also, with the report by Brown and Loosemore (1994) that dyslexic and normal readers presented similar PO consistency effects in spelling. Our finding suggests that, at least at the ages of the children we tested, dyslexic children are more likely than age-average children to demonstrate an advantage of PO consistency in spelling because a phonological processing deficit makes the PO mapping more uncertain. In the case of consistent words such uncertainty is diminished by analogies between PO mappings (Treiman & Zukoswki, 1988) whereas in the case of inconsistent words it must be magnified by the presence of alternate PO mappings for rime neighbours of the target for spelling.

Our study is the first to test effects of feedback consistency in spelling as well as in oral reading, it is also the first to test effects of feedback consistency in dyslexic and in skilled readers. We found that PO consistency affected oral reading and that OP consistency affected spelling to dictation. The observation of a feedback (PO) consistency on reading adds to the evidence of such an effect on visual word recognition (reported by Ferrand & Grainger, 2003; La Cruz & Folk, 2002; Perry, 2003; Pexman et al., 2001; Pexman et al., 2002; Stone et al., 1997; Ziegler & Ferrand, 1998; Ziegler et al., 1997) and it contrasts with the null feedback effect reported by Peereman et al. (1998). Moreover, our observation of a PO feedback consistency effect on oral reading was recorded in an experiment free of the confounds with orthographic neighbourhood size or CELEX frequency identified in previous studies by Peereman et al. (1998). We contend that the PO consistency effect in reading is a real feedback effect that must be accounted in theories of reading. The finding of a feedback (OP) consistency effect on spelling contributes to a scant data set (but see findings suggestive of such an effect reported by Laxon et al. (1988) and by Stuart & Masterson (1992)). We likewise submit that OP consistency is a real influence on spelling. These findings have important methodological implications since they strongly mandate control over feedback as well as feedforward consistency in studies testing the effect of relative predictability in reading and spelling. Our observations also have implications for theories of reading and spelling, and of the development of literacy.

We have noted that symbolic (e.g. Coltheart et al., 2001) and connectionist (e.g. Plaut et al., 1996) models of reading and spelling allow the existence of feedback effects. Such effects have yet to be addressed directly in theory or in the simulation of reading and spelling skill now obligatory in the development of accounts of literacy skills. It remains to be seen whether the models mentioned in our review, as presently instantiated, can both simulate feedback effects and continue to be successful in their simulation of previously reported quantitative characteristics of reading and spelling behaviour.

The question, of course, is: How should we view the cognitive substrate of feedback consistency effects? In our Introduction, we phrased the basis of feedback effects in terms of implicit or explicit verification of candidate outputs: checking that a candidate pronunciation in reading can be spelled in the same way as the input spelling; or checking that a candidate orthography in spelling can be pronounced in the same way as the input pronunciation. Stone et al. (1997) emphasize that feedback consistency effects may be accounted in relation to the feedback transmission of activation from output to input representations, but these effects may also be explained by the action of verification mechanisms that perform a goodness-of-fit test comparing a candidate output (recoded as input) and the input stimulus. In addition, we discussed feedback effects as, possibly, precipitates of the interactivity of development in reading and spelling skill, where such effects may arise through the impact of, for example, phonological recoding.

We believe that the next steps for research ought to be focused on the view that feedback consistency effects may reflect the verification of responses before output. In future investigations, a comparison of children diagnosed as either dyslexic or as age-average readers but differing in age would furnish a test of the view that feedback consistency may inform the checking of candidate outputs in reading or spelling. Age-average readers younger than those tested in the present study are expected, in our view, to demonstrate feedback consistency effects in reading. More skilled dyslexic readers are expected to demonstrate null feedback effects in reading.

Future researches might fruitfully investigate alternative mechanisms of verification. In this area, we believe that it would be useful to study whether feedback consistency effects may be eliminated by imposition of verbal memory load (a result that would tend to imply a verification mechanism subsisting in working memory processes) or by the effect of manipulating stimulus and of response intervals (if feedback effects occur as a result of feedback transmission of activation, such transmission may require time to be effective). Further research might also investigate methods of benefiting from verification habits, that is, whether the development of reading or spelling skills could be progressed through explicit instruction of verification testing of candidate reading and spelling responses.

It is of interest that the feedback effect of PO consistency was evident in the reading performance of dyslexic but not of control group children. The observation of a null effect of feedback PO consistency on the reading performance of the control group contrasts also with the observation of significant effects of feedback consistency in the reading of skilled adults, reviewed in the foregoing. We would argue that the contrast between skilled developing and adult reading may stem from differences between the tasks used in the present study compared to some of the adult studies. In the latter (Perry, 2003; Stone et al., 1997), the use of the lexical decision task encourages a style of response preparation that is more dependent on orthographic information. Lexical decision has been argued to be a task in which responses can be triggered by activation of the orthographic lexicon (see Coltheart et al., 2001, for a discussion of this view). This would entail greater susceptibility (compared with, for example, reading aloud) to the influence of consistency on the transmission of activation in feedforward and feedback directions to or from orthographic representations. It is difficult to see why our results would differ from those reported by La Cruz and Folk (2002), however, who report a study of feedback effects on reading aloud. And it is clearly necessary to examine the question further, paying attention to fine-grained methodological differences.

It is relevant in this context that the dyslexic children were, overall, less accurate in reading (and in spelling) than were the RA-matched children. We matched the groups in relation to the Schonell test: this is a test of single word reading that in the case of the present study was administered under no time constraint. We acknowledge that, in comparison, the experimental test of reading and spelling required participants to produce responses under strong time constraints: participants were encouraged to produce responses as quickly as they could. Under the pressure of forced pace reading or spelling, and impaired by a hypothesized deficit in phonological processing, the dyslexic children were likely to perform at a lower rate of accuracy than they had in the test of reading age, as seen in our results. Moreover, the dyslexic children are likely to have been encouraged to rely on the verification of responses, where possible, through the use of information about orthography: this verification is, we argue, manifest in the effect of feedback consistency. The RA-matched controls were not under the same pressure in the reading test due to their preserved phonological coding abilities. However, both groups of children may well have had difficulty in the spelling test. Certainly, it was the case that in the present study both groups were less accurate in spelling than in reading overall. Thus we suppose that, in the spelling test, feedback OP consistency effects were revealed by the greater difficulty of the task.

We observed an interaction between OP and PO consistency effects on performance of both reading and spelling tasks by both groups of participants. Moreover, the dyslexic children's accuracy appear to bear the interaction effect most strongly; this groupxOPxPO consistency interaction may be linked to the finding that the dyslexic but not the RA-matched controls presented a feedback consistency effect in reading. We believe that the interaction between OP and PO consistency effects, particularly that presented by dyslexic children in the reading task, has strong parallels with the observations reported by Stone et al. (1997) of an interaction between OP and PO consistency effects on the latency of lexical decisions by normal adults. In that study, as in the present study in the case of the dyslexic readers, responses to words that were inconsistent in both feedforward and feedback directions were no more hindered than responses to words inconsistent in only one direction. Our account of this interaction effect, like the account proposed by Stone et al. (1997), necessarily acknowledges that whereas we (and they) presented words that were classed as either consistent or inconsistent, in fact, words may be varyingly consistent (or inconsistent); indeed, the views of Kessler and Treiman (2001), and others, strongly suggests the complexity of the variation in OP or PO predictability that underlies the ease with which we use different words. However, development in the construction and validation of effective metrics of complex predictability is on-going (e.g. Jared, McRae & Seidenberg, 1990). Thus we can usefully compare performance on words with OP/PO consistency and words with OP or PO inconsistency (or both), to the extent that, as in the present study, it allows us to test the influence of feedback consistency. And our observation of the effect of feedback PO consistency on reading is, in our opinion, a theoretically and methodologically significant finding. Yet equally, to be able to compare the effects of inconsistency varying in extent and in direction awaits further analysis of the patterns of the mappings between spellings and sound in English. We suggest that dyslexic children, at the ages tested, may simply be driven toward a low level of performance by any form of inconsistency since the mappings they employ to read aloud are (after Harm & Seidenberg, 1999) either precise but from a severely constrained set of mappings, or imprecise and vulnerable to the influence of inconsistency. More fine-grained analysis of the consistency of mappings in English may permit a test of this view.

We have not so far discussed the role of semantics in helping to arbitrate between competing solutions to the mapping problem in reading or in spelling. Share (1995) suggests that semantics may be influential in helping a developing child to discriminate between alternate candidate pronunciations of a printed word, especially in the case of OP inconsistent or irregular words. This is a view that is certainly compatible with resonance conceptions of language processing (see Grossberg & Stone, 1986; Van Orden & Goldinger, 1994; see also Plaut et al., 1986; Weekes et al., 2003). The telling observation is that words are not normally learned in isolation, rather they most often appear in continuous text (Share, 1995). Consider how context may direct the reader to the appropriate pronunciations among the alternate readings of, for example, "bread", as "bred", "breed" or "bread". Moreover, a recent case study reported by Howard and Best (1996) suggests that inconsistent OP mappings can be handled by a phonologically impaired reader if it is possible to rely on semantics. These suggestions can be explored through a comparison of consistency effects using continuous or list style presentation of stimulus words.

In conclusion, we report a series of findings that highlight the importance of resemblances between rime neighbours for the reading and spelling of developing readers. Words that share the same phonological or orthographic rime are easier to read or spell if these rimes are mapped to the same spelling or sound. The novel observation contributed by the present study is the finding that this consistency influences the accuracy of reading and spelling when it is counted both in feedforward and feedback directions. We suggest that OP feedback consistency effects on spelling reflect the employment of a verification (of responses) process based on the influence of information about OP consistency. Such influence may be instilled through the practice of phonological recoding as a spelling vocabulary is acquired during literacy development. Likewise, the effect of feedback PO consistency on reading can be taken to reflect the use of feedback consistency to help in the accurate completion of spelling-sound mappings. In contrast to our data concerning spelling, we found that the reading accuracy of dyslexic but not of control children was affected by feedback PO consistency. We submit that this interaction may arise for a number of reasons. These include a reliance on verification process that persists in dyslexic children but not in age-average children, and the possibility that impaired phonology slows OP mappings such that feedback effects are revealed.

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Appendices: Item set

OP consistency	**consistent**	**consistent**	**inconsistent**	**inconsistent**
PO consistency	**consistent**	**inconsistent**	**consistent**	**inconsistent**
	craft	boat	cloth	load
	fish	coat	moth	fuse
	spring	hawk	hive	spear
	crust	soak	patch	crease
	truck	trail	couch	treat
	globe	heap	pouch	tool
	tuck	deal	drove	fear
	ring	cheek	drive	gear
	dust	creek	rush	boot
	rust	fail	dive	toad
	wing	curl	dull	rose
	duck	rail	lost	seat

Table 1. The chronological and reading ages of the dyslexic and control group children

Participant group		Chronological age (mths.)			Reading age (mths.)		
		Mean	SD	range	Mean	SD	range
dyslexic		133	13.4	39	92.4	9.5	31
reading-age matched		88.2	12.8	43	97.3	11.2	35

Table 2. Item mean values of length, frequency and orthographic neighbourhood size

Item Variable	Condition OPC POC Mean	OPC POC SD	OPC POI Mean	OPC POI SD	OPI POC Mean	OPI POC SD	OPI POI Mean	OPI POI SD
Word length in letters	4.5	0.7	4.3	0.5	4.5	0.5	4.3	0.7
CELEX log10 combined lemma frequency	1.4	0.5	1.5	0.5	1.5	0.7	1.5	0.6
Kucera-Francis frequency	37.4	37	43.2	42	20.5	20	39.4	38
ALLON	15.3	9.2	16.9	8.2	15.3	9.4	18.3	11
NODUPON	8.8	4.3	9.8	4.3	8.9	4.5	10.4	6

Table 3. Accuracy of oral reading and spelling to dictation: Percentage correct responses

Oral Reading

Participant group		OPC POC		OPC POI		OPI POC		OPI POI	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
dyslexic		71	20	51	24	58	25	51	27
reading-age matched		84	25	77	31	73	30	73	28

Condition

Spelling to dictation

Participant group		OPC POC		OPC POI		OPI POC		OPI POI	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
dyslexic		69	23	22	18	48	24	27	25
reading-age matched		75	27	48	35	63	31	45	33

Condition