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Computer-based cognitive assessment and the development of reading

Chris Singleton, Kevin Thomas and Joanna Horne

Department of Psychology, University of Hull, UK

ABSTRACT

This paper reports on a longitudinal study using the computer-based cognitive assessment system *CoPS,* and considers the applicability of this system in the early identification of cognitive strengths and limitations that affect the development of reading. *CoPS* comprises eight tests of basic cognitive abilities, including phonological awareness, auditory discrimination, and short-term visual and auditory-verbal memory. A total of 421 children participated in the study. Assessment with the *CoPS* tests was carried out at age 5 years, and follow-up assessments using conventional tests of reading and general ability were carried out at 6 and 8 years of age.

Correlations between the *CoPS* tests administered at age 5 and reading ability at age 8 were in the region of 0.6 for auditory-verbal memory and phonological awareness, and in the region of 0.3 for the *CoPS* measure of auditory discrimination as well as most of the other memory measures. Stepwise linear regression analyses showed that the *CoPS* tests of auditory-verbal memory and phonological awareness administered at age 5 together accounted for 50% of the variance in reading ability at age 8, compared with only 29% of the variance being attributable to intelligence. It was concluded that short-term memory is an important predictor variable for reading, in addition to the more generally acknowledged variable of phonological processing.

Discriminant function analysis showed that *CoPS* tests provide a highly satisfactory prediction of poor reading skills, with very low or zero rates for false positives and false negatives. By contrast, a word recognition test given at age 6 was not found to predict reading at age 8 to the same degree of accuracy, resulting in an unsatisfactory false positive rate of 21%. Measures of verbal and nonverbal ability at age 6 produced unacceptably high false positive rates between 50% and 70%. These findings are discussed in relation to the prediction of children at risk of reading failure. The potential of computer-based cognitive profiling for facilitating differentiated teaching in early reading is also considered.

INTRODUCTION

Research on cognitive processes involved in the acquisition and development of reading skills has three main objectives. First, to enhance generally our knowledge of *how* children learn to read. Second, to obtain a better scientific understanding of why some children experience *difficulties* in learning to read. Third, to explore the possibility that measures of cognitive functioning can help in the *identification* of children who are at risk of reading difficulties, so that early intervention can be offered. This paper focuses chiefly on the third of these objectives, although some contribution is also made to the other two.

The longitudinal study described here concerns the development of a computer-based tool for the early identification of children who are at risk of literacy difficulties, based on cognitive predictors of reading failure. The rationale for this approach is that cognitive skills provide reasonably stable precursors of literacy acquisition that can be assessed and used for predictive purposes before children learn to read and write (Singleton, 1988; 1997a). This approach does not deny the importance of other factors in influencing reading development, such as intellectual, linguistic, perceptual-motor, motivational, affective, social and educational factors (Hammill and McNutt, 1981; Pumfrey, 1991; 1997). However, it is argued that if the teacher is aware of young children's cognitive strengths and limitations and the implications that these can have for learning, then teaching can be adapted to minimise the chances of failure and maximise success.

Cognitive precursors of literacy development

There is substantial evidence that both phonological processing and short-term or working memory are important precursors of reading development. The literature on the relationship between phonological skills and early reading is considerable (e.g. see Goswami, 1999; Rack, 1997; Seymour, Duncan and Bollik, 1999; Torgesen et al, 1997). There is also a well-established connection between reading and memory (for reviews, see Baddeley, 1986; Beech, 1997; Brady, 1986; Jorm, 1983; Wagner and Torgesen, 1987). In general, it is argued (a) that phonological processes underpin the development of a phonological recoding strategy in reading, and (b) that working memory plays a significant role in this strategy, enabling constituent sounds and/or phonological codes to be held in short-term store until these can be recognised as a word and its meaning accessed in long-term memory (e.g. Gathercole and Baddeley, 1993a; Wagner et al, 1993).

When groups of good and poor readers that have been matched on intelligence are compared on various psychological measures, the most salient differences observed tend to be in underlying cognitive functions subserving phonological processing and short-term memory. For example, in an intensive longitudinal study of reading development in the UK, Ellis and Large (1987) found that only three variables (out of a total of 44) reliably differentiated children with specific reading retardation from their better-reading peers when the groups were matched for intelligence. These variables were short-term memory, phonological segmentation (e.g. ability to detect rhyme and alliteration) and reading vocabulary. A similar large-scale study in Australia reported comparable results (Jorm, Share, MacLean and Matthews, 1986). Subsequently, Bowers, Steffy and Tate (1988) found that when non-verbal intelligence was controlled in comparison between dyslexic and non-dyslexic subjects, the groups were found to differ mainly on verbal memory and rapid naming ability (the latter being a measure of lexical access speed, which is a function of both phonological processing and memory).

The above studies suggest that phonological awareness and short-term memory are processes that underpin the acquisition of reading and hence have potential as early indicators of children who are likely to experience difficulty. However, studies in which groups are matched for intelligence may be criticised on the grounds that the participants are not equivalent in the amount of reading they have experienced, and this factor could account for the findings. The good readers will have had more practice in reading, which should have facilitated greater fluency in the cognitive functions (memory and phonological processes) that are under investigation. The poor readers, on the other hand, will have had limited experience of reading, and hence will have had fewer opportunities to practice and develop the cognitive processes on which reading depends. This is an example of the so-called 'Matthew effect' noted by Stanovich (1986).

However, studies employing other methodologies provide confirming evidence that phonological and memory processes are key precursors of reading. Alternative approaches include (a) comparison of groups of good and poor readers that have been matched on reading level (on the assumption that such groups will be equivalent in reading experience, this methodology is not subject to the defect suffered by the IQ-match methodology, although the groups will inevitably be of different chronological ages), and (b) prospective longitudinal studies, which involve following up the literacy development of children whose cognitive skills have been assessed at an earlier stage.

Several studies employing reading-level controls support the conclusion that phonological skills play an important role in reading development (for reviews, see Rack, 1994; Rack, Snowling and Olson, 1992). Nicolson and Fawcett (1995) studied groups of 8 year-old good readers and 12 year-old dyslexics that were matched for reading level, as well as groups of 12 year-old good readers and 16 year-old dyslexics that were also matched for reading level. The dyslexics performed significantly poorer than their reading-level matched groups on measures of phonological segmentation and rhyming (and also on measures of balance).

Stanovich, Cunningham and Cramer (1984) administered a variety of phonological awareness tasks to 49 children aged 5–6 years, and assessed their reading ability one year later. All seven of the phoneme awareness tasks employed in this study correlated significantly with later reading ability (range 0.39 to 0.60), compared with a measure of intelligence, which only correlated 0.25. In a regression analysis (entry method) IQ combined with a reading readiness measure accounted for 59% of the variance in reading ability. By comparison, the two best phonological measures were found to account for 66% of the variance in reading ability.

Stuart and Coltheart (1988) carried out a four-year longitudinal study of 36 children involving phonological tests administered before commencing school and repeated assessment of reading, letter-sound and letter-name knowledge in each subsequent year of the study. The children were aged 4 years 5 months at the start of the project and 23 children remained at the end, when the children were aged 8 years 5 months. The results showed a decreasing effect of intelligence and an increasing effect of phonological ability over the duration of the study. In another study, Stuart

(1995) administered a battery of phonological tasks to a sample of 30 children on school entry and then measured reading ability one year later, using *the British Ability Scales Word Reading Test* (Elliot, 1992). The phonological tasks were found to correlate significant ($r = 0.73$) with reading ability.

Hagtvet (1997) reported on a longitudinal study of 74 children from the age of 4 to 9 years in Norway. The focus of the study was on the oral language precursors of reading difficulties. Regression analyses showed that phonemic awareness at age 6 was the strongest predictor of reading ability at both age 8 and 9. However, the success rate for predicting poor reading (i.e. below 33rd centile) was only 52%. The author suggest that these results do not detract from a phonological deficit hypothesis of dyslexia (see Rack, 1994), but would also support the view that reading difficulties are linked with a broader spectrum of cognitive-lingusitic deficiencies (Nicolson and Fawcett, 1995; Tunmer and Hoover, 1992).

Grogan (1995) measured various cognitive abilities in a sample of young children at age 4 years 6 months, and then assessed the children's reading skills at age 7 years 3 months. Although phonological processing ability was not assessed in this study, after partialling out age and intelligence as factors in the analysis, auditory memory scores at age 4 were found to account for 13% of the variance in reading scores at age 7, with visual sequential memory accounting for a further 5%.

Passenger, Stuart and Terrell (2000) reported on a detailed, longitudinal study in which 80 children were monitored during their first year of formal schooling (4 years 7 months to 5 years 8 months). It was found that phonological awareness (alliteration, rhyme detection and rhyme production) and phonological memory (digit span and nonword repetition) both made significant contributions to early literacy. Specifically, results of factor analysis indicated that early phonological awareness predicts subsequent single-word reading, while early phonological memory plays an important role in the development of decoding strategies.

Distinctions may be drawn between 'short-term memory' and 'working memory'. The former concerns the ability to retain information in short-term storage, while the latter implies that some additional processing is being carried out on the information when it is being held in short-term store (Gathercole and Baddeley, 1993a). Swanson (1994) found that although short-term memory and working memory were both significant predictors of reading comprehension for good as well as poor readers, working memory made the most important contribution to word recognition, accounting for 13% of the variance. In good readers, however, working memory was found to be more important than short-term memory for *both* word recognition and comprehension.

In a longitudinal study of 244 children from kindergarten for three years, Wagner, Torgesen and Rashotte (1994) used tests of memory span for digits and words, together with a battery of phonological tasks. They found that although both types of measure were significantly related to reading development, memory made a somewhat smaller contribution than phonological skills. Awaida and Beech (1995) reported on a longitudinal study of 236 children aged 4 to 6 years, in which a range of phonological, memory and visual tasks were employed. Although reading quotients were *not* predicted by phonological memory, phonological memory at age 5 was found to predict nonword reading at age 6. The authors suggest that this implies an effect of phonological memory on sublexical processes (i.e. phonic decoding) in the development of early reading, rather than on lexical processes.

The findings reported thus far indicate that we are some way from an unequivocal understanding of how, exactly, phonological processes and memory contribute to reading development. There is an ongoing dispute about the precise nature of the causal pathways involved and, in particular, whether developmental growth proceeds from small phonological units (phonemes) to large phonological units (rimes) or *vice versa* (e.g. Duncan, Seymour and Hill, 1997; Goswami, 1999; Seymour, Duncan and Bollik, 1999). There is also disagreement about which aspects of memory are most important in this context (Beech, 1997; Gathercole and Baddeley, 1993b) and about the role of articulation rate in verbal memory tasks (Avons and Hanna, 1995; McDougall and Hulme, 1994). Finally, there is lively debate regarding the implications that different versions of these theories have for teaching (e.g. Chew, 1997; Deavers and Sollity, 1998; Goswami, 1999; Johnston and Watson, 1997; Watson and Johnston, 1999). Nevertheless, there is general agreement that children with poor phonological abilities and/or poor short-term memory skills would be expected to struggle in reading development, compared with children in whom these capabilities are in the average or above-average range.

Computer-based assessment

The use of computer-based assessment systems is steadily increasing in psychology and education (Bartram, 1994; NCET, 1994, 1995; Singleton, 1997b). The potential of computer-based assessment for diagnosis of reading difficulties and identification of dyslexia has been explored by several researchers, including Seymour (1986), Høien and Lundberg (1989), Singleton (1991, 1994), Singleton and Thomas (1994) and Fawcett and Nicolson (1994). The principal advantages of computer-based systems over conventional methods of assessment are (a) that assessment of cognitive skills (such as memory) can be more precise, and (b) that significant savings can be made in both time and labour. Computerised assessment methods can usually be administered more speedily than conventional tests (particularly if the tests are adaptive) and as the scoring is generally automatic the results can be immediately available. The term 'adaptive testing' refers to any technique that modifies the nature of the test in response to the performance of the test taker. Conventional tests are *static* instruments, fixed in their item content, item order, and duration. By contrast, computer-based assessment can be *dynamic*. Since the computer can score performance at the same time as item presentation, it can modify the test accordingly, tailoring it more precisely to the capabilities of the individual taking the test. In conventional tests, for some part of the time, the individual's abilities are not being assessed with any great precision because the items are either too difficult or too easy (which can easily lead to frustration and/or boredom). In an adaptive test, however, the individual can be moved swiftly to that zone of the test that will most efficiently discriminate his or her capabilities, thus making assessment shorter, more reliable, more efficient, and often more acceptable to the person being tested (Singleton, 1997b).

Some individually administered conventional tests incorporate adaptive features, such as algorithms for test discontinuation and variable start depending on age and/or performance on initial items. However, such features can be administratively complicated. The savings in testing time and ease of administration for computer-based tests, however, are distinctive and can far out-weigh any disadvantages of transferring from conventional methods to computer-based methods. For example, Olsen (1990) compared paper-based and computer-administered school achievement and assessment tests with computerised adaptive tests. The computer-based non-adaptive version took 50%–75% of the time taken to administer the conventional version, while the testing time for the adaptive version was only 25% of the time taken for the paper-based version. Computer-based tests can also take advantage of the capabilities of the technology to create items that include animation, speech and sound. These features help to make the tests attractive to children and hence more acceptable. Studies have shown that children and adults (particularly if they feel that they might perform badly) tend to prefer computer-based assessment to pencil-and-paper tests or conventional assessment by a human assessor (Singleton, Horne and Vincent, 1995).

The longitudinal study reported in this paper utilised a computer-based system for cognitive assessment called 'CoPS' (Cognitive Profiling System), developed by Singleton, Thomas and Leedale (1996, 1997). Children were first assessed at age five on a variety of cognitive tasks administered by computer and they were followed up to age 8 using conventional tests of reading as well as verbal and nonverbal ability. The objective of the study was to evaluate this particular computer-based approach as a technique for early identification of children who are at risk of literacy difficulties.

It should be noted that the study reported here forms part of a larger longitudinal project in which spelling (and also mathematics development) were investigated; for reasons of space only the results relating to the development of reading are reported in this paper.

METHOD

Participants

A total of 421 children participated; these children were aged about 5 years at the beginning of the study and 8 years at the concluding phase. The children were selected at random from 24 primary schools in the County of Humberside, UK. The mean age at the start of the study was 5.94 years (s.d 0.25 years). There were 212 boys and 209 girls.

Materials

Computer-based assessment

The computer-based tests employed in this study comprised the suite 'CoPS' [Cognitive Profiling System] (Singleton, Thomas and Leedale, 1996, 1997). The development of this suite is decribed in the test manual, but may be briefly summarised as follows. A total of 27 different computer-based cognitive assessment tasks were originally developed by the authors and administered to the children in the sample specified above when they were aged 5 years. Of these 27 tasks, eight were retained to comprise the assessment suite, which was reprogrammed to run under DOS and RISC (Acorn) operating systems, standardised for the age range 4 years

0 months to 8 years 11 months, and published as the developmental version 'CoPS 1' (Singleton, Thomas and Leedale, 1996). Several criteria were used to determine which of the original 27 tests should be retained in the final suite. The principal criteria applied were: (i) statistical significance in predicting literacy difficulties when the children were reassessed at age 8 years; (ii) psychometric integrity (reliability, etc.); (iii) administrative robustness (i.e. computer tests that were found to be most suitable for classroom administration); and (iv) appeal to children (a major objective was to create assessment instruments that young children would enjoy, thus promoting attentiveness and motivation). For further information on the rationale for test selection, see Singleton and Thomas (1994b).

The developmental version 'CoPS 1' was subsequently revised, the principal revisions being an increase in the difficulty of several of the tests when administered to children aged 7 and 8 years, and the inclusion of alliterative items in the *Rhymes* test. The suite was reprogrammed to run under *Windows* operating systems, restandardised (for the same age range) and released under the name 'CoPS' (Singleton, Thomas and Leedale, 1997). In the interests of economy of space, only those data on the eight computer tests that comprise the final *CoPS* suite are reported here. Further details of the longitudinal study are given in Singleton and Thomas (1994b) and also in the manual that accompanies the first (developmental) published version of CoPS (Singleton, Thomas and Leedale, 1996). The computer tests are presented in a game format, with colourful graphics, sound and digitised speech. All the tests incorporate demonstration and/or practice items, and have increasing levels of difficulty. The number of items presented at each level varies according to the age of the child (see the test manual for further details). An outline of each of the eight tests in *CoPS* is given below.

Rabbits. This is a test of visual sequential memory for spatial and temporal positions. The screen displays 10 'holes' which are meant to represent rabbit burrows. A rabbit appears at different burrows in sequence. The child's task is to replicate the sequence using the mouse. The test begins with two holes in sequence and progresses incrementally to six holes in sequence.

Zoid's Friends. This is a test of visual sequential memory for colours. 'Zoid' is the name of a rotund red cartoon character who is supposed to come from another planet. In this test Zoid appears with similarly shaped 'friends', who are of different colours (red, blue, green or yellow). The child has to remember the sequence of colours and replicate this by clicking on the appropriate colours on the screen. The test begins with two 'friends' in sequence and progresses incrementally to six 'friends' in sequence.

Toybox. This is a test of visual associative memory for shapes and colours. The child has to remember which of six different colours is associated with different shapes (star, cross, triangle, etc.).

Zoid's Letters. This is a test of visual sequential memory employing letter-like symbols. The child has to remember the sequence in which the symbols appeared, by selecting from an array of similar symbols. The test begins with two symbols in sequence and progresses incrementally to five symbols in sequence.

Zoid's Letter Names. This is a test of visual/verbal associative memory for letter-like symbols and CVC nonword names. In this test, the letter-like symbols employed in the *Zoid's Letters* test are given nonsense 'names' (fid, dep, jat, etc.), which are presented aurally by the computer. The child has to remember what name is attached to each symbol. At the start of the test the symbols are presented in pairs, and the test progresses incrementally until symbols are presented in sets of four.

Races. This is a test of auditory verbal sequential memory for animal names. The scenario is a 'race' in which various animals (dog, fox, cat, etc.) are competing. The child is informed aurally by the computer of the order in which the animals finish the race (although the child cannot see the outcome of the 'race'). The child is required to replicate that sequence by clicking on the pictures of the animals in the correct order. The test begins with 'races' of three animals and progresses incrementally to 'races' of five animals. The number of syllables in each sequence of names has been controlled so that different 'races' are equivalent in phonological memory load for a given level.

Rhymes. This is a test of phonological awareness. In each item, the child has to identify which of four objects has a name that either rhymes with, or is alliterative with, the name of the target object. Each object is named aurally as well as being presented pictorially.

Wock. This is a test of auditory discrimination of phonemes. The scenario is that two of Zoid's 'friends' are trying to learn English. The child has to 'help' them by determining which of two alternative pronunciations of a name of an object is correct (e.g. 'rock' versus 'wock' – in this case the distinction between /r/ and /w/). Each object is named aurally as well as presented pictorially.

It should be pointed out that three of the tests in the *CoPS* suite – *Zoid's Friends, Toybox* and *Zoid's Letters* – although described here as 'visual' tests, involve items that can be remembered using verbal encoding strategies. For example, *Zoid's Friends* involves remembering sequences of colours. Arguably, it is possible to do this task using visual processes alone, but use of verbal labels (i.e. the names of the colours), overtly or covertly, will usually aid memory and make the task easier. *CoPS* also contains a supplementary test, *Clown*, which assesses colour discrimination ability. This test is used to check whether children who obtain low scores on *Zoid's Friends* and/or *Toybox* (which each involve colour as an essential component of the task) can reliably discriminate the colours on a purely visual basis (regardless of whether or not they know the names of the colours). If a child fails the *Clown* test, this would call into doubt a conclusion that the low scores on *Zoid's Friends* and/or *Toybox* are the result of poor memory skills. Since this is a supplementary test, results are not presented here, but children with unsatisfactory colour discrimination were not accepted for inclusion in the sample of participants in the study.

Conventional assessment

British Ability Scales Word Reading Test [BAS Word Reading] (Elliot, 1992). This is an individually administered test of oral single word reading out-of-context for the age range 5 years to 14 years 5 months.

British Picture Vocabulary Scale [BPVS] (Dunn, Dunn and Whetton, 1982). This is an individually administered test of receptive vocabulary designed for individuals from the age of 2 years 11 months to 18 years 1 month. Each item comprises four pictures and the participant is required to select the picture that is most appropriate for a given word spoken by the administrator of the test. This test is derived from the *Peabody Picture Vocabulary Test*, which yields significant correlations (approximately 0.6) with various established measures of verbal intelligence (Elliott, 1990).

Edinburgh Reading Test, Stage 1 (Godfrey Thompson Unit, 1993). This is a group test of silent reading, designed for children aged 7 years to 9 years. The test comprises a mixture of items covering single word recognition, reading vocabulary and comprehension of sentences, and use of context in reading longer passages. Separate scores of vocabulary, syntax, sequences and comprehension are provided, as well as an overall reading attainment score.

Macmillan Individual Reading Analysis [MIRA] (Vincent and De La Mare, 1989). This is an individually administered test of oral reading of short prose passages, designed for children aged 5 years 6 months to 10 years. The test provides measures of reading accuracy and reading comprehension.

Matrix Analogies Test – Short Form [MAT] (Naglieri, 1985). This is a group test of non-verbal reasoning comprising 34 items and standardised for the age range 5 to 17 years. In each item, an element in a visual pattern or visual sequence is missing and the testee is required to select the correct element from 5 or 6 alternatives. MAT-SF correlates highly ($r = 0.68$) with the nonverbal ability measure (Performance IQ) of the WISC-R.

Middle Infant Screening Test [MIST] (Hannavy, 1993). This is a group test designed to screen out the lowest 20–25% of children in reading and writing after about two years of full-time education, i.e. at about 6½ to 7 years of age in the UK. It comprises five subtests, as follows:

1. *Listening Skills* – this subtest comprises two sections; each involves identifying the relevant pictures that correspond with different oral descriptions spoken by the teacher. In the first section (given at the beginning of the test) there are nine simple sentences, e.g. *'A bird is flying to the nest with something in its beak'*. In the second section (given at the end of the test) there are six descriptions of greater complexity, each involving 2–3 sentences. For each item there are three alternative pictures which the child may choose from.
2. *Letter Sounds* – this assesses the ability to write letters from memory, and based on the sound of the letter and an example word spoken by the teacher, e.g. /f/ 'fish'.
3. *Written Vocabulary* – the child has to write as many of their own words as they can in five minutes.
4. *Three-Phoneme Words* – the child has to transcribe ten three-phoneme words spoken by the teacher (e.g. 'rub'). The child is instructed to write dashes for any sound that they don't know how to represent. Each phoneme correctly represented is scored.
5. *Sentence Dictation* – the child is required to write two sentences to dictation, e.g. *'I like my dog Ted. Today I am going to give him a big bone'*. The child is instructed to write dashes for a sound that they don't know how to represent. Each phoneme correctly represented is scored.

Finally, the total number of letters that have been reversed during any of the subtests is calculated and scored as '*Reversals*'.

Procedure

There were four phases in the study. In Phase 1 (mean age 5.94 years, s.d. 0.25 years) the children were administered the *CoPS* suite of computer tests. At Phase 2, approximately six months later, the children (mean age 6.51 years, s.d. 0.24 years) were administered *BPVS, MAT, MIRA* and the *BAS Word Reading Test*. At Phase 3, approximately 12 months after Phase 1, the *MIST* was administered (mean age 6.87 years, s.d. 0.21 years). Finally, at Stage 4, which was about 26 months after Phase 1, the *Edinburgh Reading Test* was administered (mean age 8.29 years, s.d. 0.29 years).

All the children were tested in a suitable quiet place in their schools. Because of limitations of time and children's absences from school on assessment days, it was not possible to administer all the tests and assessment tasks used in the study to all participants. Hence the sample numbers for different tests vary somewhat; in each case the numbers on which the analyses were carried out has been specified in the results. As already pointed out, this study formed part of a larger longitudinal project in which various other measures were collected from the children in the sample. The analysis in this paper is confined to the measures described above, but for details of other aspects of the study see Singleton and Thomas (1994b) and also the statistical appendix to the manual that accompanies the first (developmental) published version of *CoPS* (Singleton, Thomas and Leedale, 1996).

RESULTS

Correlational analysis

Pearson Product Moment Correlations were computed between the various measures used in the study. Table 1 shows intercorrelations between the eight computer tests in *CoPS* (administered at Phase 1 of the study). It may be observed that although most of the correlations in Table 1 are significant, the r values differ considerably. The highest correlations are found between three of the four *CoPS* tests in which auditory/verbal processing is essential (i.e. *Wock, Rhymes* and *Races*), with r values in the range 0.43 – 0.51. The correlations observed between the visual memory tests are more variable. Those which involve sequential memory (i.e. *Rabbits, Zoid's Friends,* and *Zoid's Letters*) all have r values in the region of 0.4, whereas the correlation values with the associative memory test (*Toybox*) are somewhat lower. Finally, it is worth noting that three tests of visual sequential memory (*Rabbits, Zoid's Friends,* and *Zoid's Letters*) each correlate with the auditory verbal sequential memory test (*Races*) to the same degree: 0.43. These findings suggest that although the CoPS tests cannot be claimed to measure entirely distinct cognitive functions, the pattern of intercorrelations is rational, both in relation to the construction of the tests and to the interpretation of profile results. This point will be elaborated later in this paper.

Table 2 shows intercorrelations between the various conventional tests administered. When examining this Table, it should be remembered that the conventional tests were administered at different phases of the study: *BPVS, MAT, BAS Word Reading*, and *MIRA* at Phase 2 (6 months after Phase 1), *MIST* at Phase 3 (12 months after Phase 1) and the *Edinburgh Reading Test* at Phase 4 (26 months after Phase 1). As might be expected, the reading measure administered at age 6 (*BAS Word Reading*) was found to correlate highly with the concurrent reading measure (*MIRA*)

Table 1. Intercorrelations between the CoPS tests (n for each pair shown in brackets)

Zoid's Friends	0.41 *** (282)						
Toybox	0.20 *** (284)	0.37 *** (319)					
Zoid's Letters	0.42 *** (211)	0.40 *** (224)	0.28 *** (226)				
Zoid's Letter Names	0.32 *** (120)	0.11 (191)	0.24 *** (195)	0.32 *** (143)			
Races	0.43 *** (190)	0.43 *** (133)	0.16 (134)	0.43 *** (88)	0.31 *** (115)		
Rhymes	0.42 *** (190)	0.35 *** (204)	0.22 *** (204)	0.29 *** (154)	0.15 (137)	0.44 *** (87)	
Wock	0.27 * (87)	0.43 *** (90)	0.20 * (93)	0.32 ** (77)	0.24 * (95)	0.51 *** (65)	0.43 *** (81)
	Rabbits	**Zoid's Friends**	**Toybox**	**Zoid's Letters**	**Zoid's Letter Names**	**Races**	**Rhymes**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

and with the later reading measure administered at age 8 (*Edinburgh Reading Test*). Correlations between *BAS Word Reading* and the general ability measures (*BPVS* and *MAT*) are somewhat lower, while those between *BAS Word Reading* and the different *MIST* subtests vary quite markedly. It can be seen that, in general, this pattern is repeated when the other intercorrelations are considered in similar fashion. In other words, the intercorrelations conform to a fairly predictable pattern.

Table 3 shows correlations between the *CoPS* tests and the various conventional tests administered during the study. Across the Table as a whole the correlation values are rather variable, but it can be seen that many of the CoPS tests show very promising correlations with later reading measures. The highest correlations are obtained between the CoPS tests *Races* (auditory/verbal sequential memory) and *Rhymes* (phonological awareness) and several of the reading measures (e.g. *BAS Word Reading,* $r = 0.50$ with *Races*, $r = 0.56$ with *Rhymes*; *Edinburgh Reading Test,* $r = 0.61$ with *Races*, $r = 0.59$ with *Rhymes*). Other CoPS tests, notably *Rabbits, Zoid's Friends* and *Wock,* yield correlations with reading measures in the region of 0.33–0.53. When the correlation values with reading at ages 6 and 8 are compared, it can be observed that, in general, those for visual memory and auditory discrimination (*Wock*) decline somewhat with age, while those for auditory/verbal memory increase with age. This suggests that the relative importance of these factors to reading development changes over this period.

Table 4 shows correlations between the *CoPS* tests and the subtests of the *Edinburgh Reading* test administered at Stage 4 (age 8). It can be seen that the pattern of correlations is similar to that for the Edinburgh Reading Quotient shown on the last row of Table 3, indicating a consistent relationship between the CoPS measures and the different components of reading measured over two years later.

Table 2. Intercorrelations between the conventional tests used in the study (n for each pair shown in brackets).

	BAS Word Reading	BPVS	MAT	Macmillan Accuracy	Macmillan Comprehension	MIST Dictation	MIST Listening	MIST Letter Sounds	MIST Phonemes	MIST Reversals	MIST Written Vocabulary
BPVS	0.38 *** (279)										
MAT	0.21 ** (190)	0.20 ** (190)									
Macmillan Accuracy	0.82 *** (179)	0.45 *** (159)	0.28 *** (144)								
Macmillan Comprehension	0.77 *** (179)	0.46 *** (159)	0.22 ** (144)	0.84 *** (180)							
MIST Dictation	0.68 *** (295)	0.36 *** (230)	0.04 (159)	0.53 *** (150)	0.56 *** (150)						
MIST Listening	0.34 *** (295)	0.42 *** (230)	0.09 (159)	0.33 *** (150)	0.40 *** (150)	0.47 *** (297)					
MIST Letter Sounds	0.44 *** (295	0.31 *** (230)	0.31 ** (159)	0.28 *** (150)	0.29 *** (150)	0.64 *** (297)	0.51 *** (297)				
MIST Phonemes	0.55 *** (295)	0.33 *** (230)	0.07 (159)	0.40 *** (150)	0.41 *** (150)	0.80 *** (297)	0.50 *** (297)	0.80 *** (297)			
MIST Reversals	−0.30 *** (295)	0.04 (230)	0.04 (159)	−0.36 *** (150)	−0.27 *** (150)	−0.22 *** (297)	−0.08 (297)	−0.04 (297)	−0.02 (297)		
MIST Written Vocabulary	0.52 *** (295)	0.35 *** (230)	0.15 (159)	0.52 *** (150)	0.55 *** (150)	0.55 *** (297)	0.39 *** (297)	0.46 *** (297)	0.52 *** (297)	0.24 *** (297)	
Edinburgh Reading Quotient	0.75 *** (178)	0.49 *** (142)	0.32 *** (111)	0.71 *** (108)	0.74 *** (108)	0.66 *** (154)	0.42 *** (154)	0.46 *** (154)	0.55 *** (154)	−0.19 * (154)	0.55 *** (154)

* $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Table 3. Correlations between the CoPS tests (Phase 1) and the conventional tests used at Phases 2 and 3 (n for each pair shown in brackets).

	Rabbits	Zoid's Friends	Toybox	Zoid's Letters	Zoid's Letter Names	Races	Rhymes	Wock
BAS Word Reading	0.36 *** (295)	0.43 *** (324)	0.28 *** (346)	0.28 *** (237)	0.23 *** (200)	0.50 *** (139)	0.56 *** (208)	0.43 *** (98)
BPVS	0.20 ** (237)	0.28 *** (273)	0.21 *** (270)	0.24 *** (203)	0.26 *** (156)	0.21 * (104)	0.41 *** (177)	0.42 ** (83)
MAT	0.13 (167)	0.08 (184)	0.01 (184)	0.03 (147)	0.15 (129)	0.13 (75)	0.21 * (137)	−0.05 (76)
Macmillan Accuracy	0.34 *** (169)	0.41 *** (173)	0.24 ** (173)	0.23 ** (138)	0.26 ** (124)	0.36 ** (65)	0.55 *** (127)	0.45 *** (71)
Macmillan Comprehension	0.34 *** (169)	0.45 *** (173)	0.27 *** (173)	0.23 ** (138)	0.23 * (124)	0.48 *** (65)	0.57 *** (127)	0.45 *** (71)
MIST Dictation	0.36 *** (247)	0.42 *** (268)	0.32 *** (285)	0.37 *** (194)	0.26 *** (168)	0.60 *** (118)	0.53 *** (175)	0.53 *** (87)
MIST Listening	0.34 *** (247)	0.36 *** (268)	0.32 *** (285)	0.32 *** (194)	0.38 *** (168)	0.44 *** (118)	0.34 *** (175)	0.47 *** (87)
MIST Letter Sounds	0.26 *** (247)	0.29 *** (268)	0.32 *** (285)	0.32 *** (194)	0.38 *** (168)	0.42 *** (118)	0.29 *** (175)	0.36 *** (87)
MIST Phonemes	0.33 *** (247)	0.36 *** (268)	0.33 *** (285)	0.35 *** (194)	0.28 *** (168)	0.53 *** (118)	0.45 *** (175)	0.38 *** (87)
MIST Reversals	−0.11 (247)	−0.15 * (268)	−0.06 (285)	−0.17 * (194)	−0.02 (168)	−0.11 *** (118)	−0.06 (175)	−0.29 ** (87)
MIST Written Vocabulary	0.30 *** (247)	0.36 *** (268)	0.32 *** (285)	0.24 *** (194)	0.27 *** (168)	0.51 *** (118)	0.23 ** (175)	0.48 *** (87)
Edinburgh Reading Quotient	0.35 *** (143)	0.37 *** (158)	0.17 * (168)	0.23 ** (128)	0.29 ** (111)	0.61 *** (71)	0.59 *** (90)	0.33 ** (62)

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 4. Correlations between the CoPS tests (Phase 1) and the *Edinburgh Reading Test* measures (Phase 4).

	Rabbits	Zoid's Friends	Toybox	Zoid's Letters	Zoid's Letter Names	Races	Rhymes	Wock
Vocabulary	0.29 ***	0.27 ***	0.20 **	0.19 *	0.35 ***	0.48 ***	0.56 ***	0.33 **
Syntax	0.35 ***	0.36 ***	0.19 **	0.25 **	0.28 ***	0.59 ***	0.55 ***	0.33 **
Comprehension	0.28 ***	0.36 ***	0.22 **	0.23 **	0.27 **	0.56 ***	0.58 ***	0.37 **
Sequences	0.36 ***	0.31 ***	0.14 *	0.22 **	0.28 **	0.52 ***	0.61 ***	0.36 **
N	143	158	168	128	111	71	90	63

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Regression analysis

Stepwise linear regression analysis showed that *CoPS* measures at Phase 1 (mean age 5.94 years) predicted 31% of the variance in *BAS Word Reading* scores at Phase 2. The analysis discounted all except *Rhymes* as the predictor variable. This suggests that phonological awareness is the most important cognitive predictor of word reading at this stage of development (mean age 6.51 years). However, stepwise linear regression also revealed that *CoPS* measures at Phase 1 predicted 50% of the variance in *Edinburgh Reading* scores at Phase 4 (mean age 8.29 years), and on this occasion the analysis discounted as predictor variables all *CoPS* measures except *Races* (which accounted for 37% of the variance) and *Rhymes* (which accounted for a further 13% of the variance). This suggests that when predicting a broad measure of reading ability that includes comprehension at age 8 years, verbal memory assumes a somewhat greater importance than phonological awareness. (It should be noted that in all cases cited in this paper, the regression models are significant on ANOVA at the $p < 0.001$ level).

The *MIST*, which assesses a variety of aspects of early literacy skills, includes three subtests that show consistently high correlations with other reading measures: these are *Dictation*, *Phonemes*, and *Written Vocabulary* (see Table 2). The same subtests have lower correlations with verbal intelligence (*BPVS*), although these are still significant. It is instructive, therefore, to consider what power the *CoPS* tests have in predicting *MIST* subtest scores. The results are summarised in Table 5. It can be seen that three of the auditory/verbal *CoPS* tests (*Races*, *Rhymes* and *Wock*) give a significant prediction of all *MIST* measures, except for *Reversals*, and that the best predictions are for scores in the *MIST* subtests *Dictation*, *Phonemes* and *Written Vocabulary*.

The findings of the linear regression analysis for *CoPS* predicting *Edinburgh Reading* scores at age 8 may be compared with stepwise linear regression carried out using the *BPVS, MAT, BAS Word Reading* and *MIRA* as predictor variables. All these tests had been administered at Phase 2 of the study (mean age 6.51 years), so the duration over which prediction is being made is approximately 6 months less than in the corresponding analyses for *CoPS*, which had been administered at Phase 1. It was found that these predictor variables accounted for 67% of the variance in

Table 5. Summary of stepwise linear regression analysis: CoPS (Phase 1) to *MIST* (Phase 3).

	Predictor variables	**R**	R^2	**Adjusted** R^2	**P<**
Dictation	*Races*	0.60	0.36	0.34	0.001
	Rhymes	0.67	0.45	0.41	0.001
Listening	*Wock*	0.47	0.22	0.20	0.01
Letter Sounds	*Races*	0.42	0.18	0.16	0.01
Phonemes	*Races*	0.53	0.29	0.26	0.001
Reversals	–				
Written Vocabulary	*Races*	0.51	0.26	0.23	0.01

reading at age 8. Specifically, *BAS Word Reading* scores at age 6 predicted 57% of the variance, with scores for *Macmillan Comprehension*, *BPVS* and *MAT* contributing a further 6%, 2% and 2%, respectively. It is unsurprising that measures of reading at age 6 should provide the best predictors of reading at age 8, but it should be noted that the *BPVS* and *MAT* scores contribute relatively little by way of predictive value. This conclusion is supported by inspection of results of stepwise linear regression analysis confined to *BPVS* and *MAT* scores alone, where a total of 29% of the variance in *Edinburgh Reading* scores at age 8 is accounted for. Specifically, *BPVS* scores account for 24% of the variance and *MAT* scores contribute a further 5%. By comparison, *CoPS* measures are better predictors, even though prediction was being made over a somewhat longer period.

Stepwise linear regression was also carried out on the subtests of the *MIST*, using the *BPVS, MAT, BAS Word Reading*, and *MIRA* as predictor variables. The results are shown in Table 6. All these predictor variables, with the exception of *MAT*, contributed to a significant prediction of all the *MIST* subtests. In general, the outcome is comparable with that obtained for *CoPS* (see Table 5), except that *Macmillan Accuracy* and *BPVS* together accounted for a rather small proportion of the variance (17%) in the scores on the *Reversals* subtest, which *CoPS* was unable to predict successfully.

Discriminant function analysis

In the evaluation of any assessment system, consideration must be given not only to the general predictive accuracy of the system, but also to its capability to predict specific groups that are of special interest. In this case, it is mainly those children who struggle in reading development who give cause for concern, and so it is necessary to carry out discriminant function analyses in order to ascertain the accuracy of the system in predicting these children, i.e. in determining those individuals who are subsequently found to be experiencing difficulties in reading. In the present study, this group was defined as those scoring at or more than one standard deviation below

Table 6. Summary of stepwise linear regression analysis: Conventional tests (Phase 2) to *MIST* (Phase 3).

	Predictor variables	**R**	**R^2**	**Adjusted R^2**	**P<**
Dictation	*BAS Word Reading*	0.68	0.46	0.45	0.001
Listening	*BPVS*	0.42	0.18	0.17	0.001
	Macmillan Comp.	0.49	0.24	0.23	0.001
Letter Sounds	*BAS Word Reading*	0.44	0.19	0.18	0.001
	BPVS	0.46	0.21	0.20	0.001
	Macmillan Accuracy	0.50	0.25	0.23	0.001
Phonemes	*BAS Word Reading*	0.55	0.30	0.30	0.001
Reversals	*Macmillan Accuracy*	0.36	0.13	0.13	0.001
	BPVS	0.43	0.18	0.17	0.001
Written Vocabulary	*Macmillan Comp.*	0.55	0.30	0.29	0.001
	BAS Word Reading	0.57	0.32	0.31	0.001

the mean on the *Edinburgh Reading Test* at age 8, and the comparison group comprised children who were 'good readers', i.e. scoring equal to or greater than the mean. Table 7 summarises the results of this analysis. The category 'true positive' comprises children correctly predicted as being at risk of later reading difficulties, while the 'true negative' category comprises children correctly identified as not being at risk (i.e. those who later turn out to be good readers). The category 'false positive' refers to children who were predicted as being at risk who later turned out to be good readers, i.e. what might be called 'false alarms'. Finally, the category 'false negative' comprises children who were predicted as not being at risk, but who later turned out to have reading difficulties, i.e. what might be called 'misses'. Note that the false positives and false negatives have been calculated as percentages of the target group.

The results show that the *CoPS* measures – specifically *Races* and *Rhymes* – produce very satisfactory outcomes, with very low or zero incidence of both false negatives and false positives. By comparison, the other measures shown in Table 7 all produce unacceptably high incidence of false positive (in the region of 20–70%), although false negatives are not excessive. In other words, early measures of reading and/or general ability erroneously identify considerable numbers of children as being at risk who later turn out to be good readers. As components of a screening procedure they are therefore unsatisfactory. Problems in the very early stages of reading do not necessarily mean that difficulties will be encountered later on. Equally, low general ability does not guarantee that children will turn out to be poor readers. On the other hand, poor phonological skills and/or short-term memory do have more consistent implications for later reading difficulties and are more satisfactory measures for early identification of children at risk.

DISCUSSION

The findings of this study indicate that cognitive assessment by means of computer-delivered tests can be a useful method for identifying children who are at risk of reading difficulties. The tests in the computer suite *CoPS* administered at age 5

Table 7. Summary of discriminant function analyses, predicting low reading ability (equal to or less than one standard deviation below the mean) versus good reading ability (equal to or greater than the mean) on *Edinburgh Reading Quotient* at age 8 years.

Predictor variables	True positive %	False positive %	True Negative %	False Negative %	% of cases corrrectly classified	N
CoPS Races	90.9	9.1	100	0	97.9	47
CoPS Rhymes	80	20	100	0	95.1	61
Races + Rhymes	100	0	100	0	100	23
BAS Word Reading	78.6	21.4	90.1	9.9	87.4	119
BPVS	31.8	68.2	96.1	3.9	81.8	99
MAT	29.4	70.6	90.0	10.0	76.6	77
BPVS + MAT	47.1	52.9	93.2	6.8	82.9	76
Macmillan Comprehension	76.5	23.5	93.1	6.9	89.3	75

correlated significantly with reading measures at age 6 and 8 years. Tests of auditory verbal sequential memory (*Races*) and phonological awareness (*Rhymes*) yielded the highest correlation coefficients. In general, the correlations between *CoPS* measures and later reading attainment are found to be higher than those obtained between measures of general ability and later reading attainment, but not as high as those obtained between early reading measures and later reading attainment. Stepwise linear regression analyses revealed that *CoPS* tests at age 5 accounted for 31% of the variance in reading scores at age 6, and 50% of the variance in reading scores at age 8. By comparison, a combination of conventional tests, including measures of reading and general ability, administered at age 6 accounted for a total of 67% of the variance in reading scores at age 8. In regression analyses general ability measures by themselves, however, perform less well than the cognitive measures as early predictors of reading attainment. In further regression analyses *CoPS* showed a similar pattern of performance to the combination of conventional tests in predicting development on a generalised literacy screening test (*MIST*). In all these regression analyses carried out on *CoPS*, *Races* and *Rhymes* were the chief predictor variables.

Discriminant function analysis revealed that *CoPS* outperformed conventional tests, alone or in combination, in predicting poor readers at age 8. Levels of false positives and false negatives were low or zero for the *CoPS* measures, while the conventional tests produced unacceptably high levels of false positives and moderate levels of false negatives. It was concluded that as components of a screening procedure for identifying children at risk of reading failure, the conventional tests employed in this study would be unsatisfactory and inferior to cognitive measures such as those in *CoPS*. These results are somewhat better than those of Hagtvet (1997), in which the success rate (true positives) for predicting reading at 8 from phonemic awareness at age 6 was only 52%.

The findings of the present study not only confirm the generally held view that phonological processing and short-term verbal memory are critical precursors of reading development, but also validate the use of computer-delivered tests to assess these cognitive abilities early in the child's education. The correlation values with later reading attainment obtained in the present study for phonological processing and short-term verbal memory, compared with intelligence measures as predictors, are comparable with those of similar studies reported in the literature (e.g. Stanovich, Cunningham and Cramer, 1984; Passenger, Stuart and Terrell, 2000) although a few studies have reported somewhat higher correlations for phonological processing (e.g. Stuart, 1995).

Of course, conventional methods of assessing phonological processing and short-term verbal memory could be employed instead of computer-based tests, e.g. the *Phonological Assessment Battery* (Fredericksen, Frith and Reason, 1997) and the *Children's Test of Nonword Repetition* (Gathercole and Baddeley, 1996). Arguably, however, computer-based tests are easier for teachers to deliver and more enjoyable for children, which is beneficial in promoting their motivation during the assessment. Furthermore, *CoPS* is more than just an assessment of phonological processing and short-term verbal memory; it also contains several measures of visual short-term memory and a test of auditory discrimination. The reason for including these in the *CoPS* suite are twofold. First, they yielded significant correlations with later reading development. Second, models of reading acquisition suggest that visual memory is particularly important in the earliest stages of learning to read, usually referred to as the pre-alphabetic or logographic phase (e.g. Ehri, 1995; Frith, 1985). Conclusions reported by Passenger, Stuart and Terrell (2000) from their study of 80 preliterate children during their first year of formal schooling lend some support for this view. Although their results implicate the specific contribution of phonological memory to the development of a phonological recoding strategy for reading and spelling, a rather weak association was found between preliterate phonological memory ability measured at mean age 4 years 7 months and single-word reading measured at mean age 5 years 7 months. It is suggested that other factors, such as visual memory (not specifically measured in that study) would figure more importantly at this stage.

Stuart, Masterson and Dixon (2000) also found that visual memory influences the acquisition of sight vocabulary in children aged 5 who displayed poor graphophonic skills (i.e. those who had not yet acquired the ability to segment words on the basis of their sounds and who displayed little or no knowledge of sound-to-letter mappings). These authors used the *Goulandris Visual Memory Test* (Goulandris and Snowling, 1991), which is a conventional test that corresponds closely in items and assessment format to the *CoPS* computer-based test *Zoid's Letters*. There was a highly significant correlation between *Goulandris* visual memory scores and single word learning for the children with poor graphophonic skills ($r = 0.79$ after 36 training trials). For children with good graphophonic skills, however, no association between visual memory and word learning was found. In the present study, the correlations between scores on *Zoid's Letters* and single word reading (in the region of 0.28) were clearly not of the order reported by Stuart, Masterson and Dixon. Nevertheless, the results were statistically significant. It should also be borne in mind that in the Stuart, Masterson and Dixon study, the children had to learn to recognise words that were unfamiliar to them (e.g. leopard, haddock, canoe), whereas in the present study, the children were assessed on words that they had already acquired, and no distinction was made between children with good or poor graphophonic skills.

There is evidence that poor readers have a bias towards visual encoding of words. Johnston and Anderson (1998) reported that poor readers showed a preference for using pictorial rather than verbal information, which they suggest may arise from previous difficulties in learning to attach verbal labels to visual stimuli. Ellis, McDougall and Monk (1996) reported that dyslexics aged 10 years were significantly faster on some visual processing tasks (e.g. picture categorisation) than other groups, including reading age (RA) controls. On word recognition tasks in which the words are paired with either visually similar cues or phonologically similar cues, poor readers are known to perform *better* than reading age controls on the visually similar cue items but not on the phonologically similar cue items (Holligan and Johnston, 1988; Rack, 1987). In other words, they display a less pronounced phonological similarity effect and a more pronounced visual similarity effect (Katz, 1986; Mann and Liberman, 1984).

Palmer (2000) used the *Corsi Blocks* test to measure visuospatial span in three groups of 14 year-old students: dyslexics, RA controls, and chronological age (CA) controls with normal reading ability. The *Corsi Blocks* test comprises a set of nine blocks fixed to a base in a predetermined pattern. The test administrator touches the blocks in a set sequence and the testee is required to recall that sequence by touching the same blocks in the same order. This has a direct parallel with the *Rabbits* test in the *CoPS* suite. Palmer found that the dyslexic group significantly outperformed the RA controls on this test. The results also suggested that while all participants showed evidence of using phonological coding to remember pictures, only those in the dyslexic group used visual coding.

Another recent paper by Palmer (in press) provides further evidence that it is useful for teachers to know about children's visual memory skills. In this experiment, it was found that children who maintained a visual representation of words alongside a phonological representation after age 7, were significantly worse readers than those for whom the ability to switch strategies by inhibiting the visual representation had fully developed. Children with good visual memory but poor auditory verbal memory would not only be expected to find acquisition of an effective phonological decoding strategy in reading rather difficult, but also be inclined to rely for an longer period on visual strategies. This approach is liable to run into trouble as the child's education progresses and the number of new words with which the child is confronted steadily increases. Singleton, Thomas and Leedale (1997, *Teachers Manual,* p. 73) report a case in which this occurred, while Fawcett, Singleton and Peer (1998) report a case in which the opposite pattern was observed on assessment with *CoPS*, i.e. poor visual memory skills but good verbal memory. In this latter case the child, who was very bright, was struggling (inexplicably, as far as his teachers were concerned) with learning words by sight using flash cards. His teachers were reluctant to adopt an alternative teaching approach until they were informed about his profile of cognitive strengths and weaknesses, which clarified his problems.

The auditory discrimination test in *CoPS* (*Wock*) is similar to the *Wepman Auditory Discrimination Test*, which will be familiar to many educational psychologists and special needs teachers. The purpose of both these tests is to identify children who have poor ability to make fine discriminations between speech sounds (e.g. cannot reliably discriminate between the spoken words 'pot' and 'pop', or between 'bin' and 'bing'). Children suffering from chronic 'glue ear' (*Otitis media*), in which hearing has been impaired by excessive secretions in the middle ear, will be particularly disadvantaged on these tests. Individuals who have suffered from this condition in early childhood and have still not had sufficient opportunity to learn to make such discriminations will be similarly affected. Children with other forms of hearing impairment may also score low on these tests although, interestingly, multilingual children with relatively little experience of English tend to show enhanced performance on such tests, perhaps as a consequence of having had to pay greater attention to speech sounds during early childhood (Fumoto, 1999). In all cases in which auditory discrimination is poor, children are likely to experience difficulties in acquiring an effective phonological decoding strategy in reading, and may consequently rely on a less effective visual strategy (see Singleton, Thomas and Leedale, 1997, *Teachers Manual*, p. 64). In the present study, some of the highest correlations for *Wock* were with single word reading at age 6 ($r = 0.43$) and skills involved in listening and writing to dictation in *MIST* at age 6½ years ($r = 0.53$ and 0.47, respectively). In stepwise linear regression, only *Wock* was a significant cognitive predictor variable for *MIST Listening Skills*.

In conclusion, this study has provided considerable evidence for the potential of computer-based assessment of cognitive skills in the early identification of children who are at risk of reading failure. Moreover, a profiling approach, in which individual differences in cognitive strengths and weaknesses can be examined ipsatively, confers even greater utility on such a system. On the basis of the results of this study and on current models of reading development (e.g. Ehri, 1995), it would be expected that visual memory measures would prove most useful in predicting early acquisition of single word reading and the mastery of visual strategies at the pre-alphabetic or logographic stage. Verbal memory measures, together with measures of phonological awareness and auditory discrimination, should prove most useful in predicting acquisition of phonological decoding strategies at the alphabetic or orthographic stage. The latter can be conveniently assessed by nonword reading tasks.

Because cognitive skills can be assessed before children begin to learn to read, cognitive profiling makes it possible to instigate intervention much earlier than would otherwise be possible. By differentiating teaching in the classroom, any cognitive weaknesses that children display can be compensated for, thus avoiding the deleterious effects that the experience of failure inevitably have on motivation (see Singleton, Thomas and Leedale, 1997, *Teachers Manual,* pp. 51-87). This approach does not necessitate training of cognitive skills that are found to be weak, although in some instances this may be desirable. Rather, the teacher can select from a variety of strategies for teaching and learning that will provide the best fit to the child's cognitive profile, with the particular advantage that the child's motivation is not damaged by the experience of failure. This philosophy is comparable to that of optimising teaching strategies in line with children's learning styles (Carbo, Dunn and Dunn, 1986; Reid, 1998; Riding and Rayner, 1998)

Although conventional cognitive tests could be employed instead of computer-based tests, it is maintained that the greater precision afforded by use of the computer, e.g. in delivering memory items for which presentation times are critical, as well as the savings obtained in time and labour by the teacher, and the greater enjoyment by the child, all give computer based cognitive assessment particular advantages.

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Address for correspondence: DR CHRIS SINGLETON, Department of Psychology, University of Hull, Hull, HU6 7RX, UK. E-mail: *c.singleton@psy.hull.ac.uk*