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The Impact of Sensory, Motor and Cognitive Skills on Early Reading Development

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Abstract

The influence of basic sensory, motor and cognitive skills on early reading development was examined in 392 children receiving their first year of formal schooling in the UK. Auditory processing, speech processing, rhyme, IQ, working memory, motor skill and speed and accuracy of processing were measured at school entry and reading performance was measured both at school entry and at the end of the first school year. Confirmatory factor analyses demonstrated that speech and auditory processing at school entry had a direct, independent influence on reading performance at the end of the year, even after initial reading ability had been accounted for. All other skills were indirectly related to reading development. These findings confirm the crucial role of speech and auditory skills in early reading development.

Keywords. Reading Development, Early Literacy, Speech and Auditory Skills, Motor Skills, Phonological Awareness

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Research on early literacy development has emphasised the importance of speech processing skills in predicting phonological awareness and thus reading (e.g. Carroll, Snowling, Hulme & Stevenson, 2003; Muter, Hulme, Snowling & Stevenson, 2004). In fact, deficits in speech sound representations have been highlighted as a crucial cause of early reading difficulties (the phonological deficit hypothesis; Snowling, 2001). Studies with older children have found other basic skills to be associated with reading difficulties, for example motor skills, balance and sensitivity to dynamic auditory and visual stimuli (Nicolson, Fawcett & Dean, 2001; Stein & Walsh, 1997; Talcott 2003). However, it is unclear whether deficits in these skills directly link to later reading difficulties, and whether these skills play a crucial role in normal reading development. Our study follows on from the work by Carroll et al. and Muter et al. but includes a range of cognitive, sensory and motor skills in order to separate those basic skills with a direct independent influence on normal reading development from other skills that correlate with the crucial skills and indirectly influence reading. Below, we review previous work on several skills found to be weakened in children with reading difficulties, and discuss the evidence that these skills may predict normal reading development.

Predictors of Reading Difficulties

Many studies have demonstrated that children with reading difficulties tend to have difficulties in phonological awareness tasks (e.g. Bradley & Bryant, 1978; Hulme & Snowling, 1992), and that tuition in phonological awareness can help to remediate literacy difficulties (Hatcher, Hulme, & Ellis, 1994; Lundberg, Frost, & Peterson, 1988). Puolakanaho et al. (2007) compared the sensitivity of different predictors of reading difficulty and found the key predictors to be phonological awareness, letter naming, short-term memory, rapid naming, expressive vocabulary and pseudoword repetition (see also Lyytinen et al., 2004). In addition, Boscardin, Muthen and Francis (2008) found that kindergarten phonological awareness and rapid naming were highly predictive of word recognition, and a child's skill-profile at kindergarten was directly associated with their reading ability at grades 1 and 2.

Different Types of Phonological Awareness

Goswami and Bryant (1990) hypothesise a progression in phonological awareness from syllables, rhymes and then finally phoneme awareness. However, Carroll et al. (2003) found that awareness of both types of large-segment units (syllables and rhymes) developed earlier than small units (phonemes). Carroll et al. found that their data were best explained by a model that included rhyme awareness and phoneme awareness as separable skills. In addition, Foy and Mann (2001) found that rhyme and phoneme awareness correlated with different skills. Specifically, rhyme awareness correlated with speech perception and short term memory whereas phoneme awareness correlated with letter knowledge and reading. Bryant MacLean, Bradley, and Crossland (1990) hypothesise that rhyme awareness has both a direct role in causing reading development and an indirect role, by impacting on the development of phoneme awareness. However, Muter et al. (2004) disputed the direct role, finding that word recognition was predicted by letter knowledge and phoneme sensitivity, but not by rhyme awareness.

The Role of Letter Knowledge

Unsurprisingly, letter knowledge has been found to be a major predictor of reading development, both in typical and atypical groups (Muter, Hulme, Snowling & Taylor 1998; Snowling et al, 2003). In addition to the obvious role of letter knowledge in helping children to recognise words, letter knowledge also seems to play a role in the development of phonological awareness. Wagner, Torgesen and Rashotte (1994) and Burgess and Lonigan (1998) both found evidence of a reciprocal relationship between phonological awareness and letter knowledge (see also Treiman & Bourassa, 2000).

Short Term Memory and Working Memory

Many studies have shown that children with dyslexia have deficits on short term memory and working memory tasks, although these memory deficits are usually attributed to phonological coding difficulties (see Vellutino Fletcher, Snowling & Scanlon, 2004). Alloway, Gathercole, Willis and Adams (2004) investigated working memory related skills in 4 to 6 year old children and found that performance on their battery of tests was best explained by separate constructs for phonological short term memory and phonological awareness, indicating the potential for separate influences on literacy development. However, Durand, Hulme, Larkin and Snowling (2007) found phoneme deletion and verbal ability to be unique predictors of reading, whereas phonological memory (verbal memory span) was no longer a significant predictor of literacy once phoneme deletion was factored in. Thus, verbal short term memory is unlikely to directly influence literacy development once phonological awareness has been accounted for.

Speech Skills

There is evidence that at least some children with dyslexia show deficits in both speech perception and production. With regard to speech perception skills, some studies have found deficits in dyslexic children, but links to individual differences in reading are less frequently demonstrated. Manis et al. (1997) found that eight dyslexic children from a sample of 25 showed deficits in speech perception. McBride-Chang

(1996) measured speech perception and phonological processing and reading in 8 to 10 year old children and found that speech perception had an indirect influence on reading via its relations with phonological processing abilities (naming speed was highly associated with speech perception). Carroll et al. (2003) argue that speech perception skills (measured using a mispronunciation detection task) are only indirectly related to the development of phoneme awareness, in contrast to speech production skills, which show a direct relationship. Other researchers have argued that speech production skills are impaired in dyslexic children (Snowling, 1981; Swan & Goswami, 1997), and that measures of speech production can be strong unique predictors of dyslexia (Elbro, Borstrom, & Peterson, 1998). Therefore, it seems that some measures of speech processing skills may be useful predictors of reading progress.

Auditory Processing

Some researchers have argued that weaknesses in speech processing may be underpinned by broader difficulties in processing rapidly changing auditory stimuli. Farmer and Klein (1995) argue that dyslexic children often show difficulties in auditory temporal processing tasks, and that these difficulties may provide a causal explanation of their literacy problems. However, others have argued against a causal relationship. For example, McArthur Ellis, Atkinson and Coltheart (2008) report that, while it is possible to improve performance on auditory processing tasks with training, this improvement does not lead to increased reading and spelling skills. Marshall, Snowling and Bailey (2001) argue that, while some dyslexic children show deficits in temporal processing, these deficits are not associated with phonological processing problems. In a large sample of typically developing children, Marshall et al. found moderate correlations between temporal processing, reading and phonological awareness, but once age and IQ had been controlled, temporal processing did not predict reading or phonological awareness.

Another explanation for the link between dyslexia and auditory deficits is that auditory temporal tasks tap a general measure of processing speed, and that this may cause difficulties in tasks requiring accurate timing. Witton et al. (1998) examined auditory and visual dynamic processing in a group of dyslexic and control adults. The controls outperformed the dyslexic adults on both tasks, and there was a strong correlation between the visual and auditory tasks. In addition, performance on both the visual and auditory tasks predicted non-word reading speed and accuracy. Similar results were found with groups of typically developing children (Talcott et al., 2000; 2002).

Visual Skills

Although dyslexia has been associated with various visual difficulties, the theory that has received the most support is the visual magnocellular theory. The magnocellular visual system is sensitive to movement and rapid changes in the visual field and evidence from psychophysical and neuroimaging data suggests that this system is impaired in dyslexic participants (e.g. Eden et al., 1996; Cornellisen Hansen, Hutton, Evangelinou & Stein, 1997). Talcott et al. (2000 and 2002) also found that dynamic visual sensitivity predicted reading ability in unselected primary school children. However, visual difficulties often co-occur with phonological difficulties (Bosse et al. 2007; Vellutino et al, 2004), indicating that a low level visual deficit is unlikely to be the proximal cause of dyslexia. In contrast, Bosse et al. argued that a higher level deficit in visual attention can directly lead to reading difficulties. Bosse et al. defined visual attention span as the amount of distinct visual elements that can be processed in parallel in a multi-element array and found evidence of both phonological and visual attention deficits in dyslexic children. These data suggest that visual attention span may be an alternative underlying cognitive deficit in dyslexia, and could also be predictive of normal reading development.

Balance and Motor Skills

Difficulties with balance and motor skills are commonly associated with dyslexia (e.g. Nicolson, Fawcett & Dean, 2001). However, in a meta-analysis of balance deficit studies, Rochelle and Talcott (2006) found little evidence that these balance deficits were uniquely associated with dyslexia or any evidence for a direct link from balance difficulties to reading difficulties. Nevertheless, the existence of non-language based subtypes of dyslexia remains possible (e.g. Bosse et al., 2007) and the influence of balance and motor skills on normal reading development is unknown.

Current Study

The research we have reviewed suggests several tentative hypotheses as to the relationship between early skills and reading development. Firstly, different underlying processes are likely to explain young children's performance on rhyme and phoneme awareness tasks. The role of rhyme awareness in predicting reading development is still under debate, but phoneme awareness is likely to be the stronger predictor. In addition, letter knowledge is likely to play an important role in predicting early literacy. Verbal short term memory and speech perception are likely to indirectly influence reading development, whereas speech production may have a direct influence. Although Witton et al. (1998) and Talcott et al. (2000; 2002) found auditory processing skills to predict literacy development, they were not able to determine whether these skills were directly linked to literacy, or whether they influenced literacy via other skills (such as phonological awareness). Bosse et al.

(2007) found that a visual attention deficit could explain some cases of reading difficulty, indicating that visual attention may impact on normal reading development. There is little known about the impact of balance or motor skills on normal reading development, but it is anticipated that these skills have only an indirect influence.

In order to test these hypotheses, we have conducted a longitudinal study into the impact of early sensory, motor and cognitive skills on reading development. We measured sensory, motor, and cognitive skills at school entry and then collected follow up measures of literacy at the end of the first year of formal schooling. This design enabled us to address two main research questions. Firstly, what are the common processes that drive performance on baseline cognitive, sensory and motor tasks? Secondly, what are the relationships between baseline skills and early literacy outcomes? Specifically, which baseline skills have a direct influence, and which skills have an indirect influence?

Method

Participants

We collected data from four cohorts of children beginning reception (mean age 4 years, 6 months) in three primary schools in a large town in Worcestershire, UK. The schools were located within two miles of each other with intakes of predominantly white British pupils of lower than average socio-economic status, who began school with attainments slightly below the nationally expected level (as determined by the UK Office for Standards in Education, Children's Services and Skills).

Only 11 out of the 455 children registered in the reception classes were excluded from the study. Two children were excluded because their parents opted for them not to take part. One child was excluded because his learning difficulties made it difficult to understand the task instructions. One child was excluded because he was repeating the reception year, so was a year older than the rest of our sample (he was held back a year because of his autism). Four children were excluded because English was their second language, and a further three children were excluded because they were reluctant to take part in any of the assessments. One of the schools changed head teacher in the final year of the study and the new head opted not to continue with the research. Although we had tested 52 children in the final cohort from this school at baseline, we were unable to collect follow up data on these children and therefore excluded them from the following analyses. Of the 392 remaining children tested at baseline, 44 children dropped out of the study before the follow up session because they had moved to different schools. In total, data from 392 children at baseline and 348 children at follow up (end of Reception, mean age 5 years, 2 months) were used in the following analyses.

Some of these children opted out of some tests, so the N for each measure fluctuates slightly (see Table 1 in results section). In addition, our auditory temporal processing measure (ATP) involved a training phase (auditory discrimination), and only children who passed this phase undertook the main task, so the N for the ATP measure was smaller than the N for the auditory discrimination measure.

Assessments

Measures Taken at Baseline

General cognitive abilities. Vocabulary knowledge was measured with the British Picture Vocabulary scale (BPVS; Dunn, Dunn, Whetton & Burley, 1997), a measure of receptive vocabulary. In this test, the child heard the word and pointed to the appropriate picture from a choice of four. Working memory was measured with the Digit Span task from the Dyslexia Early Screening Test (DEST; Fawcett &

Nicolson, 1996). The child heard strings of numbers presented from a cassette recording, and was asked to repeat them back. Their score was the length of the longest number string repeated correctly. Non-verbal IQ was measured using Raven's Coloured Progressive matrices, pasted onto wooden blocks (Raven, Raven & Court, 1993). These matrices are considered to be one of the most reliable measures of general reasoning ability (Carpenter, Just, & Shell, 1990). The child was presented with a pattern of abstract shapes and patterns, with a missing piece in the lower right-hand corner. The task was to discover the arbitrary abstract rule and then select the matching piece from a set of 6 options. The child's final score was their total number of correct pieces chosen out of a total of 36.

Reading (letters, words and numbers). Letter knowledge was measured by presenting the child with a list of all 26 letters (in order of decreasing frequency in written English; Vousden, 2007). The child was asked, "Could you tell me what sounds these letters make?" and the experimenter pointed to each letter in turn; the child's score was the total number of letters correctly identified by either their sound or name. Sight word reading was assessed using a list of the 100 most frequent words in written English (in order of decreasing frequency; Vousden, 2007). The experimenter said, "Let's see if you can read any of these words" and pointed to each word in turn. All children were asked to attempt the first 16 words, and after this, the test was terminated after 5 errors in a row; the child's score was the total number of words read correctly. Two standardised measures of reading were also administered. Firstly, we measured children's single word reading using the BAS word reading test A (Eliott et al, 1983). This test comprised a list of regular and irregular English words in order of increasing difficulty. The child was asked to read each word in turn until the child failed to read 10 consecutive words correctly; the child's score was the total number of words read correctly. Secondly, we measured children's passage reading using the New Macmillan Reading Analysis passage reading test (Vincent & De la Mare, 1985). In this test, children were asked to read a series of stories, presented with an illustration to the left of the text. Since scores were very low for the children in our study, we simply took the total number of words read correctly as the child's score on this test, and did not measure comprehension or calculate standardised accuracy scores. Children may be able to identify numbers before they can identify any letters or words. We therefore also measured their naming of single digit numbers using the digit naming test from the DEST (Fawcett & Nicolson, 1996). The child's score was the total number of digits identified correctly, out of seven test items.

Phonology and speech (tasks involving the processing and production of speech sounds). Speech production, explicit phonological awareness and processing of speech sounds were measured using a range of standardised tests. We used the speech rate test from the Phonological Abilities Test (PAT; Muter, Hulme & Snowling, 1997) to measure speed of speech production. In this test, the child's score was the average time taken to say "buttercup" ten times, over three trials. We measured children's rhyme awareness using two standardised tests. Firstly, in the PAT rhyme detection test (Muter et al, 1997), the experimenter pointed to a target picture, followed by pictures of three choices underneath, saying their names out loud (e.g. "this is a picture of a boat, which of these, foot, bike or coat, rhymes with boat"). The child's score was the total number of correct rhymes identified, out of 10 trials. Secondly, in the DEST Rhyme detection task (Fawcett & Nicolson, 1996), pairs of words were pronounced by the experimenter, without pictures, and the child responded "yes" if the two words rhymed, and "no" if they did not rhyme (e.g. "leg, hen", correct response was "no"). We measured children's phoneme awareness using the DEST phoneme isolation test (Fawcett & Nicolson, 1996). In this test, the child was asked to say the sound of the first letter of a word (e.g. “dog”, correct response was “d”). The child’s score was the total number of sounds identified correctly, out of 5 trials. We measured children’s phonological processing with the DEST phonological discrimination task (Fawcett & Nicolson, 1996). In this test, the child was asked whether two words that differed by one phoneme were the same or different (e.g. “bad, dad”, correct response was “different”). The child’s score was the total number of correct responses over 9 trials. We measured children’s rapid automatised naming with the DEST rapid picture naming test (Fawcett & Nicolson, 1996). In this test, the child was asked to name a series of familiar pictures as fast as possible. The child’s score was the total RT to name a list of 40 pictures, plus 5 seconds for each error. Finally, we measured children’s phoneme processing and articulation with a non-word repetition test. In this test, the child was presented with a cassette recording of the non-words from the Phonological Assessment Battery non-word reading test (PhAB; Frederickson, Frith & Reason, 1997) and asked to repeat back each word in turn. The child’s score was the total number of words repeated correctly out of 20 trials (10 one-syllable words and ten two-syllable words, in order of increasing difficulty).

*Auditory processing (tasks involving the processing of non-speech sounds).*Two tasks were used to measure children’s auditory processing. Firstly, in the DEST sound order test (Fawcett & Nicolson, 1996), the child was presented with two sounds on a cassette recording: a duck’s “quack” and a mouse’s “squeak”. For each pair, the child was asked which animal made the first sound (e.g. “squeak, quack”, correct response, “mouse”), and their score was the number correctly identified, out of 16 trials. Secondly, we created an auditory processing task based on Tallal’s (1980) auditory temporal processing task. In this task, children were presented with computer generated complex tones, composed of frequencies within the speech range. Children learned to associate two buttons with two sounds and then played back sequences of the sounds using the buttons. Tallal's task was designed for use with older children, so we piloted this task with 4 year olds to ensure that the task was appropriate. Our final task differed from Tallal's in two respects. Firstly, we used tones that differed more dramatically in pitch than those used in Tallal's original task. One tone was very low (fundamental = 300Hz) and one was very high (1000Hz). Secondly, children heard the tones when they pressed the buttons, whereas Tallal did not give her participants this feedback. In all other respects, we followed Tallal's design and procedure. The task was divided into two phases, a discrimination phase and an auditory temporal processing phase. In the discrimination phase, children learned to associate the tones with buttons, and then were given an auditory discrimination test. In the auditory discrimination test, children repeated back each tone one at a time until they achieved 12 consecutive correct responses (up to a maximum of 60 trials). The child's auditory discrimination score was their proportion of correct responses, out of the total number of trials completed. In the Auditory Temporal Processing phase (ATP), the child was trained to repeat back sequences of sounds and was then given 24 test trials consisting of four trials of each combination of sounds at 6 different ISIs (8, 15, 30, 60, 150 and 305ms). According to Tallal (1973), dyslexic participants should be impaired at ISIs of 150 or less. In the current paper, the child's score was the total number of trials where the child repeated back the correct sequence, averaged across all ISIs. The performance of sub-groups of children at different ISIs is discussed elsewhere (Shapiro, Carroll & Solity, in preparation).

Motor and balance. Motor skill was measured using three standardised tasks. Firstly, in the DEST bead threading task (Fawcett & Nicolson, 1996), children were asked to thread large beads on to a string as quickly as possible. The child's score was the number of beads threaded in 30 seconds. Secondly, in the DEST shape copying task, children were asked to copy shapes presented one at a time, using a pencil and paper. The shapes were presented in increasing difficulty, starting with two vertical lines and finishing with a diamond. The experimenter rated the child's drawings according to Nicolson and Fawcett's standard scale from 0 to 3 and the total score for 7 shapes was used. Thirdly, in Annett's (1985) peg board task, the child moved a series of pegs from holes on the far side of a board to holes on the near side. The child used one hand only each time and repeated the task six times, alternating between their left and right hand each time. The child gained three scores for this task: the average time taken to move all the pegs across the three trials with the left hand; the average time taken to move all the pegs across the three trials with the right hand and the average RT difference between the right and left hands. We also measured children's balance with the DEST Postural stability task (Fawcett & Nicolson, 1996). In this task, children were asked put on a blind-fold, stand up with their feet together and to try to remain as steady as possible. After two seconds, the experimenter pushed the DEST balance tester in the small of the child's back. The child's degree of sway was assessed according to Nicolson and Fawcett's scale from 0 to 6, where a child scored 0 if they remained rock solid and scored 6 if they made several steps forward or showed a marked loss of balance. The child's final score was their total score for two trials with their hands by their side, and two trials with their hands stretched out in front of them.

Visual attention. Visual attention was measured using a conjunction search task based on Gerhardstein & Rovee-Collier (2002). In this task, the child was shown a target dinosaur and was given two practice sessions using a 6x4 array including 2 types of distractor dinosaur, with a target present on 50% of trials. The child pressed a button with a picture of the dinosaur if it was present, and a button with a picture of the dinosaur hidden under an X when it was absent. In the first practice session, the target dinosaur “wobbled” from side to side. Once the child had made 6 correct responses in a row, they were given a second practice session where the target was still. Once they achieved 6 correct trials in a row, they proceeded to a test of 32 target present trials (2, 4, 8 or 12 distractors plus the target, positioned randomly in a 6x4 array) and 32 target absent trials (3, 5, 9 or 13 distractors). Three measures were taken for both target present and absent trials: accuracy, average RT per trial (RT) and average RT per distractor (RT slope). Immediately after the conjunction search task, we also measured the child’s general button pressing RT and accuracy. The dinosaur was either shown intact in the middle of the screen, or hidden behind a X. The child pressed the matching button to indicate whether the dinosaur was present or “hiding” for 12 practice trials followed by 10 test trials. Two measures were taken: button press accuracy and RT.

Measures Taken at Follow-up

Letter knowledge. Letter knowledge was assessed using the same letter sound knowledge test administered at baseline (children’s letter sound fluency was also measured, but these scores are not used in the current paper).

Non-word reading. Children’s non-word reading performance was assessed using two tests. Firstly, the child was presented with a 3 letter non-word and the experimenter demonstrated how to read it by sounding it out. The child was then given a practice session on more 3 letter non-words, followed by the test. In the test, the child was presented with a series of 25 non-words on an A4 sheet, written in large font. The non-words were presented in order of increasing difficulty (the first 5 non-words were all 3 letter words). The task was to read as many non-words as possible in 30 seconds. The child's score was the total number of words read correctly in this time. The second test was the non-word reading task from the Phonological Assessment Battery (PHAB, Fredrickson et al., 1997). This task was un-timed, and the score was the total number of non-words read correctly, out of 20. However, if the child scored 0 in the timed non-word test, the PHAB was not administered and the child's score was assumed to be 0.

Single word and passage reading. Single word reading was measured using the BAS word reading test A, as at baseline. Passage reading was measured using the NFER passage reading test. As at baseline, the child's score was the absolute number of words read. We also assessed comprehension but these scores were not used because word reading was too poor for these to be interpretable. Sight word reading accuracy was measured using the same sight word test used at baseline (children's sight word reading fluency was also measured, but these scores were not used in the current paper).

Results

The results are presented in five sections. Firstly, we report our exploration of the baseline data and an exploratory factor analysis. Secondly, we report regression analyses examining which skill groups have some influence on later literacy, whether direct or indirect. Thirdly, we report confirmatory factor analyses examining the factors underlying performance on the baseline tests. Fourthly, we report an exploratory factor analysis of the outcome measures. Finally, we present our final confirmatory factor analyses of the relationships between baseline skills and literacy outcomes.

Our initial exploratory factor analyses and regressions were conducted using SPSS, excluding any missing data on a pairwise basis. All confirmatory factor analyses were carried out using AMOS 7.0 (Arbuckle, 2006), accounting for missing data using maximum likelihood estimation (data are assumed to be missing nearly at random, see missing data section, below).

1. Exploration of the Baseline Data

We initially checked for floor effects in our tasks at baseline. 313 of the 389 children who attempted the BAS task at baseline read no words correctly (80%) and 303 out of the 381 children who attempted the NFER task at baseline read no words correctly (80%). We therefore removed these measures from all further analyses. Although 143 out of 380 (38%) children who attempted the sight word task scored at floor, the distribution was much closer to normal, and it was useful to retain one initial measure of word recognition. Means and SDs for the raw scores for each measure we included in our analyses are reported in Table 1. Table 1 also shows the number of children who completed each assessment (N). Although children were encouraged to participate in all assessments, some children opted out of some tasks, resulting in missing data. In addition, 123 children (33%) failed to reach criterion on auditory discrimination, and therefore did not proceed to the ATP task. Overall, 4.6% of data from the 392 children tested at baseline are missing.

Before conducting our analyses, any RT scores or reverse-scaled ratings were reflected to follow the same directionality as the other measures. In addition, the absolute value of peg board hand difference scores was taken. Square-root or log transformations were applied to measures with a positive skew to normalise the distribution. Finally, outlying scores (more than 3 standard deviations from the mean score of each measure) were removed. This resulted in a loss of 0.67% of the baseline data.

Missing Data

It is likely that our missing data are not missing completely at random. For example, it is possible that a child's refusal to complete certain tasks was correlated with their overall performance. In order to investigate this issue, we calculated the number of tasks a child completed at baseline to produce a measure of compliance. There were 23 separate tasks that each child was asked to complete (some tasks resulted in more than one measure, e.g. pegboard left hand, right hand and hand difference). Mean compliance was 22.27 (SD = 2.44, minimum = 3, maximum = 23). We then examined the correlations between compliance and all baseline and outcome measures. Surprisingly, compliance did not correlate significantly with many other baseline measures. The only significant correlations were very low: BPVS (.14), digit span (.12), Non-word repetition (.13), shape copying (.13) and peg board right hand (.15). The correlation with DEST rhyme (.10) was almost significant. Baseline compliance did not correlate significantly with any of our outcome measures.[1] These correlations indicate that these data are likely to be missing nearly at random.

Correlations between Baseline Measures

There were very high correlations between all the reaction time measures for the visual search task (all above .7). We therefore took a single measure of visual attention RT. We decided that the slope was the best measure of visual attention since it represents the time that a child took for each additional distractor, as opposed to an

[1] The distribution of compliance scores shows a strong negative skew, and therefore these correlations may not be reliable. Nevertheless, we gained a similar pattern of correlations when data from children with outlying compliance scores were removed. We also gained a similar pattern of correlations using spearman's rho.

average across all trials, regardless of the number of distractors. Therefore, we used a composite score across visual search slopes to measure visual attention (mean z scores for target absent and target present slope). The composite scores were based on the data with outliers, and then outliers were removed from the composite scores. In addition, there were two further high correlations. Scores for the pegboard task using the right hand were highly correlated with scores using the left hand (.68). Since these measures were so highly correlated, they may be measuring the same skill. We therefore created one composite pegboard measure (mean z scores for left and right pegboard). The next highest correlation was between scores on the digit span task and scores on letter knowledge (.62). The pegboard hand difference scores did not correlate well with any other measures (all correlations were very low, and many were negative). In addition, postural stability scores did not correlate well with any other measures (all correlations were .1 or below). We therefore removed postural stability and hand difference from all further analyses, since these measures would not fit well in a model of baseline skills. Table 2 shows correlations between all remaining baseline measures, including the composite scores.

Exploratory Factor Analysis of the Baseline Measures

We conducted an exploratory factor analysis (principal components analysis, PCA) to examine how the remaining 24 baseline measures clustered together. The PCA was rotated to a final solution using varimax rotation. Six factors emerged with eigenvalues in excess of 1.00. However, factors 5 and 6 appeared to be best explained by the same skills (Speech and Motor), indicating that we may have extracted too many factors. A five factor solution indicated just one factor for Speech and Motor skills and therefore appeared to provide a better explanation of the data, which accounted for 49.81% of the variance (see Table 3 for a description of each factor and the factor loadings for the five factor solution). In our confirmatory factor analysis, we examined how many of these factors were needed to provide a good model of the data (see section three, below).

2. Regression Analyses Examining the Predictive Power of Baseline Scores on Literacy Outcomes

We used the five factors extracted from our PCA analysis to guide the creation of composite scores to represent the five key baseline skills (see Table 4 for a list of the measures that contributed to each composite score). Z scores were taken for each measure, and an average z score used as the composite score. When there was missing data for a child, we took the average score from all remaining scores. We also created a single composite outcome score for literacy (average of BAS word reading, NFER passage reading, sight words, timed non-word test, PHAB non-word test and letter knowledge z scores). Composite scores were created from the transformed data with outliers, and outliers removed from the composite scores.

Simple linear regressions were conducted to examine the predictive power of each composite baseline score on outcome literacy, when entered individually. As shown in Table 5, all baseline scores were significant predictors of later literacy when entered individually. We also conducted a simultaneous multiple regression analysis to examine which predictors had a significant independent influence on literacy outcomes. As shown in Table 6, all measures apart from accuracy had a significant independent influence on literacy. However, since accuracy was a significant predictor when entered individually, it is likely to have an indirect influence on later literacy.

3. Confirmatory Factor Analyses of the Relationship Between Baseline Skills

All measures made some contribution to literacy outcomes according to our regression analyses. We therefore included all measures in our confirmatory factor analyses to examine the relationships between baseline skills. The measures of goodness of fit for each model are shown in Table 7. We present Chi square statistics, which were used to make comparisons between the models. However, since the Chi square statistic is sensitive to sample size and non-normality of the distribution, we also report additional measures of fit that can be used to compare our models. We report Bentler and Bonnett's (1980) normed fit index (NFI), Bollen's (1989) incremental fit index (IFI) and Bentler's (1988) comparative fit index (CFI). For all of these, values above .9 indicate a good fit. We also report values on the root mean square error of approximation (RMSEA), which gives an estimate of the discrepancy in fit per degree of freedom, with values less than .08 indicating a good fit.

Our initial model (Model 1, Table 7) was based on the groupings indicated by our exploratory factor analyses, but with factors separated where theoretically plausible in order to generate the most complex theoretically possible model. Model 1 consisted of 9 factors: IQ, Accuracy, RT, Reading, Rhyme, Speech, Motor, Phonological Awareness (PA) and Auditory plus an independent observed variable measuring visual attention. We then combined factors in order of the highest correlations in model, where theoretically plausible, and compared each new model with the initial model (Model 1). We found that the following actions did not significantly reduce the fit of the model: linking visual attention to the RT factor; linking the PA and Speech factors; combining the Speech and Auditory factors (renamed Speech & Auditory). A model including these features was therefore accepted (model 4; 7 factors). No further theoretically plausible combinations of factors could be made. Models 5-7 tested further modifications to the model.

Removing the link from RT to rapid naming, and instead linking rapid naming from Speech & Auditory significantly improved the fit (model 5). Removing the link from Speech & Auditory to phoneme isolation and instead linking phoneme isolation from Reading significantly improved the fit (model 6; Reading renamed Reading & Phoneme). Phoneme isolation was the only explicit phoneme awareness task, and therefore may be better explained by the reading latent variable than the Speech & Auditory latent variable which explains performance on speech and non-speech processing measures. In contrast, we found that linking from Reading to phoneme discrimination, rather than from Speech & Auditory to phoneme discrimination provided a worse fit to the data. This implies that phoneme discrimination is better explained by the Speech & Auditory latent variable than the reading latent variable, perhaps because phoneme discrimination does not require explicit phoneme awareness, and is more similar to our other speech processing measures. Finally, linking digit span from IQ instead of Speech & Auditory significantly improved the fit (model 7; IQ renamed IQ & Memory). Since no further theoretically plausible modifications were possible, Model 7 was accepted as the best model of the baseline data.

4. Exploration of the Outcome Data

We followed up the literacy performance of 348 of the children originally assessed at baseline. Although children were encouraged to participate in all assessments, a very small minority of children opted out of some tasks, resulting in a very small proportion of missing data (0.16% of the outcome data). Scores for the literacy tests conducted at follow up are reported in Table 1. A square-root transformation was applied to all measures apart from letter sound knowledge in order to normalise their distributions. In addition, outlying scores (more than 3 standard deviations from the mean score of each measure) were removed resulting in a loss of 3.62% of the outcome data.

Correlations among the Outcome Measures

The correlation matrix in Table 8 shows that there were very high correlations among all word reading and non-word reading measures (all above .7). Letter knowledge showed a moderately high correlation with all other measures. This pattern of correlations indicates that the word and non-word reading measures may be tapping into the same skill for very young readers.

Exploratory Factor Analysis of the Outcome Measures

We conducted an exploratory factor analysis to examine how the six outcome measures clustered together. Only one factor emerged with an eigenvalue in excess of 1.00 (4.64, 77.38% of variance). Since the word and non-word reading scores were so highly correlated, we created a single composite reading score (average of all reading z scores) and letter knowledge was maintained as a separate measure. We built models with a single latent variable explaining both letter knowledge and reading outcome measures.

5. *Structural Equation Models of how the Baseline Factors are Related to Literacy Outcomes*

Since Model 7 provided the best fit to the baseline data, we used this model as a starting point for examining the links between baseline skills and literacy outcomes. The initial model included a link from each of the baseline skills to outcomes. We then examined progressively simpler models, where links from baseline skills to outcomes were removed in order of the weakest regression weightings in the model. Removing the links from RT, Accuracy, IQ & Memory, Rhyme and Motor skills to outcome Literacy did not significantly worsen the fit of the model. As shown in

Figure 2, the best model of the baseline and outcome data includes just two direct links, from Reading & Phoneme and from Speech & Auditory. Nevertheless, all baseline skills were correlated (as shown in Figure 1). In particular, there were very high correlations (above .7) between Auditory & Speech and Reading & Phoneme; between Auditory & Speech and IQ & Memory; between Reading & Phoneme and IQ & Memory and between Motor and IQ & Memory. In addition, there were high correlations (above .6) between Auditory & Speech and RT; between Auditory & Speech and Motor and between Rhyme and IQ & Memory. It is important to note that most of these high and very high correlations involved the crucial predictive factors (Auditory & Speech and Reading & Phoneme). Therefore, a child who performed well on these crucial predictors of reading was also likely to have performed well on many other tasks. In particular, IQ & Memory was highly correlated with the crucial skills, indicating that children with high IQ and good memory were more likely to have performed well on speech and auditory and reading tasks at the beginning of school. In addition, RT and Motor skills were highly correlated with Auditory & Speech skills. These correlations may be explained by the speed of processing component of the speech and auditory tasks (e.g. rapid naming, speech rate) and the articulation component (e.g. rapid naming, speech rate, non-word repetition).

Discussion

We investigated two research questions. Firstly, we examined performance on a range of cognitive, sensory and motor tasks, in order to uncover common processes that drive performance on these tasks. Secondly, we assessed the relationships between baseline skills and early literacy outcomes in order to uncover which skills have a direct influence, and which skills have an indirect influence. Our findings support some of the predictions we made in the Introduction. Importantly, our data allow us to distinguish between skills that are directly linked to early reading development and those that indirectly influence reading through correlations with the crucial skills.

The Impact of Baseline Skills on Early Reading Development

Phonological Awareness and Letter Knowledge

We found rhyme and phoneme awareness to be separable skills (supporting Carroll et al., 2003; Muter et al., 2004; Foy & Mann, 2001). Our baseline model indicated that performance on reading and phoneme awareness measures arose from different underlying processes than performance on our rhyme awareness measures. A child’s performance on reading and phoneme measures at the beginning of school had a strong, direct influence on their literacy outcomes at the end of the year, but, supporting Muter et al, we found no direct influence of rhyme. Our reading and phoneme construct included letter knowledge and phoneme deletion, supporting Muter et al.’s findings that letter knowledge and phoneme awareness are critical.

Working Memory

We found that working memory and phonological skills formed separate constructs (supporting Alloway et al., 2004), but only phonological skills directly influenced reading development (explicit phoneme awareness as part of our reading and phoneme construct, and phonological processing as part of our speech and auditory construct; supporting Durand et al., 2007). In addition, we found no direct influence of vocabulary on reading. However, it should be noted that our reading measures primarily tapped decoding skills. Although we included a passage reading test, reading comprehension was not included in our analyses because reading scores were so low. Thus, the relationship between vocabulary and reading may change over time as children become more competent readers. In fact, Muter et al. (2004) found vocabulary skills to be predictive of reading comprehension, but not decoding.

Speech and Auditory Processing

We found that performance on speech and auditory measures were best explained by a single factor, indicating that the same underlying processes drove performance on our speech and non-speech tasks, whether production of sounds was involved or not. Thus, we found no clear evidence of a separation between speech perception and speech production tasks, unlike Carroll et al., 2003. However, this single factor explaining performance on all auditory and speech measures at the beginning of the year had a direct, independent influence on reading, even when initial reading skill was accounted for, confirming the importance of speech processing skills (Carroll et al., 2003). Although we used different tests to Witton et al. (1998) and Talcott et al. (2000; 2002), two of our auditory tests tapped into auditory temporal processing, indicating that sensitivity to dynamic auditory stimuli did contribute to the impact of this factor on reading development.

Visual Skills

Our visual task was comparable to the visual attention span tasks used by Bosse et al. (2007) but was adapted for pre-readers. Children with larger visual attention spans, and faster visual processing speed should have been faster and more accurate on the task. However, we found that performance on our visual task was best explained by speed and accuracy constructs, and neither of these constructs were directly linked to later reading. Nevertheless, it is important to note that we were unable to measure sensitivity to dynamic visual stimuli in our study with such young children so a direct link from sensitivity to dynamic visual stimuli to early reading remains possible (e.g. see Talcott et al., 2000, 2002).

Motor Skills and Balance

We found no direct influence of motor skills on early reading (Nicolson Fawcett & Dean, 2001). Nevertheless, motor skills were highly correlated with the speech and auditory factor. Therefore, children with good motor skills would be likely to be also good at the speech and auditory tasks. However, it would be their speech and auditory skills that crucially influenced their literacy development, not their motor skills. We were unable to include balance in our model, but the poor correlations with all other measures indicate that it is unlikely to have a strong association with normal literacy development (despite the association of balance deficits with reading difficulty demonstrated by Rochelle & Talcott, 2006). It is possible that both these skills are associated with reading difficulties because balance and motor deficits are reliable markers for a wide range of developmental disorders (see White, Frith, Milne, Rosen, Swettenham & Ramus, 2006), but do not have a direct influence on normal reading development.

It is possible that the causal relationships between baseline skills and literacy change as reading develops. For example, speed of processing, visual skills and motor skills are all likely to become more important in predicting more advanced reading. Therefore, speech and auditory skills may do most of the work in the very first stages of learning to read, but other skills are likely to become increasingly important as reading develops.

Further Research

An obvious remaining issue is how instructional practice can impact on these early skills. It is important to be aware of the practical limitations of research into predictors of literacy. Simply because speech and auditory skills are crucial predictors of reading doesn’t mean we should train these skills (e.g. McArthur et al., 2008, found that remediation of auditory processing deficits did not impact on reading). Instead, the majority of the research on instruction suggests that the best skills to teach are those that are as close as possible to the actual process of reading itself (Foorman, Breier & Fletcher, 2003; Shapiro & Solity, 2008). Nevertheless, isolating early predictors of reading development will allow a rigorous comparison of the effectiveness of different teaching methods for children with different cognitive skills. For example, children who perform poorly in our speech and auditory tests at the beginning of Reception are likely to be particularly sensitive to the methods used to teach crucial reading skills such as phonics and/or phonological awareness. A major issue for further research is therefore how pre-school cognitive skills and teaching method interact in their impact on reading development. For example, intensive small group phonological awareness and phonics interventions may allow children with poor speech and auditory skills to "catch up" with their peers on these crucial pre-reading skills, therefore reducing their likelihood of developing reading difficulties. Alternatively, children with poor pre-school speech and auditory skills may be taught effectively within normal whole-class teaching, as long as the training focuses on the most crucial phonological awareness and phonics skills, and teachers are trained to differentiate between different achievement groups (see Shapiro & Solity, 2008). In the long term, research into the interaction between these crucial pre-reading skills and instruction will impact on how resources are allocated for remediation and standard teaching.

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Table 1

Maximum and Minimum Scores, Means and Standard deviations for all Baseline and Outcome Measures

Baseline Measure		N	Minimum	Maximum	Mean	SD
1	BPVS	391	6.00	89.00	44.98	11.36
2	Digit span	378	0.00	7.00	2.81	1.61
3	Ravens	385	5.00	29.00	14.61	4.48
4	Letter knowledge	387	0.00	28.00	5.80	6.25
5	Sight word reading	380	0.00	100.00	1.92	5.81
6	Digit naming	388	0.00	7.00	3.68	2.61
7	Speech rate (s)	364	4.37	33.47	10.46	3.03
8	PAT rhyme	387	0.00	10.00	4.25	3.03
9	DEST rhyme	381	0.00	8.00	3.87	2.04
10	Phoneme isolation	377	0.00	5.00	1.13	1.85
11	Phoneme discrimination	378	0.00	9.00	5.53	1.80
12	Rapid naming (s)	376	34.14	237.00	87.01	29.74
13	Sound order	380	0.00	16.00	9.77	2.87
14	Non-word repetition	377	0.00	20.00	9.79	3.73
15	ATP	248	2.00	24.00	12.79	4.93
16	Button press accuracy	374	2.00	10.00	9.15	1.36
17	Target absent accuracy	376	9.00	32.00	29.15	4.04
18	Target present accuracy	376	5.00	32.00	28.85	3.87
19	Auditory discrimination	371	38.33	100.00	83.55	16.02
20	Bead threading	382	0.00	7.00	3.83	1.45
21	Postural stability	356	0.00	36.00	4.68	5.89

22	Peg board left	387	12.38	74.26	20.47	5.53
23	Peg board right	387	12.02	39.18	18.78	3.84
24	Shape copying	386	0.00	19.00	7.10	3.79
25	Peg board hand difference	387	-8.93	52.11	1.69	4.24
26	Button press RT (ms)	374	541.70	10821.13	1877.19	1118.87
27	Target absent RT (ms)	376	1127.07	11530.44	3988.67	1415.74
28	Target present RT (ms)	376	761.60	10441.26	3090.96	1359.55
29	Target absent slope (ms per distractor)	376	183.91	1975.59	666.69	244.59
30	Target present slope (ms per distractor)	376	245.58	2772.27	713.27	330.44

Outcome Measure		N	Minimum	Maximum	Mean	SD
1	Letter knowledge	347	1.00	26.00	20.97	5.01
2	Timed non-word	346	0.00	21.00	2.30	2.98
3	PHAB non-word	346	0.00	18.00	3.12	3.26
4	BAS word reading	348	0.00	70.00	9.28	10.96
5	Sight word reading	338	0.00	100.00	21.23	25.13
6	NFER passage reading	345	0.00	460.00	29.62	53.52

Table 2

Correlations among Baseline Measures

		IQ			Literacy			Auditory and speech									Accuracy				Motor			VA
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	BPVS																							
2	Digit span	0.35																						
3	Ravens	0.34	0.34																					
4	Letter knowledge	0.36	0.41	0.28																				
5	Sight word reading	0.29	0.24	0.11	0.50																			
6	Digit naming	0.37	0.40	0.30	0.62	0.34																		
7	Speech rate	0.19	0.17	0.10	0.22	0.10	0.27																	
8	PAT rhyme	0.32	0.31	0.26	0.28	0.18	0.24	0.11																
9	DEST rhyme	0.24	0.16	0.18	0.25	0.22	0.17	0.03	0.39															
10	Phoneme isolation	0.36	0.38	0.24	0.55	0.32	0.37	0.20	0.38	0.26														
11	Phoneme discrimination	0.19	0.30	0.13	0.32	0.20	0.31	0.18	0.17	0.12	0.25													
12	Rapid naming	0.24	0.24	0.13	0.34	0.20	0.38	0.32	0.13	0.17	0.27	0.22												
13	Sound order	0.26	0.30	0.21	0.39	0.31	0.40	0.17	0.24	0.21	0.31	0.26	0.25											
14	Non-word repetition	0.18	0.32	0.11	0.23	0.13	0.19	0.14	0.13	0.10	0.23	0.15	0.16	0.24										
15	ATP	0.33	0.35	0.28	0.47	0.30	0.41	0.16	0.23	0.23	0.37	0.30	0.30	0.50	0.27									

16	Button press accuracy	0.23	0.24	0.12	0.15	0.15	0.14	0.13	0.14	0.07	0.21	0.12	0.20	0.17	0.08	0.15										
17	Target absent accuracy	0.22	0.19	0.16	0.09	0.06	0.18	0.02	0.07	0.09	0.06	0.05	0.21	0.20	0.13	0.07	0.32									
18	Target present accuracy	0.08	0.16	0.07	0.16	0.15	0.16	0.08	-0.01	0.01	0.10	0.07	0.18	0.15	0.10	0.16	0.20	0.42								
19	Auditory discrimination	0.21	0.29	0.27	0.24	0.08	0.24	0.09	0.18	0.08	0.14	0.13	0.29	0.21	0.06	0.25	0.29	0.35	0.21							
20	Bead threading	0.22	0.19	0.22	0.20	0.08	0.14	0.21	0.17	0.11	0.20	0.12	0.20	0.06	0.10	0.09	0.12	0.13	0.09	0.18						
21	Peg board	0.26	0.26	0.30	0.25	0.17	0.26	0.29	0.23	0.16	0.20	0.14	0.31	0.18	0.22	0.25	0.13	0.22	0.11	0.23	0.39					
22	Shape copying	0.29	0.31	0.31	0.32	0.19	0.33	0.22	0.31	0.22	0.25	0.16	0.18	0.27	0.24	0.30	0.09	0.19	0.15	0.18	0.23	0.46				
23	Button press RT	0.24	0.19	0.17	0.22	0.12	0.25	0.27	0.09	0.08	0.18	0.16	0.32	0.23	0.09	0.27	0.02	0.07	-0.02	0.08	0.17	0.27	0.21			
24	Visual search slope	0.26	0.20	0.18	0.25	0.19	0.27	0.19	0.12	0.16	0.16	0.22	0.39	0.22	0.06	0.26	0.06	0.17	0.05	0.15	0.19	0.28	0.18	0.58		

Note. VA = Visual Attention

Table 3

Variance Explained by each Baseline Factor (Rotation Sums of Squared Loadings) and Factor Loadings Above or Equal to 0.3 for the Baseline Measures

		Reading, PA & speech	Speech & Motor	Accuracy	Rhyme & IQ	Visual & RT
	Eigenvalue	6.17	1.68	1.59	1.39	1.12
	Percentage of Variance	25.7	7.02	6.62	5.80	4.68
1	BPVS	0.33	.	.	0.44	.
2	Digit span	0.48	0.34	.	.	.
3	Ravens	.	0.34	.	0.47	.
4	Letter knowledge	0.75	.	.	.	.
5	Sight word reading	0.60	.	.	.	.
6	Digit naming	0.66	.	.	.	.
7	Speech rate	.	0.51	.	.	.
8	PAT rhyme	.	.	.	0.69	.
9	DEST rhyme	.	.	.	0.67	.
10	Phoneme isolation	0.60	.	.	0.33	.
11	Phoneme discrimination	0.51	.	.	.	.
12	Rapid naming	0.35	.	.	.	0.50
13	Sound order	0.61	.	.	.	.

14	Non-word repetition	0.41	0.46	.	.	.
15	ATP	0.65	.	.	.	.
16	Button press accuracy	.	.	0.59	.	.
17	Target absent accuracy	.	.	0.79	.	.
18	Target present accuracy	.	.	0.65	.	.
19	Auditory discrimination	.	.	0.62	.	.
20	Bead threading	.	0.60	.	.	.
21	Peg board	.	0.70	.	.	.
22	Shape copying	.	0.59	.	.	.
23	Button press RT	.	.	.	.	0.77
24	Visual search slope	.	.	.	.	0.81

Table 4

Descriptions of the Composite Baseline Scores Used in the Regression Analyses

Composite Score	Reading, PA, Auditory	Speech and Motor	Accuracy	Rhyme and IQ	Visual and RT
Predictors	Letter knowledge	Speech rate	Button press accuracy	BPVS	Rapid naming
	Sight word reading	Non-word repetition	Target absent accuracy	Ravens	Button press RT
	Phoneme isolation	Bead Threading	Target present accuracy	PAT rhyme	Visual search slope
	Phoneme discrimination	Peg board	Auditory discrimination	DEST rhyme	
	Digit naming	Shape copying			
	Sound order				
	ATP				
	Digit span				

Table 5

Separate Linear Regressions for each Baseline Predictor on Literacy Outcomes

Predictors	R^2	B	SE B	Beta (standardised co-efficient)
Read, PA, Auditory	.48***	.90	.05	.71***
Speech and Motor	.21***	.62	.07	.46***
Accuracy	.07***	.32	.06	.26***
Rhyme and IQ	.22***	.59	.06	.47***
Visual and RT	.19***	.48	.05	.44***

Note. *** p < .001

Table 6

Multiple Regression Examining the Relative Power of each Baseline Predictor on Literacy Outcomes

Predictors	R^2(adjusted)	B	SE B	Beta (standardised co-efficient)
Read, PA, Auditory	.53	.70	.06	.55***
Speech and Motor		.16	.06	.12**
Accuracy		-.01	.05	-.004*ns*
Rhyme and IQ		.12	.06	.10**
Visual and RT		.12	.05	.11**

Note. ns $p > .05$, ** $p < .05$, *** $p < .001$

Table 7

Comparative Goodness of Fit of Accepted Confirmatory Factor Analysis Models of the Baseline Data

Model	Model fit			Goodness of fit			Test of closeness		Stepdown goodness of fit	
	df	X^2	p<	NFI	IFI	CFI	RMSEA	90%CI	df	X^2
1. Nine factor model	208	320.872	0.001	0.863	0.947	0.945	0.037	.029-.045		
2. Nine factor model (linked visual attention from RT)	216	341.17	0.001	0.855	0.941	0.939	0.038	.031-.046	8	20.298
3. Eight factor model (combined PA and Speech)	224	370.394	0.001	0.842	0.931	0.929	0.041	.033-.048	8	29.224
4. Seven factor model (combined Speech and Auditory)	231	385.204	0.001	0.836	0.927	0.925	0.041	.034-.048	7	14.81
5. Seven factor model, rapid naming linked	231	375.032	0.001	0.84	0.932	0.93	0.04	.032-.047	0	-10.172

from Speech & Auditory										
6. Seven factor model, phoneme isolation linked from reading	231	361.551	0.001	0.846	0.938	0.936	0.038	.030-.045	0	-13.481
7.Seven factor model, digit span linked from IQ	231	355.222	0.001	0.849	0.941	0.939	0.037	.029-.045	0	-6.329

Table 8

Correlations among the Outcome Measures

		Word reading			Non-word reading	
		1	2	3	4	5
1	BAS					
2	Sight word reading	0.87				
3	NFER	0.89	0.87			
4	Timed nonword	0.74	0.75	0.73		
5	PHAB nonword	0.73	0.75	0.70	0.84	
6	Letter knowledge	0.66	0.61	0.57	0.55	0.59

Figure Captions

Figure 1. Model of the relationships among baseline skills.

Figure 2. Model of the relationships between the seven baseline factors and a single literacy outcome factor.

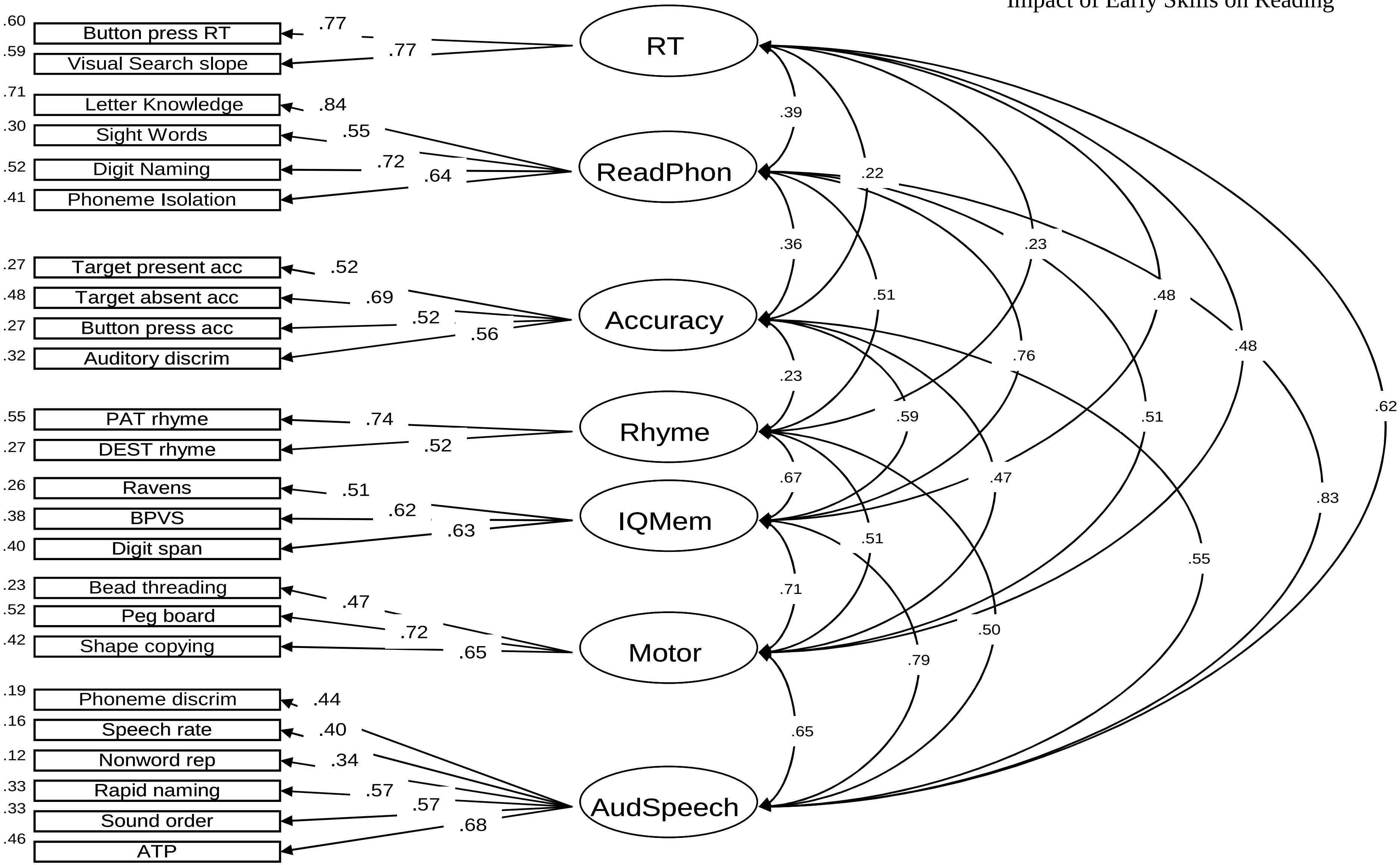
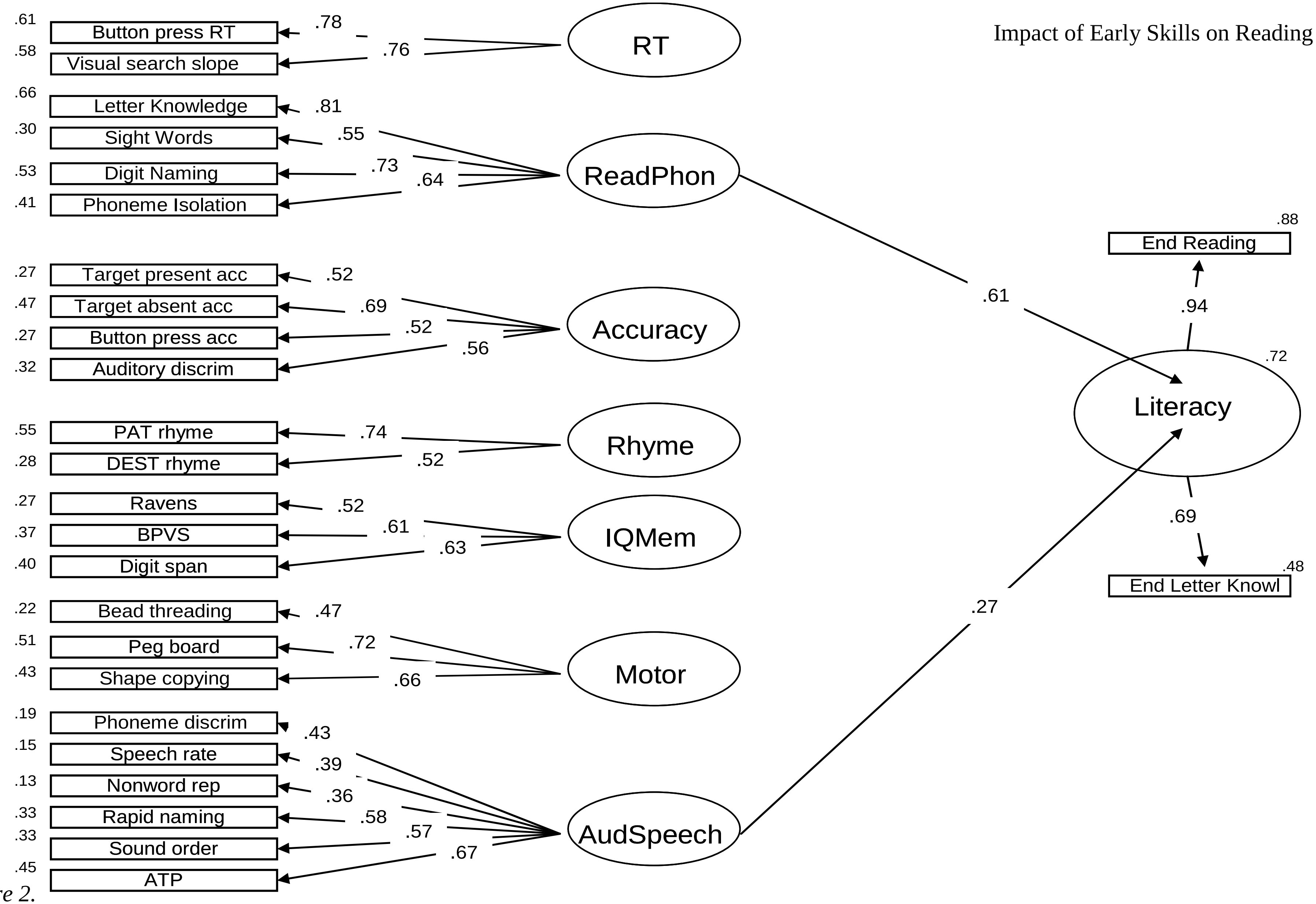

RT
ReadPhon
Accuracy
Rhyme
IQMem
Motor
AudSpeech
Button press RT
Visual Search slope
Letter Knowledge
Sight Words
Digit Naming
Phoneme Isolation
Target present acc
Target absent acc
Button press acc
Auditory discrim
PAT rhyme
DEST rhyme
Ravens
BPVS
Digit span
Bead threading
Peg board
Shape copying
Phoneme discrim
Speech rate
Nonword rep
Rapid naming
Sound order
ATP

Figure 1.

Note. Correlations between the constructs are represented by double headed arrows. All significant correlations were included in the model (correlations between RT and Accuracy and between Accuracy and AudSpeech were not included). Factor loadings are represented by single headed arrows, with standardised regression weights shown. Squared multiple correlations for each of the observed variables are given at the far left of the figure.

Key. Target present acc: Visual attention, target present accuracy; Target absent acc: Visual attention, target absent accuracy; Button press acc: Button press accuracy; Auditory discrim: Auditory discrimination; Phoneme discrim: Phoneme discrimination; Nonword rep: Non-word repetition; ATP: Auditory temporal processing; ReadPhon: Reading & Phoneme; IQMem: IQ & Memory; AudSpeech: Auditory & Speech.



RT
ReadPhon
Accuracy
Rhyme
IQMem
Motor
AudSpeech
Literacy
End Reading
End Letter Knowl
.61 Button press RT .78
.58 Visual search slope .76
.66 Letter Knowledge .81
.30 Sight Words .55
.53 Digit Naming .73
.41 Phoneme Isolation .64
.27 Target present acc .52
.47 Target absent acc .69
.27 Button press acc .52
.32 Auditory discrim .56
.55 PAT rhyme .74
.28 DEST rhyme .52
.27 Ravens .52
.37 BPVS .61
.40 Digit span .63
.22 Bead threading .47
.51 Peg board .72
.43 Shape copying .66
.19 Phoneme discrim .43
.15 Speech rate .39
.13 Nonword rep .36
.33 Rapid naming .58
.33 Sound order .57
.45 ATP .67
.61
.27
.72
.94
.88
.69
.48

Figure 2.

Note. Factor loadings are represented by single headed arrows, with standardised regression weights shown. Squared multiple correlations for the baseline observed variables are given at the far left of the figure, and squared multiple correlations for the outcome observed variables and the endogenous factor are given at the far right of the figure. Correlations between the baseline factors are not shown (see Figure 1 for estimates).

Key. End Letter Knowl: End of Reception letter knowledge.