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# Number skills and knowledge in children with specific language impairment

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Abstract

The number skills of groups of 7 to 9 year old children with specific language impairment (SLI) attending mainstream or special schools are compared with an age and nonverbal reasoning matched group (AC), and a younger group matched on oral language comprehension. The SLI groups performed below the AC group on every skill. They also showed lower working memory functioning and had received lower levels of instruction. Nonverbal reasoning, working memory functioning, language comprehension, and instruction accounted for individual variation in number skills to differing extents depending on the skill. These factors did not explain the differences between SLI and AC groups on most skills.

Keywords: number development; working memory; specific language impairment; instruction

Number skills and knowledge in children with specific language impairment

Language is fundamental to education because it is the major form of representation of cultural knowledge and the principal medium of instruction. Children whose spoken language development is impaired should therefore be at risk for learning difficulties. How oral language impairment affects the development of mathematical cognition during the school years has received little attention. Some studies indicate that the mathematical competence of adolescents is compromised by early language impairment (Aram & Nation, 1980; Snowling, Adams, Bishop, & Stothard, 2001). Reading difficulties might contribute to this relationship. Instruction and assessment make increasing demands on literacy as children progress through school. Children with language impairment are at greater risk of developing reading difficulties. Children with specific language impairment (SLI) are those who combine oral language impairment with nonverbal intelligence in or above the average range. Their risk of developing reading difficulties is substantial but not as great as that for children with both language and nonverbal impairments (Bishop & Adams, 1990; Catts, Fey, Tomblin, & Zhang, 2002).

Children with SLI show disorders of phonological processing. This is also characteristic of children with specific reading disability, or developmental dyslexia. Although some suggest that SLI and developmental dyslexia are not distinct disorders (Kamhi & Catts, 1986), Bishop and Snowling (2004) argue that this ignores the additional semantic and syntactic deficits shown by children with SLI.

Previous studies of children with SLI suggest they show deficits in some number skills but not others (Donlan, Bishop, & Hitch, 1998; Donlan & Gourlay, 1999; Fazio, 1994, 1996; Jordan, Levine, & Huttenlocher, 1995). The present study compares children with SLI with their typically developing peers and with younger children with similar oral comprehension skills using tasks derived from the early elementary school curriculum and existing research on number development.

The tasks differ in whether they concern skills and knowledge that most first grade school children are expected to possess or whether they assess aspects of number that are the focus of instruction in the first years of schooling (see Table 1). No task involves extraneous literacy demands. The only reading required is of numerals. The following sections review research relating to the tasks and other characteristics assessed.

*Counting*

Proficient counting requires understanding of counting principles, procedural skills, knowledge of the arbitrary sequence for numbers below 20 and knowledge of the syntax and grammar for the structure of higher numbers (Fuson, 1988; Gelman & Gallistel, 1978; Siegler & Robinson, 1982). By the end of first grade, most children can successfully recite the number list well beyond 20 and accurately count sets of objects up to this numerosity. They can also count forwards and backwards from numbers in the decades. By third grade, they can count on from numbers in the thousands (Skwarchuk & Anglin, 2002).

Children with SLI are considerably delayed in their development of counting accuracy and knowledge of the count list but less impaired in their understanding of counting principles (Fazio, 1994, 1996). It is likely that they will experience difficulty in progressing to higher numbers as these involve mastering linguistic rules.

*Basic Calculation, Knowledge of Combinations, and Story Problems*

Basic calculations are the addition and subtraction of numbers less than 10. Development of expertise in basic calculation involves learning addition and subtraction combinations, developing a range of backup strategies, and mastering different problem formats, principally number-fact problems and story problems (Cowan, 2003). Instructional guidance in the UK (Department for Education and Employment, 1999) emphasises all these aspects. In the UK, as in the US (Geary, 2004), opinions differ as to the importance of knowledge of combinations and so attention paid to this aspect is likely to vary.

Most young children solve number-fact problems in several ways that include retrieval, guessing, and backup strategies involving counting (Siegler & Jenkins, 1989). Their strategy choices show several adaptive characteristics such as using backup strategies when retrieval is likely to be inaccurate. From first to third grade they develop new backup strategies, such as decomposition and counting on from the larger addend, and make increasing use of retrieval (Siegler, 1994).

Limited knowledge of simple addition combinations is frequently found in children with maths difficulties (MD) (e.g. Geary, Brown, & Samaranayake, 1991; Hanich, Jordan, Kaplan, & Dick, 2001; Jordan, Hanich, & Kaplan, 2003a; Jordan & Montani, 1997; Russell & Ginsburg, 1984) and in children with SLI (Fazio, 1996). In consequence their retrieval is less accurate and they depend more on backup strategies. Their skill in executing backup strategies is also impaired, particularly with larger numbers (Geary, 1990; Geary, Hoard, Byrd-Craven, & DeSoto, 2004). In general they show less adaptive choices (Geary & Burlingham-Dubree, 1989; Siegler, 1988).

Story problems involving addition and subtraction can vary substantially in complexity (Riley & Greeno, 1988; Riley, Greeno, & Heller, 1983). Most children from kindergarten onwards succeed on problems where the result is the unknown but it is not until third grade that similar levels of success are achieved on problems with unknown initial quantities. More complex story problems make greater demands on both mathematical and language understanding because the child has to understand the story to be able to identify the corresponding arithmetic problem. Persistent weakness in solving story problems by children with MD has frequently been reported (e.g. Hanich et al., 2001; Jordan & Hanich, 2000; Jordan, Hanich, & Kaplan, 2003b; Ostad, 1997; Russell & Ginsburg, 1984). Children with language impairments are likely to find the linguistic demands of story problems challenging.

*Transcoding*

Competence in written arithmetic requires skill in transcoding, translating between the Hindu-Arabic system using digits and place value and the verbal numeration system for representing number. Although both systems share a common base, the correspondence between these forms, at least in English, is weak. For example, in the teens, the spoken number order is the reverse of the numeral representation, e.g. ‘nineteen’ and ‘19’. A further difference is that in numbers above a hundred, the verbal form in UK English uses the conjunction ‘and’ to link parts of the same number, e.g. ‘one hundred and ninety-five’ for ‘195’. It is possible that this induces the common error in writing numbers of concatenation (Nunes & Bryant, 1996), such as writing ‘1008’ for ‘one hundred and eight’.

By the end of first grade, children are expected to read and write numbers up to 20. By the end of third grade, their range is expected to expand to numbers above 1000. Children with MD are typically unimpaired in transcoding small numbers (e.g. Geary, Hamson, & Hoard, 2000; Geary, Hoard, & Hamson, 1999). Tasks with multidigit numbers may be more problematic as Hanich et al. (2001) found children with either reading or maths difficulties showed weakness in understanding the base-10 system. Transcoding clearly has lexical and syntactic elements and so may be affected by linguistic impairment.

Place value is not expected to be understood until third grade. An ability that draws on understanding of place value is relative magnitude - the ability to compare multidigit numbers such as 2795 and 2975 and identify the larger (Sowder, 1992). By fourth grade, children can determine the larger of two multidigit numbers with the same number of digits by reading the numbers from the left and comparing digit by digit until a larger digit is found.

Donlan and Gourlay (1999) reported many children with SLI to be as capable as typically developing peers in comparing multidigit numbers.

*Working Memory*

Children with SLI differ from their typically developing peers in their working memory characteristics (Gathercole & Baddeley, 1990). Fazio (1994, 1996, 1999) suggests that working memory deficits are mainly responsible for the deficits in counting and knowledge of number facts that children with SLI show.

Number tasks make demands on one or more aspects of working memory: counting (Healy & Nairne, 1985; Nairne & Healy, 1983), backup strategies in basic calculation and development of knowledge of combinations (Geary, 1993, 1994, 2004; Geary et al., 2004), story problems (Brainerd, 1983; Hitch, 1978), and transcoding (Deloche & Seron, 1987). Deficits in working memory are believed to contribute substantially to the problems of children with MD (Geary, 2004). This suggests it is important to assess whether differences in working memory explain differences between children with SLI and their peers. This, however, raises the question of which aspect of working memory.

Earlier versions of an influential working memory model (Baddeley, 1986; Baddeley & Hitch, 1974) consisted of three components: the phonological loop, central executive and visuo-spatial sketchpad. The phonological loop is a temporary storage system from which information is lost if not rehearsed. Tasks that measure it include forward digit span. The central executive is involved in attentional control and can be assessed by various tasks that require both storage and processing of information such as backward digit span (Pickering & Gathercole, 2001) and counting span (Geary et al., 2004; Hitch & McAuley, 1991). The visuo-spatial sketchpad integrates visual, spatial and possibly kinesthetic information into a unified representation that may be temporarily stored and manipulated (Baddeley, 2003) and can be measured with Corsi span (Pickering & Gathercole, 2001).

Recent versions of the working memory model (Baddeley, 2000, 2003) have included a fourth component, the episodic buffer. This is a limited capacity storage system that allows combining information from different modalities. Currently no measures of it exist.

Swanson and Sachse-Lee (2001) found story problem accuracy related to each of the three earlier components. In contrast, central executive functioning but not phonological loop functioning was found to differentiate children with MD from typically developing children in the studies by Geary et al. (1999) and McLean and Hitch (1999). McLean and Hitch (1999) also found impaired visuo-spatial functioning, indexed by Corsi span, in their MD group.

The varying relations between measures of working memory and aspects of maths ability might be because the importance of working memory components differs with number task. An alternative is that they result from the different amounts of variance shared between aspects of memory functioning and intelligence. Relations between intelligence and both memory and arithmetic performance have long been recognized: omnibus intelligence tests have included span measures and arithmetic items since Binet. Current research and meta-analyses of adult data indicate substantial relationships between working memory and intelligence but conclude they are not the same (Ackerman, Beier, & Boyle, 2005). Some claim that the more complex span measures used to measure central executive functioning are more strongly related to intelligence than simple span measures (Engle, Tuholski, Laughlin, & Conway, 1999).

We therefore include a measure of nonverbal reasoning as well as assessments of each component of working memory. The Raven's Coloured Progressive Matrices (Raven, Raven, & Court, 1998) is the children's subset of Raven's Progressive Matrices, a test described as the best measure of *g* (Snow, Kyllonen, & Marshalek, 1984; Spearman & Jones, 1950) and often used in studies of the relationship between intelligence and working memory.

It is considered nonverbal because the child does not need to speak or understand speech to understand what is required or to indicate their response.

*Instruction*

Our sample of children with SLI is recruited from special schools for children with language difficulties and language units in mainstream schools. An additional source of variation between their number skills and those of typically developing children might result from differences in curriculum coverage. To assess this we therefore collected information from the children's teachers about what they had taught.

*Summary of Aims*

Studies of the development of mathematical cognition in children with SLI have found that some number skills are less compromised than others. Where children with SLI are impaired, it is uncertain whether this is due to linguistic or working memory deficits. We also suggest that children with SLI might receive less curriculum coverage in mathematics because specialist support is likely to concentrate on improving their linguistic skills.

The aims are a) to investigate whether the number skills of children with SLI differ from those of their typically developing peers, matched in nonverbal reasoning, and a group of younger typically developing children matched on language comprehension; b) to compare their working memory characteristics; c) to compare their curriculum coverage; d) to determine whether differences between children with SLI and their typically developing peers remain after taking into account influences of nonverbal reasoning, language comprehension, working memory, and curriculum coverage; and e) to assess whether differences in basic calculation accuracy reflect differences in strategy use and error rates.

## Method

*Participants*

Participants were 167 children drawn from a pool of 260 attending 27 state schools in England and Wales. The schools served socially mixed catchment areas. The Specific Language Impairment (SLI) and Age Control (AC) groups were in third grade. Most children with SLI were in language units of mainstream schools and were taught predominantly in mainstream classes. Some children with SLI were attending special schools for children with language disorders with much smaller classes. Children in the Language Control (LC) group were all attending mainstream schools, mostly in first grade classes with a few of the youngest being in kindergarten classes.

From a population of children who had received a diagnosis of SLI, we selected an initial sample that were between 7 and 9 years old and demonstrated at least normal nonverbal ability. The criterion for normal nonverbal ability was a standard score on the Raven’s Coloured Progressive Matrices (Raven et al., 1998) of 85 or more, i.e. no less than 1 SD below the mean for their chronological age.

This yielded 60 children (8 girls, 52 boys). They were assessed with the Test for Reception of Grammar (TROG) (Bishop, 1983), a test of language comprehension used in identifying specific language impairment. It consists of 20 blocks of four items and testing is discontinued if the child fails one or more items in five consecutive blocks. All blocks, except the first three, assess comprehension of oral statements. Each item requires identification of the picture, out of four, that matches the utterance, e.g. 'the pencil is above the flower'. A child's score is the number of blocks for which they answered every item correctly. Testing followed the instructions in the manual.

The AC initial sample were selected to match the initial SLI sample in chronological age, gender distribution, and either attended the same school as the SLI children or one nearby with a similar catchment area. They were also selected on the same nonverbal ability criterion and the group constructed to approximate the initial SLI sample in distribution of Raven's standard scores.

The initial LC sample were selected primarily to match the initial SLI sample in distribution of raw scores on the TROG but also to match them in terms of Raven's standard scores, gender distribution, and school characteristics. To be considered for either the AC or LC samples, children had to have no known history of speech or language difficulties.

Children in all three initial samples were administered the Children's Test of Nonword Repetition (CNRep, Gathercole & Baddeley, 1996), a standardised phonological memory task particularly sensitive to language impairment, and a past tense production (PTP) task derived from Marchman, Wulfeck, and Weismer (1999). Unfortunately, this was not possible for four children (one of the AC initial sample, and three of the LC group). The CNRep consisted of 40 items. We administered the CNRep using the tape of nonwords provided and following the instructions in the manual. The PTP consisted of 20 verbs, 10 regular and 10 irregular. Past tense production was elicited by showing pictures for each verb, accompanied with present tense utterances using third person singular nouns and pronouns, e.g. "This boy is watching TV. He watches TV every day. Yesterday he...?"

Exploratory data analysis of the distributions on these tests and the TROG within each initial sample identified outliers. Two children were excluded from the SLI group because their scores were exceptionally high on one or more of the language tests. Four children were excluded from the AC and LC samples because their scores were exceptionally low (two from each group).

To confirm group membership according to language measures, a discriminant analysis was conducted between the AC ($n = 57$) and SLI ($n = 58$) samples using TROG, PTP, and CNRep scores. This yielded one discriminant function, $\chi 2$ (3) = 169.4, $p< 0.001$.

There were three misclassifications, all children in the SLI group. They were dropped from the final SLI group.

The characteristics of the final groups are in Table 2. The final SLI group comprised 44 children from language units in mainstream schools and 11 from special schools.

Internal reliability of the Raven's Coloured Progressive Matrices was good, with a Cronbach alpha of .83. Consistent with the study design, there were no group differences in standard scores: $F$ (3,163) = 0.89, *ns*, $\eta^2$ = .02, power = .24. Groups differed in raw scores: $F$ (3,163) = 25.42, $p$ < .0005, $\eta^2$ = .32, power = 1. For this and subsequent analyses, post hoc Ryan-Einot-Gabriel-Welsch Range (R-E-G-W-Q) comparisons ($p$ < .05) were used to compare groups and the results are summarised in Table 2.

Internal reliability of the TROG was good, with a Cronbach's alpha of .88. The groups differed in both raw and standard scores: raw scores, $F$ (3,163) = 84.97, $p$ < .0005, $\eta^2$ = .61; standard scores, $F$ (3,163) = 51.68, $p$ < .0005, $\eta^2$ = .49. Both power levels were 1.

Internal reliabilities of both CNRep and PTP were good, with Cronbach's alphas for each of .90. The groups differed in both measures: CNRep, $F$ (3,163) = 81.21, $p$ < .0005, $\eta^2$ = .60, PTP, $F$ (3,163) = 102.43, $p$ < .0005, $\eta^2$ = .65. Both power values were 1.

*Working Memory Measures*

Three subtests of the Working Memory Test Battery for Children (Pickering & Gathercole, 2001) were used to assess aspects of working memory. They were forward digit span (Forward), to assess phonological loop functioning, Corsi span (Corsi), to assess visuo-spatial sketchpad functioning, and backward digit span (Backward) to assess central executive functioning. They were administered in accordance with the manual. Each of these yields a span score reflecting the largest number of items reproduced in correct order on more than 50% of trials. Reliabilities for each span task were good: Forward, Cronbach's alpha = .90; Corsi, Cronbach's alpha = .87; Backward, Cronbach's alpha = .86.

Separate one-way ANOVAs confirmed the groups differed in each measure: Forward, $F$ (3,163) = 19.81, $p < .0005$, $\eta^2 = .27$, Corsi, $F$ (3,163) = 9.62, $p < .0005$, $\eta^2 = .15$, Backward, F (3,163) = 18.21, p < .0005, $\eta^2 = .25$. All power values were 1.0. Table 2 shows group means and differences.

*Curriculum Coverage*

To assess curriculum coverage we asked teachers to complete a checklist for each child to show what the child had been taught. The checklist consisted of 22 items differentiated according to objectives in the National Numeracy Strategy (Department for Education and Employment, 1999). Counting items established the range in which the child had been taught to recite numbers forwards and backwards, 1-20, 21-100, and whether the child had practised counting in the ranges 101-1000, and above 1000. Knowledge of addition combinations items assessed the range of number bonds taught differentiated by their sum: up to 5, up to 10, up to 20. A basic calculation item assessed whether the child had been taught to do simple addition and subtraction problems with sums or minuends less than 20. Story problem items assessed whether simple and complex story problems had been covered, using examples of subtraction problems (Change 2 and Change 6, Riley & Greeno, 1988). Transcoding and relative magnitude items assessed teaching of reading and writing numbers (1-20, 21-100, 101-1000, and above 1000), place value (tens and units, hundreds, and thousands), and comparison of numbers (two-digit, three-digit, and four-digit). The questionnaires were completed by 82 teachers; 28 for the LC sample, 4 for the SLI special school sample, 7 for both SLI mainstream and AC children, 22 for SLI mainstream children only, and 21 for AC children only. Initial analysis indicated some items showed little variance because over 95% of children were reported to have covered them. They were counting backwards and forwards from 1 to 20, number bonds up to 5, basic calculation, simple story problems (Change 2), reading and writing numbers 1 – 20, and comparing written and spoken two-digit numbers. The remaining items formed a reliable scale with a maximum score of 15 (Cronbach's alpha, .89, item-to-scale correlations, .38 to .80). An SLI Mainstream girl's teacher could not say whether she had been taught complex story problems. We assumed she had not. Overall the groups differed in the instruction they had received, $F$ (3,163) = 86.63, $p < .0005$, $\eta^2 = .62$, power = 1. Table 2 shows instruction group means and differences

*Materials and Procedures for Number Tasks*

After the screening and working memory assessment sessions, children were tested on the following tasks, amongst others, in two sessions lasting approximately half an hour. Counting and knowledge of addition combinations were the first number tasks the child received. The order of the others was varied.

*Counting.* Ability to recite the number list was assessed in five different trials. One required children to count from one until they reached 41. Another required them to continue counting backwards from 23 to one after counting backwards together with the experimenter from 25. The other three trials assessed oral counting over decade, century, and thousand boundaries: 25 to 32, 194 to 210, and 995 to 1010. In each of these, the experimenter said the first three numbers together with the child. All trials were oral. For each trial, the child was classified as passing or failing. Combining the trials yielded a scale with a maximum score of five that was reliable and one-dimensional (Cronbach's alpha, .77, item-to-scale correlations, .48 to .60).

*Knowledge of addition combinations.* Fourteen items assessed children's knowledge of addition facts by forcing them to retrieve answers quickly as in Jordan and Montani (1997). The experimenter explained she was interested in what facts they knew without having to count. She gave the example of 1 + 1 as a number fact that they knew and determined their preference for operand name, i.e. 'plus' or 'add'. She told them to answer as quickly as possible or say if they would have to work it out. As she orally presented an item, she held up a card with the item presented visually. The first 4 items were small number tie facts (2 + 2, 3 + 3, 4 + 4, and 5 + 5). If the child gave incorrect answers to all of these or said they knew none of the answers, the task was discontinued. The remaining items were 10 non-tie single digit addition problems, 4 with sums less than 10 (2 + 5, 6 + 3, 4 + 3, 6 + 2) and 6 with sums greater than 10 (7 + 5, 9 + 8, 7 + 8, 7 + 6, 9 + 3, 4 + 9). Items were recorded as known only if all the following criteria were met: a correct answer within 3 seconds, no visible or audible indication of computation, and the child said they had not had to work it out. Number facts formed a reliable and one-dimensional scale with a maximum score of 14 (Cronbach's alpha, .87, most item-to-scale correlations, .31 to .65). One item (7 + 8) showed a lower item-to-scale correlation of .11. This was because only three children knew it.

*Basic calculation: Addition and subtraction.* Children's ability to solve simple addition problems and the complementary subtraction problems was assessed with two sets of 8 items: basic calculation I and basic calculation II. Basic calculation I comprised addition and subtraction problems with sums and minuends less than 10 (2 + 5, 7 - 5, 2 + 6, 8 - 6, 3 + 6, 9 - 6, 3 + 5, 8 - 5). Basic calculation II consisted of addition and subtraction problems with sums and minuends above 10 and less than 20 (5 + 7, 12 - 7, 7 + 8, 15 - 8, 8 + 9, 17 - 9, 6 + 7, 13 - 7). All problems were presented orally.

Objects were provided and the children were told they could use these or any other method to solve the problems. After establishing the child's preferred method of referring to addition ('add' or 'plus') and subtraction ('take away' or 'minus'), two practice problems (1 + 1, 2 - 1) with feedback were used to ensure the child realised that both addition and subtraction problems would follow. Basic calculation I items were presented first followed by basic calculation II items. Testing was discontinued for children who answered all basic calculation I problems incorrectly or became confused or tired. Items within a set were presented in random order with the constraint that complementary problems were never adjacent. Combining the accuracy scores for each trial in a set yielded two scales with maximum scores of 8 that were reliable and one-dimensional: Basic calculation I, Cronbach's alpha, .84, item-to-scale correlations, .47 to .64; Basic calculation II, Cronbach's alpha, .87, item-to-scale correlations, .55 to .72.

For each problem attempted, children were coded as using either retrieval or backup strategies; retrieval if they answered without using the objects or their fingers and without giving any sign of counting, otherwise backup.

*Story problems.* Children were asked to solve story problems that varied in required operation, addition or subtraction, and complexity, result unknown or initial quantity unknown. They were told they could 'work out' the answers in any way they wished; in their head, using their fingers or using the counters provided. All problems were orally presented. There were four practice trials, one of each type of story problem: Change 1, Change 2, Change 5 and Change 6 (Riley & Greeno, 1988) using very small addends and minuends, i.e. 1 and 2. The main problems were presented in two blocks, each consisting of two examples of each problem type. In the first block, the sums or minuends were less than 10. In the second block, they were less than 20. Testing was discontinued after the first block if none of the problems had been answered correctly. Story problems formed a reliable and one-dimensional scale with a maximum score of 16 (Cronbach's alpha, .92, item-to-scale correlations, .47 to .72).

*Transcoding: Reading numbers.* This task required children to read printed multidigit numbers aloud. It used a set of items that comprised 8 numbers with between two and five digits, presented one at a time in large print. The numbers were, in order of presentation, 17, 305, 80, 400, 50042, 3051, 60000, and 4800. If a child simply read the digits without constructing the number, e.g. said 'Three O five' for 305, they were asked if they knew another way to say it. An answer was only considered correct if it was the complete number name, e.g. ‘Three hundred and five’.

*Transcoding: Writing numbers.* Children were first asked to write the numbers from 1 to 10 to identify any peculiarities in production of single numerals. They were then asked to write a set of 8 multidigit numbers consisting of between two and five digits. The numbers were, in order of presentation, 'thirty', 'five hundred', 'fifteen', 'three hundred and eight', 'twenty-five thousand and fifty', 'four thousand five hundred', 'seven thousand two hundred', and 'six thousand and forty-two'. Only completely co-ordinated written numbers were considered correct, e.g. for 'six thousand and forty-two', the only correct answer was 6042.

*Transcoding: Matching spoken and printed numbers.* This multiple-choice task required children to select the printed number that matched a spoken number. It comprised 12 items, 4 of each of the following length of number; 2, 3 and 4 digits. Each item presented the child with three different foils and the correct answer. The foils were either phonologically similar numbers, e.g. 40 for “fourteen”, reversals, e.g. 41 for “fourteen”, visually similar, e.g. 17 for “fourteen”, or concatenation errors, e.g. 67003, 6000703, and 6007003 for “six thousand, seven hundred and three”.

Combining items from the three transcoding tasks yielded a reliable and one-dimensional scale with a maximum score of 28 (Cronbach’s alpha, .93, item-to-scale correlations, .34 to .74).

*Relative magnitude.* The magnitude comparison task assessed understanding of place value by requiring children to pick the larger of two multidigit numbers. The task consisted of six blocks of 8 trials varying in the number of digits in each of the numbers (2, 3, 4 & 5), and the type of trial (transparent, challenging). In transparent pairs, the two numbers differed only in one digit, e.g. 1892 vs. 1792. Challenging pairs presented the same digits in different orders, e.g. 918 vs. 819, or had the smaller number contain larger digits, e.g. 29996 vs. 31112.

Items were presented on a laptop computer and children responded by pressing keys under the number they considered larger. Children were judged to pass a particular block if they correctly responded to 7 or more of the 8 trials correctly (binomial probability, $p < .05$). Number of blocks passed yielded a reliable scale (Cronbach's alpha, .80, item-to-scale correlations .33 to .66) with a maximum score of 6.

## Results

### *Accuracy data*

Data were collected from all children on all tasks with one exception; a child in the LC group did not receive the knowledge of addition combinations task because he did not know that 1 + 1 is 2. He is considered to have no knowledge of addition combinations.

The groups differed in accuracy on every task: counting, $F$ (3,163) = 48.48, $p < .0005$, $\eta^2 = .47$; addition combinations, $F$ (3,163) = 43.27, $p < .0005$, $\eta^2 = .44$; basic calculation I, $F$ (3,163) = 15.84, $p < .0005$, $\eta^2 = .23$; basic calculation II, $F$ (3,163) = 25.81, $p < .0005$, $\eta^2 = .32$; story problems: $F$ (3,163) = 52.34, $p < .0005$, $\eta^2 = .49$; transcoding tasks: $F$ (3,163) = 73.77, $p < .0005$, $\eta^2 = .58$; relative magnitude, $F$ (3,163) = 27.87, $p < .0005$, $\eta^2 = .34$. All power levels = 1. Table 3 reports means and differences between groups.

In accordance with the aims of the study, multiple regression analyses are used to determine whether the performance of children with SLI differs from that of their chronological peers (AC group) when relations between performance and curriculum coverage, working memory, receptive grammar and nonverbal reasoning are taken into account. Zero order correlations between nonverbal reasoning, working memory, instruction, and number task measures are shown in Table 4. Because of the large number of correlations, a significance level of .01 was adopted. In the multiple regressions, dummy variables are used which code the SLI Mainstream group as the reference group. The results are summarized in Table 5. We repeated the analyses excluding the SLI Special School group but in no case did they yield substantially different results.

*Strategy Data: Addition and Subtraction*

Due to data collection difficulties, the discontinuation policy and refusals, complete strategy data across both basic calculation I and II problem sets were only available for 77% of the whole sample (36/55 LC, 2/11 SLI Special, 37/44 SLI Mainstream, 54/57 AC). We therefore restrict analysis to comparisons of the SLI Mainstream and AC groups. Their data are more complete and allow the comparisons of interest. Table 6 shows backup strategy use and error rates for backup and retrieval strategies.

The SLI Mainstream group used backup strategies more often than the AC group on both problem sets: basic calculation I, $F$ (1, 90) = 10.71, $p < .005$, $\eta^2 = .11$, power = .90, basic calculation II, $F$ (1, 90) = 7.55, $p < .01$, $\eta^2 = .08$, power = .78. Their backup strategy error rates were only higher on the larger number problems: basic calculation I, $F$ (1, 56) = 1.03, *ns*, basic calculation II, $F$ (1, 65) = 30.05, $p < .0005$, $\eta^2 = .32$, power = 1. Their retrieval error rates were higher on both problem sets: basic calculation I, $F$ (1, 78) = 17.17, $p < .0005$, $\eta^2 = .18$, power = .98, basic calculation II, $F$ (1, 63) = 10.80, $p < .005$, $\eta^2 = .15$, power = .90.

## Discussion

This study contributes to knowledge about children with SLI in several ways. First, we have found they perform markedly below their peers on a range of number tasks. The findings support and extend previous research. Second, we have established that they differ from their peers on all aspects of working memory measured. Third, we have detected differences between children with SLI and their peers in the instruction they have received. Fourth, differences in language comprehension are uniquely related to variation in performance of some number tasks. Finally, our analyses have shown that differences on some number tasks remain between children with SLI and their typically developing peers, after allowing for variation attributable to nonverbal reasoning, language comprehension, working memory characteristics and instruction.

In the following discussion, we consider what our data suggest about working memory and instruction for children with SLI, the relation between working memory resources and variation in number development, and the roles of nonverbal reasoning and language comprehension. We must first acknowledge limitations of our study in sample characteristics, measures, and nature of the data.

Our sample of children with SLI is extremely imbalanced in gender distribution, with a preponderance of boys. The overrepresentation of boys in samples of children with language impairment is generally found (Law, Boyle, Harris, Harkness, & Nye, 2000) though explanations are contested and the imbalance in the present sample exceeds those typically reported in older studies. The greater imbalance in the current sample is, however, consistent with recent UK studies (Conti-Ramsden, Botting, Simkin, & Knox, 2001; Broomfield & Dodd, 2004). In both these studies, 75% of children with diagnoses of language impairment were boys.

We recruited children with SLI from mainstream and special schools. Most UK children with language impairment are in mainstream schools and the proportion is increasing in line with inclusive education policy (Lindsay et al., 2002). The balance in our sample between mainstream and special school broadly corresponds to national provision. Our study was not designed to compare children in the different settings and the special school group is too small for conclusive comparisons.

Our study lacked measures of reading ability and processing speed. The absence of measures of reading is particularly regrettable given the comorbidity of reading and maths difficulties (Lewis, Hitch, & Walker, 1994), the incidence of reading difficulties in children with SLI (Bishop & Adams, 1990; Catts et al., 2002), and the relation between reading skills and computation (Hecht, Torgesen, Wagner, & Rashotte, 2001). Lower processing speed is also suggested to explain deficits associated with SLI (Miller, Kail, Leonard, & Tomblin, 2001). Including measures of reading ability and processing speed would have enabled assessment of their relation to specific number skills. They may have accounted even better for some of the variation attributed to language comprehension and explained the residual differences between children with SLI and typically developing children.

As Table 4 shows, most predictor variables correlated with each other. Neither these nor separate diagnostic tests indicated problems of multicollinearity, but most variance was shared. Table 5 shows unique contributions of individual predictors to explaining variance were small, despite reasonable overall $R^2$s. Our discussion of the contribution of individual components to explaining variation in performance should be considered in the context of the substantial shared variance and the small amounts of unique variance.

*Working Memory*

Both samples of children with SLI differed from their peers substantially on each aspect of working memory. The differences were particularly marked on the two measures of phonological memory, nonword repetition and forward digit span. On these, they performed below the level of the younger language control group.

Nonword repetition and forward digit span correlate with vocabulary independently of intelligence (Baddeley, Gathercole, & Papagno, 1998) and limitations in them are found in children with reading difficulties (Bishop & Snowling, 2004). These findings are consistent with the claim that the phonological loop is particularly important in learning new words and establishing the links between spoken and written forms. Attempts to establish whether phonological loop limitations are a cause or a consequence of linguistic and literacy deficiencies have been hampered by methodological challenges and the acknowledgement that during development they are likely to interact (Jarrold, Baddeley, Hewes, Leeke, &

Phillips, 2004). However, Jarrold et al. (2004) obtained evidence that, at least in early vocabulary acquisition, it is phonological loop functioning that drives vocabulary acquisition rather than the converse. They compared two groups of children with general mental retardation matching in vocabulary but differing in chronological age. The younger children were superior in both nonword repetition and forward digit span with the differences being slightly greater for nonword repetition. This indicates that the memory measures are more related to rate of vocabulary acquisition than level of knowledge.

Both nonword repetition and forward digit span require the ability to reproduce verbal information in serial order, phonemes in nonword repetition and number words in forward digit recall. The extremely low level of performance on the test of nonword repetition by both SLI groups, over 3 SD below the AC group mean, is a greater deficit than that shown on forward digit span, approximately 1 SD below the AC group. Several factors might account for this discrepancy in deficits.

First, as Baddeley (2003) suggests, the task of repeating an unfamiliar sequence of phonemes may resemble more closely the task of vocabulary learning than sequencing highly familiar items. This is consistent with the tendency of nonword repetition to correlate more reliably than digit span with vocabulary and the characterisation of nonword repetition as a more sensitive marker for SLI.

Second, previous research indicates nonword repetition remains deficient in older children and adults whose early language impairment resolves (Bishop & Snowling, 2004). Forward digit spans may show greater age related change in children with SLI than nonword repetition. This may be due to their greater familiarity with the number words and the smaller set of sounds encountered in digit span tasks than in nonword repetition tasks. Either of these would result in enhanced effectiveness of redintegration (Brown & Hulme, 1995), the process by which partially degraded memory traces are reconstructed or filled in from long-term memory and a 'best guess' about the stimulus (Jarrold et al., 2004).

The observed deficit in central executive functioning may result from the use of backward digit span as the measure. Other measures of central executive functioning such as listening recall or counting span are, however, likely to show even greater differences between SLI children and their peers. Listening recall tasks require linguistic comprehension skills that they are deficient in. Counting span is affected by speed of counting (Cowan et al., 2003; Hitch & McAuley, 1991) and children with SLI count slowly. Unfortunately, nonverbal central executive tasks appropriate for children do not exist (Pickering & Gathercole, 2001).

The deficit in visuo-spatial functioning indicated by the difference in Corsi spans is consistent with emerging evidence with younger children with SLI (Hick, Botting, & Conti-Ramsden, 2005). As indicated by the SDs in Table 2, the SLI Mainstream group showed greater variability on this measure and the mean differences between both SLI groups and the AC group were small.

Future research will have to determine what underlies the differences on this and the other span measures. Such research might draw on analyses of the mechanisms that underlie age-related components in working memory (e.g. Cowan, Saults, & Elliott, 2002). These include strategy use and efficacy, control of attention, increased speed of processing information and slower decay of information. Any of these might contribute to the differences between children with SLI and their peers.

*Instruction*

Our attempt to assess curriculum coverage yielded a scale of instruction that related to performance in varying degrees for different aspects of number. Comparisons of the groups on the instruction scales indicated that children with SLI had not been taught to the same level as their typically developing peers on any aspect of number. As instruction was related to performance, it is important to take instructional differences into account in comparing SLI groups with their typically developing peers. The causal relationships underlying the relations between instruction and achievement are unknown. It may be that children do not achieve as much because they have not been taught to the same level. It is also possible that the level of instruction is lower because of their slower progress. Future research should establish whether and how teachers differentiate the curriculum for children with SLI.

*Number Skills and Working Memory*

Consistent with previous research and theory, aspects of working memory functioning accounted for variance on many tasks. However, the indications of the particular importance of individual components were not always in line with expectations and frequently nonverbal reasoning and language comprehension were more important.

Counting requires mastery of count word vocabulary and compounding rules (Skwarchuk & Anglin, 2002). It might therefore be expected to show the influence of phonological loop functioning given the importance of this for vocabulary acquisition. It did not. Geary et al.'s (2004) analysis of the importance of working memory capacity for addition combinations suggests an explanation. They suggest working memory resources are more important for learning than for retrieval. For many children, particularly those in the AC group, knowledge of the count list and moving through it either forwards or backwards were already well established and so for them the counting tasks did not make particular demands on working memory. An alternative explanation is that there was more redundancy between variance accounted for by working memory and that accounted for by nonverbal reasoning. Investigation of the fluency with which children perform counting tasks such as these might enable a distinction between performance based on relatively automatised retrieval and that based on active construction. Comparing associations with working memory and ability to count within familiar ranges and counting within novel ranges might also help decide between the interpretations.

The test of knowledge of addition combinations merely assessed number of facts known and not the dynamics of retrieval. We therefore expected to find phonological loop functioning to be important because it would affect learning of the combinations as hypothesized by Geary (1993). It was not. This may be because our assessment of phonological loop functioning did not discriminate between sources of variation. Geary (1993) specified decay rate of information as the principal component of working memory that affected learning of number facts. As mentioned above, several other characteristics contribute to differences in working memory capacity (Cowan et al., 2002). If these other characteristics were more responsible than decay rate for the variation in digit spans in our sample, this could explain the failure to find phonological loop functioning to be important.

Visuo-spatial functioning did partially explain variation in knowledge of addition combinations. Geary's (1993) hypothesis of the importance of decay rate was based on the view that children acquire their knowledge of addition combinations from carrying out basic calculations and storing the problems and their answers. It may be that Corsi span variation better reflected differences in decay rates.

Several other explanations are possible. One is that it reflects the importance of spatial ability for this aspect of number development. Geary and Burlingham-Dubree (1989) found adaptiveness of strategy choices to be related to spatial abilities in younger children: one component of their measure was accuracy of retrieval which is related to knowledge of combinations. Also McLean and Hitch (1999) found Corsi span deficits in their sample of children with MD.

Another possibility is that it reflects variation in method of assessment. We showed children the addends on cards while saying them. A further possibility is that the importance of visuo-spatial functioning results from differences in instructional practice. If the dominant mode for teaching children addition facts is through use of visual media such as flash cards and tables then variation in visual memory may be more important for differences in learning. Certainly, the use of visual methods for developing knowledge of combinations is recommended for teaching children (Askew, 1998; Thornton, 1990), particularly those with reading or language difficulties (Chinn & Ashcroft, 1998; Grauberg, 1998; Hutt, 1986). Investigating the relation between instructional practices and working memory related variation in learning might usefully contribute to our understanding of both.

Accuracy in basic calculation should be related to working memory capacity when strategies other than retrieval are involved. Consistent with this, central executive functioning made independent contributions to explaining variance on both problem sets with some indication that this increased when larger numbers were involved. The strategy analyses showed greater use of backup strategies on the more complex problem set.

Story problem accuracy varied with working memory functioning. The role of visuo-spatial functioning is consistent with Geary's (2004) proposal and previous research on working memory and story problems (Swanson & Sachse-Lee, 2001). Unlike Swanson & Sachse-Lee (2001), we did not find a substantial contribution of central executive functioning. This discrepancy might be due to the methodological differences between the studies. Their problems included extraneous information and were presented in written form: ours were orally presented and included no extraneous information. Their samples of learning difficulty and chronological age match children were from fifth and sixth grade: our SLI and AC samples were recruited from third grade. Their measure of central executive functioning was a composite based on three measures, none of which was backward digit span.

Another possible explanation is that the discrepancy results from differences in analytic strategy. Although Swanson and Sachse-Lee (2001) also measured nonverbal reasoning with a version of Raven's Coloured Progressive Matrices, they did not enter it into the regression analyses. As they did not measure instruction, this could not be entered. An analysis of our data without instruction and nonverbal reasoning as predictors supports this: it did indicate a significant contribution of central executive functioning.

As Deloche and Seron (1987) proposed, working memory functioning, specifically central executive functioning, contributed to performance on the transcoding tasks. Like counting, the tasks drew on knowledge of the number system but they also required the ability to translate between spoken and numeral representations. This may be why working memory made an even greater contribution to explaining performance differences.

Central executive functioning also contributed to explaining variation on relative magnitude comparison, the measure of understanding of place value and so did visuo-spatial functioning. The latter may reflect the task demands rather than its involvement in acquisition of understanding: to compare the numbers successfully the child must make accurate eye movements from one to the other. Baddeley (2003) suggests that such a task involves visuo-spatial sketchpad functioning.

Working memory characteristics accounted for some of the differences between children in their performance of number tasks. Much remains to be done to establish why. As mentioned above, it is unclear which component processes of working memory functioning are important. Second, future investigation will have to distinguish between the contributions working memory resources make to the acquisition of skills and those made to performance of tasks that assess them. Where working memory resources do affect learning, clarification is needed of the relation between working memory and forms of instruction. Finally, as in assessing the role of working memory in vocabulary acquisition (Jarrold et al., 2004), the possibility that differences in working memory functioning reflect differences in knowledge needs examination. Chi's (1978) comparison of digit and chess piece spans in children skilled in chess and less skilled adults provided a powerful illustration of the importance of domain relevant knowledge for assessments of working memory.

*Number Skills and Nonverbal Reasoning*

Performance on the Raven's Coloured Progressive Matrices (CPM) uniquely accounted for variation in accuracy on every task apart from knowledge of addition combinations. Although the findings are clear, whether they indicate the importance of nonverbal reasoning is not. Analyses of both child and adult versions of Matrices tests indicate that variation is attributable to perceptual processes in addition to reasoning (van der Ven & Ellis, 2000).

Variation attributed to the Matrices test may also reflect an aspect of working memory functioning not captured by the measures of working memory used. This might be executive functioning, which Bull & Scerif (2001) found to be related to mathematical ability independently of working memory span. Executive functioning is implicated in tasks that require inhibition of responses and switching between tasks or strategies. Both are required to succeed on the CPM where early items require selection of an identical design and later items require selection of a complementary design. If the observed relations between CPM and number skills reflect the relations between both and executive functioning then the contribution of CPM will diminish when measures of executive functioning are included.

*Number Skills and Language*

As Table 4 shows, the zero-order correlations between number tasks and language comprehension were consistently higher than those with working memory and nonverbal reasoning. In the multiple regressions, oral language comprehension made unique contributions to explaining variation on all tasks apart from knowledge of addition combinations and relative magnitude. This pattern is broadly consistent with the roles ascribed to language skills in number development but the findings for basic calculation were not anticipated. They may reflect the inclusion of the LC group. Analyses that excluded them indicated smaller contributions of oral language comprehension to explaining variation in basic calculation but a very similar contribution to counting and even greater contributions to story problems and transcoding.

Nevertheless, the absence of reading measures in the present study prevents confident attribution of these relationships to oral language skills. Oral language comprehension is related to written language comprehension. Hecht et al. (2001) found a composite measure of reading skills that included reading comprehension was associated with computational skill.

Differences between the SLI Mainstream and AC groups were found after allowing for language comprehension, working memory and instruction on counting, knowledge of addition combinations, story problems and transcoding. What underlies these is uncertain. It may be variation in unassessed oral or written language skills or other ways in which children with SLI differ from their peers, such as motor skills (Hill, 2001) or speed of processing (Miller et al., 2001). Although only knowledge of addition combinations required rapid response, it is clearly possible that motor difficulties can contribute to problems in learning to count and slower processing speed can affect learning generally.

Overall then, our results show that children with SLI are clearly at risk for difficulties with number. They also suggest that the factors responsible for these difficulties vary with the aspect of number development considered. To be more confident about these attributions requires more comprehensive studies and a greater understanding of the roles these factors play. Further research is also needed to clarify the overlap between SLI and groups of children identified as having reading and maths difficulties. Groups of children with reading difficulties are likely to include some children with SLI but would also have children with solely phonological processing difficulties. If children with comorbid reading and math difficulties are children with SLI rather than those with just phonological deficits, this would inform discussion of the importance of phonological skills for both reading and number (Hecht et al., 2001).

References

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin, 131*, 30-60.

Aram, D., & Nation, J. (1980). Pre-school language disorders and subsequent academic difficulties. *Journal of Communication Disorders, 13*, 159-198.

Askew, M. (1998). *Teaching primary mathematics: A guide for newly qualified and student teachers*. London: Hodder & Stoughton.

Baddeley, A. (1986). *Working memory*. Oxford: Clarendon.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417-423.

Baddeley, A. (2003). Working memory and language: an overview. *Journal of Communication Disorders, 36*, 189-208.

Baddeley, A., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*, 158-173.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47-90). New York: Academic Press.

Bishop, D. V. M. (1983). *Test for the Reception of Grammar*. Available from the author at the University of Oxford.

Bishop, D. V. M., & Adams, C. (1990). A prospective study of the relationship between specific language impairment, phonological disorders and reading retardation. *Journal of Child Psychology and Psychiatry, 31*, 1027-1050.

Bishop, D. V. M., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different? *Psychological Bulletin, 130*, 858-886.

Brainerd, C. J. (1983). Young children's mental arithmetic errors - a working-memory analysis. *Child Development, 54*, 812-830.

Broomfield, J., & Dodd, B. (2004). Children with speech and language disability: Caseload characteristics. *International Journal of Language & Communication Disorders, 39,* 303-324.

Brown, G. D. A., & Hulme, C. (1995). Modeling item length effects in memory span: No rehearsal needed. *Journal of Memory and Language*, *34*, 594-621.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*, 273-293.

Catts, H. W., Fey, M. E., Tomblin, J. B., & Zhang, X. (2002). A longitudinal investigation of reading outcomes in children with language impairments. *Journal of Speech, Language, and Hearing Research, 45*, 1142-1157.

Chi, M. T. H. (1978). Knowledge structures and memory development. In R. S. Siegler (Ed.), *Children's thinking: What develops?* (pp. 73-105). Hillsdale, NJ: Erlbaum.

Chinn, S. J., & Ashcroft, J. R. (1998). *Mathematics for dyslexics: A teaching handbook* (2nd ed.). London: Whurr.

Conti-Ramsden, G., Botting, N., Simkin, Z., & Knox, E. (2001). Follow-up of children attending infant language units: Outcomes at 11 years of age. *International Journal of Language & Communication Disorders, 36*, 207-219.

Cowan, N., Saults, J. S., & Elliott, E. M. (2002). The search for what is fundamental in the development of working memory. *Advances in Child Development and Behavior, 29,* 1-29.

Cowan, N., Towse, J. N., Hamilton, Z., Saults, J. S., Elliott, E. M., Lacey, J. F., et al. (2003). Children's working-memory processes: A response-timing analysis. *Journal of Experimental Psychology: General, 132*, 113-132.

Cowan, R. (2003). Does it all add up? Changes in children's knowledge of addition combinations, strategies, and principles. In A. J. Baroody & A. Dowker (Eds.), *The development of arithmetic concepts and skills* (pp. 35-74). Mahwah, NJ: Erlbaum.

Deloche, G., & Seron, X. (1987). Numerical transcoding: A general production model. In C. Janvier (Ed.), *Problems of representation in the teaching and learning of mathematics* (pp. 137-170). Hillsdale, NJ: Erlbaum.

Department for Education and Employment. (1999). *The National Numeracy Strategy. Framework for teaching mathematics from Reception to Year 6*. Cambridge, England: Cambridge University Press.

Donlan, C., Bishop, D. V. M., & Hitch, G. J. (1998). Magnitude comparisons by children with specific language impairments: evidence of unimpaired symbolic processing. *International Journal of Language and Communication Disorders, 33,* 149-160.

Donlan, C., & Gourlay, S. (1999). The importance of non-verbal skills in the acquisition of place-value knowledge: Evidence from normally-developing and language-impaired children. *British Journal of Developmental Psychology, 17*, 1-19.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128,* 309-331.

Fazio, B. B. (1994). The counting abilities of children with specific language impairment: A comparison of oral and gestural tasks. *Journal of Speech and Hearing Research, 37*, 358-368.

Fazio, B. B. (1996). Mathematical abilities of children with specific language impairment: A two-year follow-up. *Journal of Speech and Hearing Research, 39,* 839-849.

Fazio, B. B. (1999). Arithmetic calculation, short-term memory, and language performance in children with specific language impairment: A 5-year follow-up. *Journal of Speech, Language, and Hearing Research, 42*, 420-431.

Fuson, K. C. (1988). *Children's counting and concepts of number*. New York: Springer-Verlag.

Gathercole, S. E., & Baddeley, A. (1990). Phonological working memory deficits in language-disordered children: Is there a causal connection? *Journal of Memory and Language, 29*, 336-360.

Gathercole, S. E., & Baddeley, A. (1996). *The Children's Test of Nonword Repetition*. London: The Psychological Corporation.

Geary, D. C. (1990). A componential analysis of an early learning deficit in mathematics. *Journal of Experimental Child Psychology, 49,* 363-383.

Geary, D. C. (1993). Mathematical disabilities: Cognitive, neuropsychological and genetic components. *Psychological Bulletin, 114*, 345-362.

Geary, D. C. (1994). *Children's mathematical development: Research and practical applications*. Washington, DC: American Psychological Association.

Geary, D. C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities, 37*, 4-15.

Geary, D. C., & Brown, S. C. (1991). Cognitive addition: Strategy choice, and speed-of-processing differences in gifted, normal, and mathematically disabled children. *Developmental Psychology, 27*, 398-406.

Geary, D. C., & Burlingham-Dubree, M. (1989). External validation of the strategy choice model of addition. *Journal of Experimental Child Psychology, 47*, 175-192.

Geary, D. C., Hamson, C. O., & Hoard, M. K. (2000). Numerical and arithmetical cognition: A longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology, 77,* 236-263.

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto, M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology, 88*, 121-151.

Geary, D. C., Hoard, M. K., & Hamson, C. O. (1999). Numerical and arithmetical cognition: Patterns of functions and deficits in children at risk for a mathematical disability. *Journal of Experimental Child Psychology, 74*, 213-239.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, MA: Harvard University Press.

Grauberg, E. (1998). *Elementary mathematics and language difficulties: A book for teachers, therapists and parents*. London: Whurr.

Hanich, L. B., Jordan, N. C., Kaplan, D., & Dick, J. (2001). Performance across different areas of mathematical cognition in children with learning difficulties. *Journal of Educational Psychology, 93*, 615-626.

Healy, A. F., & Nairne, J. S. (1985). Short-term memory processes in counting. *Cognitive Psychology, 17*, 417-444.

Hecht, S. A., Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (2001). The relations between phonological processing abilities and emerging individual differences in mathematical computation skills: a longitudinal study from second to fifth grades. *Journal of Experimental Child Psychology, 79,* 192-227.

Hick, R., Botting, N., & Conti-Ramsden, G. (2005). Cognitive abilities in children with specific language impairment: consideration of visuo-spatial skills. *International Journal of Language & Communication Disorders, 40*, 137-149.

Hill, E. L. (2001). Non-specific nature of specific language impairment: a review of the literature with regard to concomitant motor impairments. *International Journal of Language & Communication Disorders, 36*, 149-171.

Hitch, G. J. (1978). The role of short-term working memory in mental arithmetic. *Cognitive Psychology, 10*, 302-323.

Hitch, G. J., & McAuley, E. (1991). Working memory in children with specific arithmetical learning difficulties. *British Journal of Psychology, 82*, 375-386.

Hutt, E. (1986). *Teaching language-disordered children: A structured curriculum*. London: Edward Arnold.

Jarrold, C., Baddeley, A. D., Hewes, A. K., Leeke, T. C., & Phillips, C. E. (2004). What links verbal short-term memory performance and vocabulary level? Evidence of changing relationships among individuals with learning disability. *Journal of Memory and Language, 50*, 134-148.

Jordan, N. C., & Hanich, L. B. (2000). Mathematical thinking in second-grade children with different forms of LD. *Journal of Learning Disabilities, 33*, 567-578.

Jordan, N. C., Hanich, L. B., & Kaplan, D. (2003a). Arithmetic fact mastery in young children: A longitudinal investigation. *Journal of Experimental Child Psychology, 85*, 103-119.

Jordan, N. C., Hanich, L. B., & Kaplan, D. (2003b). A longitudinal study of mathematical competencies in children with specific mathematics difficulties versus children with comorbid mathematics and reading difficulties. *Child Development, 74*, 834-850.

Jordan, N. C., Levine, S. C., & Huttenlocher, J. (1995). Calculation abilities in young children with different patterns of cognitive functioning. *Journal of Learning Disabilities, 28*, 53-64.

Jordan, N. C., & Montani, T. O. (1997). Cognitive arithmetic and problem-solving: A comparison of children with specific and general mathematics difficulties. *Journal of Learning Disabilities, 30*, 624-634.

Kamhi, A. G., & Catts, H. W. (1986). Toward an understanding of developmental language and reading disorders. *Journal of Speech and Hearing Disorders, 51*, 337-347.

Law, J., Boyle, J., Harris, F., Harkness, A., & Nye, C. (2000). Prevalence and natural history of primary speech and language delay: findings from a systematic review of the literature. *International Journal of Language & Communication Disorders, 35*, 165-188.

Lewis, C., Hitch, G. J., & Walker, P. (1994). The prevalence of specific arithmetic difficulties and specific reading difficulties in 9-year-old to 10-year-old boys and girls. *Journal of Child Psychology and Psychiatry, 35*, 283-292.

Lindsay, G., Soloff, N., Law, J., Band, S., Peacey, N., Gascoigne, M., et al. (2002). Speech and language therapy services to education in England and Wales. *International Journal of Language & Communication Disorders, 37*, 273-288.

Marchman, V. A., Wulfeck, B., & Weismer, S. E. (1999). Morphological productivity in children with normal language and SLI: A study of the English past tense. *Journal of Speech, Language, and Hearing Research, 42*, 206-219.

McLean, J. F., & Hitch, G. J. (1999). Working memory impairments in children with specific arithmetic learning difficulties. *Journal of Experimental Child Psychology, 74*, 240-260.

Miller, C. A., Kail, R., Leonard, L. B., & Tomblin, J. B. (2001). Speed of processing in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 44*, 416-433.

Nairne, J. S., & Healy, A. F. (1983). Counting backwards produces systematic errors. *Journal of Experimental Psychology: General, 112*, 37-40.

Nunes, T., & Bryant, P. (1996). *Children doing mathematics*. Oxford: Blackwell.

Ostad, S. A. (1997). Developmental differences in addition strategies: a comparison of mathematically disabled and mathematically normal children. *British Journal of Educational Psychology, 67*, 345-357.

Pickering, S. J., & Gathercole, S. E. (2001). *Working Memory Test Battery for Children (WMTB-C)*. London: The Psychological Corporation.

Raven, J., Raven, J. C., & Court, J. H. (1998). *Raven's progressive matrices: Coloured progressive matrices* (1998 ed.). Oxford: Oxford Psychologists Press.

Riley, M. S., & Greeno, J. G. (1988). Developmental analysis of understanding language about quantities and of solving problems. *Cognition and Instruction, 5*, 49-101.

Riley, M. S., Greeno, J. G., & Heller, J. I. (1983). Development of children's problem-solving ability in arithmetic. In H. P. Ginsburg (Ed.), *The development of mathematical thinking* (pp. 153- 196). New York: Academic Press.

Russell, R. L., & Ginsburg, H. P. (1984). Cognitive analysis of children's mathematical difficulties. *Cognition and Instruction, 1*, 217-244.

Siegler, R. S. (1988). Individual differences in strategy choices: Good students, not-so-good students, and perfectionists. *Child Development, 59*, 833-851.

Siegler, R. S. (1994). Adaptive and nonadaptive characteristics of low-income children's mathematical strategy use. In L. A. Penner, G. M. Batsche & D. L. Nelson (Eds.), *The* *challenge in mathematics and science education: psychology's response* (pp. 341-366). Washington, DC: American Psychological Association.

Siegler, R. S., & Jenkins, E. (1989). *How children discover new strategies*. Hillsdale, NJ: Erlbaum.

Siegler, R. S., & Robinson, M. (1982). The development of numerical understandings. *Advances in Child Development and Behavior, 16*, 241-312.

Skwarchuk, S., & Anglin, J. M. (2002). Children's acquisition of the English cardinal number words: A special case of vocabulary development. *Journal of Educational Psychology, 94*, 107-125.

Snow, R. E., Kyllonen, P. C., & Marshalek, B. (1984). The topography of ability and learning correlations. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 2, pp. 47-103). Hillsdale, NJ: Erlbaum.

Snowling, M., Adams, J. W., Bishop, D. V. M., & Stothard, S. E. (2001). Educational attainments of school leavers with a preschool history of speech-language impairments. *International Journal of Language & Communication Disorders, 36*, 173-183.

Sowder, J. T. (1992). Making sense of numbers in school mathematics. In G. Leinhardt, R. Putnam, & R. A. Hattrup (Eds.), *Analysis of arithmetic for mathematics teaching* (pp. 1-51). Hillsdale, NJ: Erlbaum.

Spearman, C., & Jones, L. W. (1950). *Human ability*. London: Macmillan.

Swanson, H. L., & Sachse-Lee, C. (2001). Mathematical problem solving and working memory in children with learning disabilities: Both executive and phonological processes are important. *Journal of Experimental Child Psychology, 79*, 294-321.

Thornton, C. A. (1990). *Basic number facts: strategies for teaching and learning. Book I: Addition and subtraction. An activity based program.* (Vol. 1). Columbus, OH: ERIC Clearinghouse for Science Mathematics and Environmental Education.

van der Ven, A. H. G. S., & Ellis, J. L. (2000). A Rasch analysis of Raven's standard progressive matrices. *Personality and Individual Differences*, *29*, 45-64.

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Table 1

*Number Tasks with Examples of First Grade and Third Grade Versions*

| Task | First grade | Third grade |
|---|---|---|
| Counting | 1 to 41 | 194 -210 |
| Addition combinations | 4 + 4 | 7 + 6 |
| Basic calculation | | |
| Addition | Five plus seven | |
| Subtraction | Eight minus six | |
| Story problems | | |
| Addition | Mary had 3 crayons. She got 5 more. How many does she have now? | Ann had some pencils. She lost 6. She now has 3. How many did she have to start with? |
| Subtraction | Mark had 7 shirts. He lost 5. How many does he have now? | Susan had some badges. She got 6 more. She now has 9. How many did she have to start with? |
| Transcoding | | |
| Reading | 17 | 3051 |
| Writing | Fifteen | Six thousand and forty-two |
| Matching | Sixteen to 19, 61, 16, or 60 | Five thousand and four to 4005, 5040, 5004, or 50004 |
| Relative magnitude | Which is more, 24 or 31? | Which is more, 4123 or 4213? |

Table 2

*Descriptive Statistics for the Groups on Nonverbal Reasoning (Raven), Language, Working Memory, and Instruction.*

| Measure | LC[1] | | SLI Special[2] | | SLI Mainstream[3] | | AC[4] | |
|---|---|---|---|---|---|---|---|---|
| | *M* | *(SD)* | *M* | *(SD)* | *M* | *(SD)* | *M* | *(SD)* |
| Age (in years) | $6.0_a$ | (0.4) | $8.2_b$ | (0.3) | $8.2_b$ | (0.5) | $8.2_b$ | (0.3) |
| Raven (Standard) | $106.6_a$ | (10.9) | $102.3_a$ | (9.1) | $103.2_a$ | (12.3) | $105.0_a$ | (11.6) |
| Raven (Raw score) | $18.4_a$ | (4.0) | $23.6_b$ | (2.9) | $24.3_b$ | (4.8) | $25.0_b$ | (4.5) |
| Language | | | | | | | | |
| TROG (Standard) | $94.5_a$ | (7.2) | $80.4_b$ | (4.9) | $80.9_b$ | (6.5) | $101.0_c$ | (11.6) |
| TROG (Raw score) | $11.7_a$ | (1.7) | $11.1_a$ | (1.4) | $11.6_a$ | (1.7) | $16.0_b$ | (1.8) |
| PTP | $10.7_a$ | (2.8) | $4.5_b$ | (3.8) | $5.8_b$ | (3.9) | $15.9_c$ | (2.6) |
| Working memory | | | | | | | | |
| CNRep | $22.5_a$ | (5.8) | $11.8_b$ | (5.5) | $11.7_b$ | (5.7) | $27.2_c$ | (4.6) |
| Forward span | $4.1_a$ | (0.6) | $3.6_b$ | (0.5) | $3.7_b$ | (0.8) | $4.7_c$ | (0.9) |
| Corsi span | $3.3_a$ | (0.7) | $3.6_{ab}$ | (0.7) | $3.6_a$ | (1.0) | $4.0_b$ | (0.6) |
| Backward span | $2.2_a$ | (0.6) | $2.2_a$ | (0.4) | $2.2_a$ | (0.7) | $3.0_b$ | (0.7) |
| Instruction | $4.1_a$ | (2.0) | $3.8_a$ | (1.8) | $7.8_b$ | (3.1) | $11.1_c$ | (2.3) |

*Note.* [1] *n* = 55 (8 girls, 47 boys); [2] *n* = 11 (2 girls, 9 boys); [3] *n* = 44 (6 girls, 38 boys); [4] *n* = 57 (8 girls, 49 boys). Means in the same row that do not share a subscript differ significantly at $p < .05$ (R-E-G-W-Q comparisons)

Table 3

*Number Task Performance by Group*

| Measure | Maximum possible | LC | SLI Special | SLI Mainstream | AC |
|---|---|---|---|---|---|
| Counting | 5 | $1.75_{a}$ (1.09) | $1.55_{a}$ (1.29) | $1.84_{a}$ (1.43) | $4.07_{b}$ (1.00) |
| Addition combinations | 14 | $3.51_{a}$ (2.02) | $4.18_{ab}$ (2.18) | $5.23_{b}$ (2.45) | $8.11_{c}$ (2.16) |
| Basic calculation I | 8 | $4.40_{a}$ (2.64) | $4.36_{a}$ (3.01) | $5.55_{b}$ (2.02) | $7.12_{c}$ (1.59) |
| Basic calculation II | 8 | $2.80_{a}$ (2.63) | $1.91_{a}$ (2.30) | $3.93_{a}$ (2.56) | $6.40_{b}$ (2.02) |
| Story problems | 16 | $3.13_{a}$ (2.40) | $2.27_{a}$ (2.41) | $4.39_{a}$ (3.48) | $10.65_{b}$ (4.51) |
| Transcoding | 28 | $8.78_{a}$ (3.42) | $8.73_{a}$ (2.69) | $12.20_{b}$ (5.69) | $20.75_{c}$ (4.72) |
| Relative magnitude | 6 | $1.91_{a}$ (1.67) | $3.09_{b}$ (1.70) | $3.05_{b}$ (1.82) | $4.63_{c}$ (1.23) |

*Note.* For all groups, numbers entered are means with standard deviations in parentheses. Means in the same row that do not share a subscript differ significantly at $p < .05$ (R-E-G-W-Q comparisons)

Table 4

*Correlations between Measures*

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Nonverbal reasoning | - | .44 | .21 | .42 | .36 | .46 | .46 | .44 | .52 | .49 | .51 | .56 | .50 |
| 2. Language comprehension | | - | .56 | .35 | .52 | .56 | .70 | .56 | .53 | .64 | .73 | .75 | .52 |
| 3. Forward span | | | - | .18 | .46 | .28 | .51 | .38 | .38 | .43 | .51 | .44 | .28 |
| 4. Corsi span | | | | - | .28 | .32 | .32 | .43 | .35 | .34 | .46 | .42 | .44 |
| 5. Backward span | | | | | - | .45 | .56 | .46 | .45 | .52 | .51 | .62 | .49 |
| 6. Instruction | | | | | | - | .60 | .53 | .40 | .46 | .59 | .70 | .53 |
| 7. Counting | | | | | | | - | .66 | .60 | .68 | .73 | .80 | .62 |
| 8. Addition combinations | | | | | | | | - | .60 | .62 | .72 | .71 | .67 |
| 9. Basic calculation I | | | | | | | | | - | .78 | .66 | .60 | .56 |
| 10. Basic calculation II | | | | | | | | | | - | .73 | .69 | .62 |
| 11. Story problems | | | | | | | | | | | - | .81 | .59 |
| 12. Transcoding | | | | | | | | | | | | - | .74 |
| 13. Relative magnitude | | | | | | | | | | | | | - |

*Note.* $N = 167$. Nonverbal reasoning is raw score on Raven's. Basic calculation I comprises addition and subtraction problems with sums and minuends less than 10. Basic calculation II consists of addition and subtraction problems with sums and minuends above 10 and less than 20. For coefficients greater than .20, $p < .01$; for coefficients greater than .26, $p < .001$.

Table 5

*Summary of Simultaneous Multiple Regression Analyses*

| | Counting | | Addition combinations | | Basic calculation I | | Basic calculation II | | Story problems | | Transcoding | | Relative magnitude | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *β* | *sr*² | *β* | *sr*² | *β* | *sr*² | *β* | *sr*² | *β* | *sr*² | *β* | *sr*² | *β* | *sr*² |
| Nonverbal reasoning | .18** | .02 | .07 | | .29*** | .04 | .20** | .02 | .16* | .01 | .17** | .02 | .16* | .01 |
| Language comprehension | .23** | .02 | .03 | | .23* | .02 | .35*** | .04 | .28*** | .02 | .27*** | .02 | .12 | |
| Forward span | .12 | | .10 | | .10 | | .08 | | .13* | .01 | -.01 | | -.03 | |
| Corsi span | -.01 | | .17** | .02 | .08 | | .05 | | .16** | .02 | .05 | | .18** | .02 |
| Backward span | .14* | .01 | .11 | | .16* | .02 | .21** | .03 | .05 | | .21*** | .03 | .20** | .03 |
| Instruction | .21** | .02 | -.01 | | -.05 | | -.07 | | .11 | | .21** | .02 | .13 | |
| AC v SLI (M) | .25** | .02 | .28* | .02 | -.04 | | -.01 | | .19* | .01 | .17* | .01 | .10 | |
| LC v SLI (M) | .14 | | -.24** | .02 | -.10 | | -.12 | | .01 | | -.04 | | -.10 | |
| SLI (S) v SLI (M) | .03 | | -.09 | | -.11 | | -.17* | .02 | -.06 | | -.05 | | .05 | |

*Note.* N = 167. SLI (M) is SLI Mainstream School. SLI (S) is SLI Special School. $R^2$ = .63 for Counting, .51 for Addition combinations, .43 for Basic calculation I, .52 for Basic calculation II, .66 for Story problems, .75 for Transcoding, and .48 for Relative magnitude.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 6

*Strategy Use and Error Rates on Basic Calculation*

| | Problem set | | | |
|---|---|---|---|---|
| | I | | II | |
| Measure | SLI | AC | SLI | AC |
| | Mainstream | | Mainstream | |
| Backup use | 53[a] (37) | 28[b] (35) | 64[a] (40) | 41[b] (40) |
| Backup error | 24[c] (25) | 17[d] (35) | 51[a] (29) | 16[b] (22) |
| Retrieval error | 33[e] (38) | 07[b] (18) | 50[f] (39) | 22[g] (29) |

*Note.* For all measures, numbers entered are mean percentages with standard deviations in parentheses. [a] $n = 37$; [b] $n = 54$; [c] $n = 31$; [d] $n = 27$; [e] $n = 29$; [f] $n = 22$; [g] $n = 43$.