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Children with a Specific Language Impairment Respond Differently than Controls to Increasing the Demands of the Multi-digit Magnitude Comparison Task: Implications for Underlying Processing Methods

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Abstract

Previous studies have found that although children with specific language impairments (SLI) perform at the level of typically-developing peers when reaction times are examined in the multi-digit magnitude comparison task (non-verbal test of conceptual place-value knowledge) they perform below the control group when accuracy scores are compared. This study aims to examine accuracy responses in more detail. Analysis was carried out on accuracy data previously collected by Cowan et al. (2005) from children with SLI, a control group matched for chronological age and a younger control group matched for language ability. The demands of the task were varied by increasing the number length from 2-5 digits and reducing the transparency of the number pairs by including reversed digits (e.g. 24 vs. 42) or conflicting information due to the smaller number containing the largest digit (e.g. 77 vs. 69). It was found that groups responded significantly differently to variations in task demand, suggesting the processing strategies used may vary in type or efficiency. In particular, in response to transparent stimuli that differed by only one digit, increasing stimulus length had more affect on the accuracy scores of the language-control group than the SLI group and had no impact on the age-control group. It was also found that the SLI group performed above the level of language-controls and below that of age-controls when the stimuli were transparent or contained conflicting information, but at the level of the language-control group for stimuli that contained digits that had been reversed. This may suggest that although children with SLI have conceptual understanding in advance of their language ability, elements of their language impairment may be impacting on the use of place-value knowledge in certain circumstances.

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Introduction

Investigating how information is processed in the presence of impairments can uncover much about the typical development of processing systems. This study investigates numerical processing in children with specific language impairments (SLI) to further examine the influence language may have on the development of mathematical skills.

There are conflicting opinions as to whether verbal skills are required to develop numerical abilities. Bialystok (1992) proposed that understanding single-digit Hindu-Arabic notation is functionally dependent on prior acquisition of the verbal number sequence and this is supported by Carey (2004) who also proposes that language has a causal 'bootstrapping' role in the acquisition of number concepts. Wynn's study in preschoolers (1990) appeared to support this view as she claimed subjects could perform accurate counts of objects and events before they had developed the conceptual understanding of numerosity.

However, another study by Wynn (1992) claimed that babies of five months, who are not yet at the verbal counting stage, appeared to have numerical understanding preceding their language development as they were shown to look longest in test conditions that went against the rules of addition and subtraction in a habituation paradigm. This contrasting viewpoint is supported by researchers such Gallistel and Gelman (1992) and Gelman and Butterworth (2005) who claim that although language skills can facilitate the use of numerical concepts they are not required to underpin the development of these concepts (see Gelman & Butterworth 2005 for a review of the evidence proposed by Carey 2004).

Evidence surrounding this issue has been gathered from various sources, including neurological and neuroanatomical studies in adults with or without an acquired deficit in mathematical or language skills and from a developmental perspective by examining children with specific learning difficulties.

Neurological and Neuroanatomical Evidence

Although it can be argued that specialised areas of the brain in adults may not reflect the independence of the development of language and numerical processing, an insight into their relative associations can be viewed through patterns of impairments observed in neurology patients.

Dissociations between language and numeracy have been observed in various conditions. Patients with Pick's Disease, a degenerative condition resulting in dementia, have severely impaired language ability while arithmetical skill remains efficient (Rossor et al. 1995). This pattern was also seen in a patient with semantic dementia (Cappelletti et al. 2001) who was able to read and write number words but no other word types (Butterworth et al. 2001). Conversely, stroke patients have been described with unimpaired language ability but very densely impaired numerical ability (acalculia/dyscalculia) (e.g. Cipolotti et al. 1991).

It also appears that numerical knowledge based on non-verbal processing can be dissociated from numerical processing more reliant on language as Dehaene and Cohen (1999) found that patients with reading difficulties (dyslexia) could not retrieve stored arithmetic facts but could do subtraction problems by accessing and manipulating quantities semantically, whereas patients with semantic acalculia showed the opposite pattern. These processing areas also appear to be located in distinct anatomical regions as Dehaene and Cohen (1997) observed a pattern of deficits in two acalculic patients that suggested the left subcortical network contributes to the storage and retrieval of rote arithmetic facts and the bilateral inferior parietal network is dedicated to the mental manipulation of numerical quantities. Dehaene and Cohen (1999) confirmed this anatomical difference using fMRI scanning to show that approximate numerical judgements activated the bilateral parietofrontocingular network, showing little or no dependence on language, while more complex and exact calculations, thought to be more dependent on language, were associated with the left inferior-frontal region. PET studies have also found that during numerical tasks, especially retrieval of simple arithmetic facts, areas of the brain classically associated with language processing remain inactive, suggesting numerical processing can occur without relying on verbal processes (Presenti et al. 2000). Adults who have developed normally can only tell us so much about the developmental processes, whereas examining the abilities of children with specific impairments can provide a different insight into the developmental association between language and numeracy.

Evidence from Children with Specific Learning Difficulties

Dyslexia and developmental dyscalculia (the most generally agreed features being difficulties in learning and remembering arithmetic facts and executing calculation procedures (Geary 1993)) can often co-occur, posing the suggestion that language and numerical development are inter-dependent. However, although mathematical difficulties occur in 40% of children with dyslexia they do not occur in all cases (Lewis et al. 1994). To investigate this further, Landerl et al. (2004) examined performance in a range of basic number tasks in 8-9 year-old children with dyslexia only, dyscalculia only, or both. They found children whose difficulties included dyscalculia had impaired performance in numerical tasks, whereas those with only a reading impairment did not, unless the task involved articulation. They concluded that dyscalculia is a specific disability in numerical processing and that reading impairments do not necessarily affect non-verbal numerical tasks, although they can contribute to poor performance on tasks with a phonological component. In contrast, Jordan et al. (2003) found children with dyslexia-only performed below typically-developing children on understanding of place-value, solving numerical story problems and written computation tasks, and those children with both reading and arithmetic impairments performed worst of all. They concluded that language deficits may inhibit problem-solving, including the conceptual understanding required in numerical tasks. Landerl et al. suggested the differences found in the two studies may be attributed to the less stringent inclusion criteria used for the experimental groups in the Jordan et al. study, which could have resulted in the inclusion of children in the dyslexia-only group who had mathematical difficulties for a wide variety of reasons.

Other studies have provided evidence for dissociation between verbal and non-verbal numerical skills in children with specific learning difficulties. These have often included tasks testing understanding of place-value, knowledge of which requires the conceptual understanding that the place a digit occurs in a number denotes the numerical value, e.g. units or decades (Becker & Varelas 1993). This can be tested using the magnitude comparison task where the largest number out of two must be judged. Sokol and Macaruso (1994) describe a child with difficulties in production of Hindu-Arabic numerals but no difficulty with spoken numerals, although comprehension of both were intact, and another individual who produced place-value errors when transcoding Hindu-Arabic numerals from spoken or written input, providing evidence that representations of place-value knowledge in Hindu-Arabic notation and the verbal realisation of numbers may be separate. Donlan and Gourlay (1999) supported this finding as they described a child with SLI who could perform the magnitude judgement task but could not transcode spoken to written Hindu-Arabic numerals, demonstrating spoken number knowledge is not necessary for the non-verbal numerical process, while two children with SLI could transcode spoken to Hindu-Arabic numerals but could not make the comparison judgement, demonstrating that spoken number knowledge is not sufficient to support knowledge of place-value. Such investigations into the numerical ability of children with SLI provide a valuable insight into the involvement of language in the development of numeracy skills as they have fundamental impairments in language.

Evidence from Studies in Children with SLI

A specific language impairment (SLI) is characterised by a severe impairment of expressive and/or receptive language with no obvious cause (e.g. hearing impairment) and where other aspects of non-verbal development are apparently intact (Bishop 1997). The language impairments seen in children with SLI are diverse and the underlying causes can be varied but it commonly involves: problems with speech that are not due to anatomical abnormalities; expressive language difficulties associated with lexical and grammatical development; and varying degrees of comprehension deficits (Haynes & Naidoo 1992, from Donlan & Gourlay 1999). It is important to consider what other impairments children with SLI may have as there has been some debate as to whether their difficulties are specific to language skills.

It has been shown that children with SLI can have impairments in several aspects of information processing such as phonological memory (Gathercole & Baddeley 1990), working memory capacity (e.g. Fazio 1998) and automatic retrieval of items from long-term memory (Lahey & Bloom 1994). Indeed, some researchers have suggested that the impairments seen in SLI can be attributed to a general processing impairment. Johnston and Smith (1989) found that children with difficulties predominantly in expressive language performed a task appropriately when verbal instructions were used but fell below the level of typically-developing children with non-verbal instruction, prompting Johnston to propose a general 'thought impairment' was present that included non-verbal cognition (Johnston 1994). Another study also proposed a general processing impairment based on examining language-learning mechanisms in children with SLI by presenting a novel linguistic rule using auditory modality (Connell & Stone 1992) or embodiment of a novel morpheme in a visual symbol system (Stone & Connell 1993). They found that when rule usage was merely observed, children with SLI appeared to learn the rule less easily in both modalities than controls but achieved comparable levels when imitation was used, and concluded a general deficit in processing symbolic information may be present.

However, although it has certainly been found that children with SLI have a poorer long-term outcome for mathematical achievement (Fazio 1999), further studies in children with SLI have provided evidence that rather than the presence of a general deficit, more specific areas of processing are affected and that certain fundamental numerical skills appear to develop well independently of language processing.

In a study of pre-school children with SLI (3-5 years), Siegel et al. (1981) found they had no difficulty with simple numerical concepts such as 'larger' or 'more' but had significant difficulty with more complex numerical concepts such as one-to-one correspondence that involve sequential processing. Donlan (1993, from Donlan 2003) repeated Siegel's study but used equivalence tasks using small or large sets of objects and found that impaired language skills did not prevent development of numeracy skills, as children with SLI (age 6-years) performed better than language-controls (children of lower age but equivalent language skills) on the small set task, suggesting non-verbal strategies were used that were in advance of language level. However, in the large set task, requiring counting and retrieval of linguistically stored facts, language level was found to influence performance. Arvedson (2002) also found that although pre-school children with SLI performed above those matched for grammatical ability when numerical tasks were less reliant on language, their scores significantly decreased when they were prompted to use verbal counting to facilitate problem-solving whereas those of age-controls (typically-developing children of the same age) and the grammar-control group increased. This suggests numerical processing in children with SLI was hindered rather than aided by use of language skills. These studies suggest conceptual numerical knowledge[1] involving non-verbal processes can be well-developed even when language skills are impaired but that deficits can occur in numerical procedural knowledge[2] which is more reliant on language (Donlan 1993).

Donlan and colleagues (Donlan et al. 1998; Donlan & Gourlay 1999) further investigated conceptual number skills in children with SLI by measuring reaction times (RT) in the magnitude comparison task. Children with SLI performed single-digit comparisons faster than language-controls (Donlan et al. 1998) and performed at the same level as age-controls in double-digit judgements (Donlan & Gourlay 1999). This confirmed that children with SLI had developed non-verbal conceptual skills ahead of their language ability. They also used repetition of irrelevant sounds (concurrent articulation) to examine any underlying contribution of verbalisation but found this had no effect on performance. Interestingly, in a later study examining accuracy in the multi-digit magnitude comparison task, Donlan et al. (2006) found the SLI group now performed below the level of age-controls (although still above language-controls) but that performance on verbal

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[1] Conceptual knowledge is the implicit or explicit understanding of the principle that governs a domain. This knowledge is flexible and not tied to specific domain types and is therefore able to be generalised (Rittle-Johnson et al. 2001). Conceptual knowledge is accessed in tasks where children rely on their knowledge of relevant concepts to generate methods of problem-solving, e.g. the number magnitude task requires access of place-value knowledge.

[2] Procedural knowledge refers to the ability to execute action sequences to solve problems. This type of knowledge is tied to specific problem types and is therefore not widely generalizable, e.g. standard arithmetic computations where children are likely to use previously learned step-by-step solution methods (Rittle-Johnson et al. 2001).

counting scores could account for the group difference, although this is not necessarily a causal relationship. Koponen et al. (2006) looked further at the effects of verbal skills on numeracy development by subdividing children with SLI based on their verbal and non-verbal number skills to determine whether the children who had reached a certain competency in number skills had differing linguistic skills to those that had poorer numeracy skills. They found language comprehension did not seem to affect numerical skill and concluded numerical ability in children with SLI children was not based on language ability.

A long-term study by Fazio (1994; 1996; 1999), who followed children from age 4-9 years, had also shown that conceptual knowledge in children with SLI could be intact but confirmed that the difficulties with procedural knowledge present in pre-school children persisted in older children. This was exhibited by the children with SLI using less mature procedural strategies than typically-developing children. For example, two years after her initial study the children with SLI performed below age-controls in simple arithmetic tasks due to the fact they employed the counting-all strategy rather than the more advanced counting-on strategy. A further three years on (Fazio 1999) the children with SLI were still relying on less efficient counting strategies rather than those based on the retrieval of linguistically stored facts, as when extra time was given for written numerical tasks the performance of children with SLI increased, whereas no improvement occurred with age-controls. Later studies from Donlan and colleagues (Cowan et al. 2005; Donlan et al. 2006) confirmed the presence of procedural deficits as their SLI groups performed below the level of age-controls on tasks such as basic calculation and counting word sequence.

Although procedural deficits have been shown to impact on basic calculation skills, an important adaptation to examining understanding of arithmetic principles was performed by Donlan et al. (2006) who used calculation tasks that contained only unfamiliar novel symbols (Martian Maths), i.e. independent of knowledge of specific numerical values. Children with SLI now performed at the same level as age-controls in calculation tasks, establishing that children with language impairments can grasp the logical principles underlying simple arithmetic as well as their peers despite deficits in procedural knowledge. This further supports evidence that the development of numeracy skills can be dissociable from language development, especially as performance in this task was found to be unrelated to count aloud scores.

These studies in children with SLI support proposals that a system of non-verbal mental representation underlies the development of numeracy; that children with SLI have conceptual knowledge of numerical representations ahead of their language skills; and that verbal processing is not centrally involved in the numerical judgement task, although verbal counting skills appear to be correlated in some way (Donlan et al. 2006). However, the restrictions placed on numerical processing by procedural deficits appear to accumulate in time and affect the acquisition and use of more advanced concepts (Fazio 1999).

The Magnitude Comparison Task

Many of these studies have used the magnitude comparison task to test conceptual understanding of place-value, and the current study also exploits the benefits of this task. It is particularly useful in examining the relationship between language and numerical development as it requires no explicit verbalisation while requiring access to the meaning of digits (Donlan et al. 1998). It has also been shown to be a predictor of variations in arithmetic skill (Durand et al. 2005). Importantly, the magnitude comparison task can also to provide a window into the possible cognitive processing systems involved in numeracy and, therefore, we can consider what processing strategies may be used in children with and without SLI.

Processing Models of Numerical Comparison.

Moyer and Landauer (1967) used a single-digit magnitude comparison task in adults and demonstrated that the time taken to make the judgement was inversely proportional to the difference between the two numbers. This was termed the Symbolic Distance Effect and replicated observations seen in comparisons made along physical continua, such as line length. Moyer and Landauer (1967) concluded that the displayed numerals are converted to analogue magnitudes and a comparison is then made between them. If numbers are encoded onto an analogue 'mental number line' the less distance between them the less obvious the difference is and so the time needed to make the judgement is increased. Sekuler and Mierkiewicz (1977) replicated this finding in children of various ages. The question then became, what happens when numbers are greater than a single digit? In a double-digit comparison, are the digits encoded together before the comparison is made (holistic model) or are the corresponding individual digits from each number compared separately (lexicographic model) either in a sequential manner or simultaneously in parallel?

Dehaene et al. (1990) argued in favour of a holistic processing model. In their adult study they examined RTs in a double-digit comparison task using a constant 'standard' number to which the other number was compared. They found RT decreased with overall distance between the numbers and was influenced by the magnitude of the unit distance even when comparison of the units was unnecessary because the decade values differed. They argue if the numbers were being processed lexicographically in sequence the unit values should not exert an affect on RT if the decades are different and judged first. Therefore, they concluded the magnitudes of decades and units are encoded holistically and the integrated numbers are then compared on an analogue number line. This does not seem to take into account parallel lexicographic processing but they did note that their results could fit with a variant of the lexicographic model proposed by Hinrichs et al. (1981) who suggested the influence of unit values could be accounted for within a lexicographic model if an interference effect occurred due to the presence of incompatible number pairs (those where the larger unit is present in the overall smaller number, e.g. 42 vs. 37). Dehaene examined this by presenting the decades or the units asynchronously, the idea being that an interference effect would only occur if the unit comparison took place first and if the decade digit was presented prior to this the effect of the unit difference would not match their earlier result. They found asynchronous presentation did not affect their results and so concluded that the unit effect was due to the holistic manner of processing (although presenting digits separately may have altered the processing by introducing a sequential element or numbers may have been integrated, held in memory and compared separately).

However, other studies have presented evidence that number comparisons may not be processed in an entirely holistic manner. Nuerk and colleagues (Nuerk et al. 2001; Nuerk et al. 2005a) also examined the effect of using compatible and incompatible number pairs in a double-digit comparison task in adults. They predicted that if decades and units do not play a separate role in the magnitude representation, as in holistic processing, then compatibility should not have an influence when the overall distance between number pairs is controlled. They consistently found a compatibility effect, where incompatible number pairs required more processing time and concluded this was not consistent with a processing model that is entirely holistic. However, they considered a major component of processing to be holistic as when they manipulated absolute distance and performed a multiple-regression analysis it was found that overall distance was the strongest predictor of RT. Therefore, they proposed a hybrid model in which the integrated magnitude and the magnitude representations of the separate decades and units are all separately represented, i.e. that there are separate bins for the magnitude representations of decades and units within or in addition to the mental number line (Nuerk et al. 2001).

Donlan and Gourlay (1999) also manipulated the types of number pairs used in a double-digit comparison task performed by children with SLI and control groups. Three types of stimuli were used varying in 'transparency': transparent number pairs that differed by one digit (e.g. 50 vs. 60), reversible/transposable number pairs (e.g. 56 vs. 65) or incompatible number pairs (e.g. 53 vs. 39). In a similar way to Nuerk's later study, they predicted that if processing were simply holistic the RT would increase the smaller the overall distance between number pairs, regardless of what type of stimuli were used. They also found an effect of both overall distance and transparency in all subject groups with RT increasing with decreasing transparency, and concluded a more complex process occurs within a holistic processing model whereby encoding and comparison must be more carefully examined when stimuli are reduced in transparency and conflicting information is present (Donlan & Gourlay 1999). Their study also argued against lexicographic processing of double-digit comparisons as the pattern of results was not consistent with a judgement being made only on the difference between the first digits in each pair. These two studies suggest that although comparisons appear to be based on a holistic magnitude representation, encoding becomes more complex and inefficient in both children and adults when conflicting information is present.

The type of processing may be different again once numbers increase above two digits. Indeed, there appears to be a general agreement that for multi-digit numbers above two, which are less immediately familiar and large enough to challenge holistic processing, a sequential lexicographic processing method is used. Poltrock and Schwartz (1984) investigated RT in a magnitude comparison task containing either four or six digit numbers. They predicted that if processing was sequential, RT would increase linearly with how many comparisons were needed before reaching a pair of numbers that differed, and would not depend on the number of locations at which the integers are different; and this was the pattern they observed. They also presented evidence against holistic processing being used in larger number comparisons. They predicted if holistic processing were used and the numbers in the four and six-digit comparisons differed by the same amount the comparison time should be the same, whereas it took significantly longer to encode the six-digit comparison. They also found that when the numbers varied in the leftmost position the difference in encoding time between the four and six digit comparisons was much reduced, suggesting a sequential approach.

Therefore, fast holistic encoding of magnitude may be restricted to small numbers with which the individual is familiar with (Dehaene et al 1990) and that lexicographic/sequential processing is required for larger numbers with less familiarity or perhaps double-digit numbers in young children who have not yet been exposed to them.

Aim of the Current Study

The current study further analyses data collected during a multi-digit magnitude comparison task by Cowan et al. (2005). Although Donlan and Gourlay (1999) found children with SLI performed at the level of typically-developing peers when RTs were measured, when Donlan and colleagues later examined accuracy scores in a larger study they found that the SLI performed below their peers (although still above the language-control group) in the comparison task (Cowan et al. 2005; Donlan et al. 2006). This study examines the accuracy responses in more detail by analysing responses to multi-digit magnitude comparison stimuli that not only vary in transparency but also in stimulus length. From this it can be determined whether the responses of the SLI group differ with the increasing demands of the task in the same manner as the control groups. It may then be possible to infer whether the SLI group are using the same processing systems in this non-verbal numerical task as the typically-developing children. From the results of increasing the demands of the comparison task we can consider how language impairments, and therefore the influence of language processing, impact on the conceptual understanding of place-value knowledge.

Method

The raw data used in this project was collected in a previous study (Cowan et al. 2005), the details of which are given below. The design and analysis of the data was conducted independently and was the first analysis performed to examine the accuracy as a function of stimulus type in conjunction with increasing stimulus length.

Participants

Participants consisted of 167 children drawn from 27 state schools in England and Wales which serve socially mixed catchment areas. The SLI group was matched with two control groups, one matched for age and one for language ability, containing children with no known history of speech or language difficulties.

The final SLI group was comprised of 55 children (8 girls, 47 boys) selected from a population who had received a diagnosis of SLI, which was confirmed using language assessments. Of these, 44 children attended language units in mainstream schools (mean age 8.2years, SD 0.5years) and 11 attended special schools for children with language disorders (mean age 8.2years, SD 0.3years).

The final age-control group (AC) was comprised of 57 children (8 girls, 49 boys) selected to match the SLI group for chronological age (mean age 8.2years, SD 0.3years), gender and nonverbal ability and attended either the same school as the SLI children or one nearby with a similar catchment area.

The final younger language-control (LC) group (mean age 6.0years, SD 0.4years) comprised of 55 children (8 girls, 47 boys) selected to match the SLI group in language ability (measured using the TROG: Test for Reception of Grammar, Bishop, 1983), gender and nonverbal ability and all attended mainstream schools.

Assessments

Language: All initial populations of the three subject groups were assessed for ability in language comprehension, non-word repetition and past tense production. Language comprehension was assessed using the Test for Reception of Grammar

(TROG; Bishop, 1983), a test used in identifying SLI. The TROG contains 20 blocks of four items, where an utterance must be matched to one picture out of four. The test is discontinued if a child fails one or more items in five consecutive blocks. Non-word repetition is a test of working memory in language and was assessed using the Children's Test of Non-word Repetition (CNRep; Gathercole & Baddley, 1996), a standardised assessment of phonological memory particularly sensitive to language impairment. The CNRep consists of 40 items and was administered using the tape of non-words provided. Past tense production (PTP) was assessed using a task derived from Marchman, Wulfeck and Weismer (1999). The test consisted of 10 regular and 10 irregular verbs and PTP was elicited by showing pictures of each verb accompanied by present tense utterances using third person singular nouns and pronouns.

From the initial populations, two children were excluded from the SLI group for scoring exceptionally highly on one or more languages assessments and four children were excluded from the AC and LC groups due to exceptionally low scores.

Non-verbal ability: All initial populations of the three subject groups were assessed for non-verbal ability using Raven's Coloured Progressive Matrices (CPM; Raven et. al. 1998). The CPM is the children's subset of Raven's Progressive Matrices designed to assess the ability to task-solve by thinking logically, e.g. detect and select the missing section of picture design out of six options. This eductive ability is one out of two components of general intelligence (g-factor). There are 36 items presented in 3 sets of 12. The test is considered non-verbal because the child does not need to speak or understand speech to understand what is required and to indicate their response.

A normal level of non-verbal ability was a requirement for inclusion in the final SLI group, as defined by a standard score of 85 or more on the CPM. This score represents no less than one standard deviation below the mean for their chronological age. The AC and LC groups were selected for non-verbal ability using the same criterion.

Procedure

Multi-digit magnitude comparison task: The magnitude comparison task assessed understanding of place value by requiring children to pick the larger of two multi-digit numbers. Items were presented on a laptop computer and children selected the number they considered larger by pressing a key underneath the number. The order of presentation of the stimuli was newly randomised for each participant. The task consisted of two practice trials and 46 test trials varying in stimulus length (2 digits: 16 trials; 3 digits: 15 trials; 4-5 digits: 15 trials). The type of stimulus was also varied in transparency. In transparent pairs, the two numbers differed only by a single digit (Type 1: 24 trials). Less transparent pairs consisted either of numbers that contained the same digits presented in a different order, e.g. 36 vs. 63 (Type 2: 12 trials), or pairs where the smaller number contained the largest digit, e.g. 77 vs. 69 (Type 3: 10 trials). The stimuli presented are provided in Table 1. For each child, each trial was scored as accurate (1) or inaccurate (0) to produce a total score for each stimulus type at each stimulus length. This score was divided by the number of trials for each condition to produce a proportion/percentage accuracy score so that conditions with different numbers of trials could be directly compared.

Table 1. Stimuli presented.

Stimulus length	**Type 1**	**Type 2**	**Type 3**
2 digits	30 vs. 60 80 vs. 70 45 vs. 55 62 vs. 32 57 vs. 53 93 vs. 95 24 vs. 21 72 vs. 78	36 vs. 63 18 vs. 81 72 vs. 27 54 vs. 45	77 vs. 69 37 vs. 43 52 vs. 48 24 vs. 31
3 digits	200 vs. 500 800 vs. 600 350 vs. 450 720 vs. 520 325 vs. 335 750 vs. 740 128 vs. 125 730 vs.732	104 vs. 401 918 vs. 819 493 vs. 394 243 vs. 342	875 vs. 869 399 vs. 401 703 vs. 699
4-5 digits	3000 vs. 8000 2674 vs. 2677 3581 vs. 3541 1892 vs. 1792 82000 vs. 72000 25040 vs. 25050 14657 vs. 15657 71578 vs. 71576	7431 vs. 7341 4123 vs. 4213 13928 vs. 13298 65894 vs. 65984	8971 vs. 10507 29996 vs. 31112 34343 vs. 8769
Practice		500 vs. 100 100 vs. 500	

Results

The accuracy of the multi-digit magnitude comparison task was analysed using a 3x3x3 mixed design ANOVA with factors: **Subject Group** (age-control (AC), specific language impairment (SLI) and language-control (LC)); **Stimulus Type** (Type 1: the two numbers differ by only one digit, Type 2: the two numbers contain digits that have been transposed, Type 3: the smaller number of the pair contains the highest individual digit); and **Stimulus Length** (2, 3 and 4-5 digits). Mean accuracy scores are provided for each subject group at each stimulus length for each stimulus type in Table 2.

Main Effects

The main effect of subject group was significant ($F=39.63$, $df = 2, 164$, $p<0.001$), with AC>SLI>LC (AC vs. SLI and LC: $p<0.001$; SLI vs. LC: $p<0.01$); means and SE: 84.89 ± 1.74 (AC); 70.95 ± 1.77 (SLI); 63.08 ± 1.77 (LC). The main effect of stimulus length was significant ($F=74.33$, $df = 2, 328$, $p<0.001$). As the stimulus length increased the score decreased significantly at each increment ($p<0.001$); means and SE: 83.40 ± 1.31 (2 digits); 70.67 ± 1.41 (3 digits); 64.86 ± 1.35 (4-5 digits). The main effect of stimulus type was significant ($F=97.28$, $df = 2, 328$, $p<0.001$), with Type 1> Type 2> Type 3 (Type 1 vs. Type 2: $p<0.001$, Type 2 vs. Type 3: $p<0.01$); means and SE: 85.03 ± 1.02 (Type 1); 69.40 ± 1.48 (Type 2); 64.47 ± 1.50 (Type 3).

Interactions between Subject Group, Stimulus Type and Stimulus Length

There is a significant 3-way interaction ($F=3.74$, $df = 8, 656$, $p<0.001$) between the different factors in the comparison task. The 3-way interaction is represented in Figures 1-3 and demonstrates the way in which variations in subject group are affected by variations in both stimulus type and stimulus length.

It can be seen that group effects are different for each stimulus type and that these differences vary according to stimulus length for Type 3 stimuli but not apparently for Type 1 or Type 2 stimuli. The relationship between the subject groups changes with stimulus type in that: for Type 1 stimuli, AC>SLI>LC ($p<0.001$) with the effects of stimulus length appearing to increase by group, though the interpretation is limited by the ceiling effect evident with the AC group (Figure 1); this relationship changes for Type 2 stimuli in that scores in all groups decrease with increasing stimulus length and that although the AC group still score more highly ($p<0.001$), the SLI and LC group now score equally ($p=1.0$) (Figure 2); the relationship for Type 3 is similar in that AC>SLI=LC (AC vs. SLI: $p<0.001$; SLI vs. LC: $p=0.054$), however, the SLI and LC groups are close to being significantly different and, importantly, the relationships between the subject groups now varies with stimulus length in that once the longest stimulus length is reached the score for the AC group decreases to the level of the SLI group ($t=0.49$, $df=110$, $p=0.623$) but remain above those of the LC group ($t=2.26$, $df=110$, $p<0.05$).

Figure 1: The mean accuracy score for each subject group with increasing stimulus length for stimulus Type 1 (the most transparent comparison where the two numbers differ by only one digit).

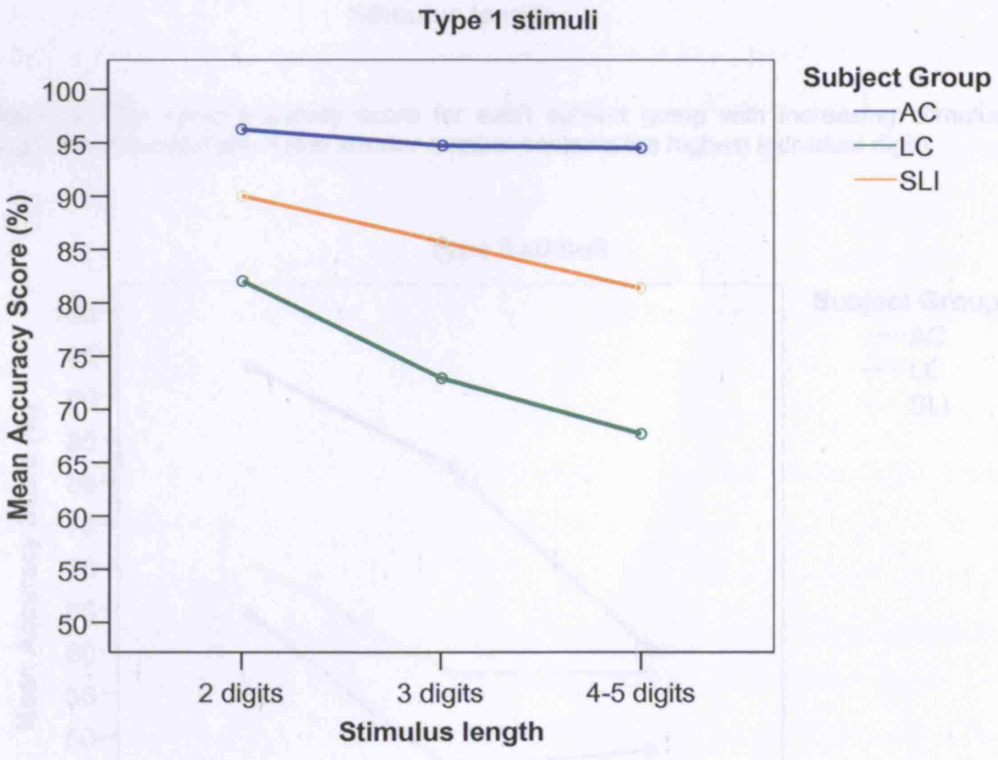


Figure 2: The mean accuracy score for each subject group with increasing stimulus length for stimulus Type 2 (the two numbers contain digits that have been transposed).

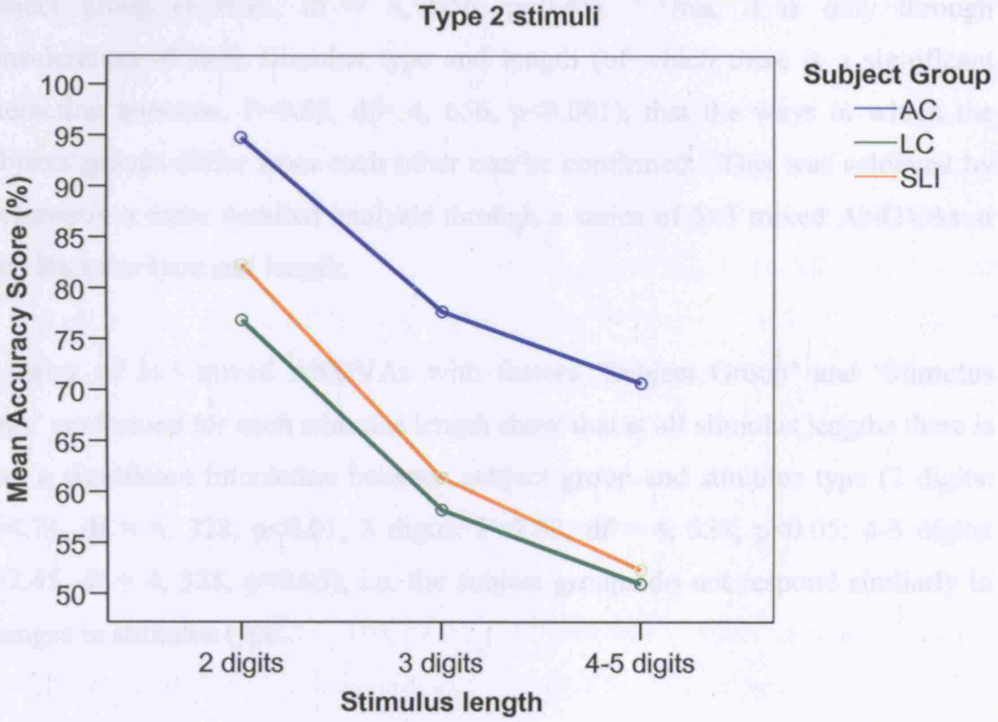
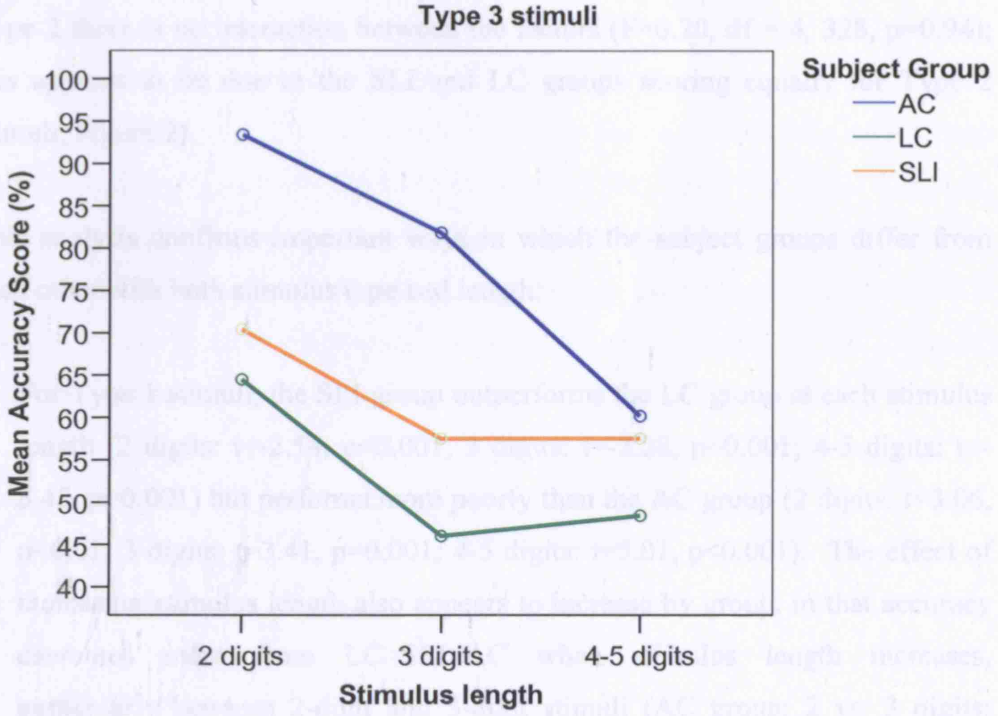


Figure 3: The mean accuracy score for each subject group with increasing stimulus length for stimulus Type 3 (the smaller number contains the highest individual digit).



Follow-up analyses show that there is no significant interaction between stimulus type and subject group (F=2.02, df = 4, 656, p=0.091) or stimulus length and subject group (F=0.92, df = 4, 656, p=0.45). Thus, it is only through consideration of both stimulus type and length (of which there is a significant interaction between, F=9.88, df= 4, 656, p<0.001), that the ways in which the subjects groups differ from each other can be confirmed. This was achieved by performing a more detailed analysis through a series of 3x3 mixed ANOVAs at each stimulus type and length.

A series of 3x3 mixed ANOVAs with factors 'Subject Group' and 'Stimulus Type' performed for each stimulus length show that at all stimulus lengths there is now a significant interaction between subject group and stimulus type (2 digits: F=4.71, df = 4, 328, p<0.01; 3 digits: F=2.83, df = 4, 328, p<0.05; 4-5 digits: F=2.45, df = 4, 328, p<0.05), i.e. the subject groups do not respond similarly to changes in stimulus type.

A series of 3x3 mixed ANOVAs with factors 'Subject Group' and 'Stimulus Length' performed for each stimulus type show that for Type 1 and 3 there is a significant interaction between subject group and stimulus length (Type 1: F=4.06, df = 4, 328, p<0.01; Type 3: F=4.57, df = 4, 328, p<0.001), whereas for Type 2 there is no interaction between the factors (F=0.20, df = 4, 328, p=0.94); this appears to be due to the SLI and LC groups scoring equally for Type 2 stimuli; Figure 2).

This analysis confirms important ways in which the subject groups differ from each other with both stimulus type and length:

1. For Type 1 stimuli, the SLI group outperforms the LC group at each stimulus length (2 digits: t=-2.58, p<0.001; 3 digits: t=-3.28, p=0.001; 4-5 digits: t=-3.45, p=0.001) but performs more poorly than the AC group (2 digits: t=3.06, p<0.01; 3 digits: t=3.41, p=0.001; 4-5 digits: t=5.01, p<0.001). The effect of increasing stimulus length also appears to increase by group, in that accuracy decreases more from LC>SLI>AC when stimulus length increases, particularly between 2-digit and 3-digit stimuli (AC group: 2 vs. 3 digits:

t=1.22, p=0.226; 3 vs. 4-5 digits: t=0.155, p=0.878 (a ceiling effect is evident at all stimulus lengths); SLI group: 2 vs. 3 digits: t=2.42, p<0.05; 3 vs. 4-5 digits: t=1.75, p=0.087; LC group: 2 vs. 3 digits: t=3.36, p<0.001; 3 vs. 4-5 digits: t=1.51, p=0.137).

2. For Type 2 stimuli, the SLI and LC groups perform identically (p=1.0, means and SE: 65.30 ± 2.57 (SLI), 61.97 ± 2.57 (LC)). Both are significantly poorer than the AC group (p<0.001, mean and SE: 80.99 ± 2.53). All groups show strong effects of stimulus length (AC group: F=19.58, df= 2, 112, p<0.001; SLI group: F=16.58, df= 2, 108, p<0.001; LC group: F=14.0, df= 2, 108, p<0.001).

3. For Type 3 stimuli, differences between groups as a function of stimulus length appear to reflect floor effects on SLI and LC for some longer stimuli (3 digits: 34.5% of children with SLI and 51% of LC children score 50% or less; 4-5 digits: 40% of children with SLI and 54.5% of LC children score 50% or less). However, the SLI group does appear to outperform the LC group at longer stimulus lengths (SLI vs. LC above 2 digits: t=-2.67, p<0.01) and performs at the level of the AC group for 4-5 digit stimuli (t=0.49, p=0.623, means and SE: 60.23 ± 3.71 (AC), 57.58 ± 3.77 (SLI)).

Therefore, reducing stimulus transparency 'costs' the SLI group more than the LC group, particularly for Type 2 stimuli where the two numbers in the comparison task contain digits that are transposed/reversed. However, for Type 3 stimuli, where the smaller number of the comparison pair contains the highest individual digit, the SLI group manage the comparison task with more success than the LC group at longer stimulus lengths and in fact, score at the level of the AC group for 4-5 digits numbers.

Table 2. Mean accuracy scores.

Subject Group	Stimulus length	Stimulus Type	Mean	Standard Error of the Mean (SEM)
AC	2 digits	Type 1	96.272	1.811
		Type 2	94.737	2.999
		Type 3	93.421	3.456
	3 digits	Type 1	94.737	2.306
		Type 2	77.632	3.828
		Type 3	81.874	4.052
	4-5 digits	Type 1	94.518	2.324
		Type 2	70.614	4.254
		Type 3	60.228	3.706
LC	2 digits	Type 1	82.045	1.844
		Type 2	76.818	3.053
		Type 3	64.545	3.518
	3 digits	Type 1	72.955	2.348
		Type 2	58.182	3.896
		Type 3	46.060	4.125
	4-5 digits	Type 1	67.727	2.366
		Type 2	50.909	4.331
		Type 3	48.482	3.773
SLI	2 digits	Type 1	90.000	1.844
		Type 2	82.273	3.053
		Type 3	70.455	3.518
	3 digits	Type 1	85.682	2.348
		Type 2	61.364	3.896
		Type 3	57.578	4.125
	4-5 digits	Type 1	81.364	2.366
		Type 2	52.273	4.331
		Type 3	57.582	3.773

Discussion

Main Effects

The raw data was taken from the study by Cowan et al. (2005) and replicates their finding that in general the SLI group performed above the level of the language-control (LC) group but below that of typically-developing peers. This is consistent with studies that demonstrate children with SLI can develop conceptual understanding of numerical concepts, including place-value knowledge (Donlan et al. 1998, Donlan & Gourlay 1999) and abstract arithmetic principles (Donlan 2006), above the level of their language ability, i.e. using their non-verbal skills. Therefore, it appears that at a fundamental level numerical development can be dissociated from the development of verbal processes. However, the SLI group still perform below the level of typically-developing peers and are, therefore, being hampered in some way by processing difficulties associated with their impairment; this will be discussed in more detail further on.

The main effect of stimulus type observed in this study, where responses become more inaccurate as the transparency of the number pairs is reduced, is also in line with other studies that have shown that RT is increased when incompatible/conflicting information is present, suggesting processing becomes more complex and/or less efficient (Nuerk et al. 2001; Nuerk et al. 2005a). Donlan and Gourlay (1999) used the same stimuli types as the current study but measured RT and also found that judgements between transparent stimuli were faster than those that contain reversible digits or incompatible number pairs. Therefore, although the current study did not include stimuli matched for absolute distance between the number pairs, it supports the conclusion that, at least with more complicated stimuli, holistic processing is not solely responsible for processing the magnitude judgement.

The main effect demonstrating that accuracy decreases with increasing number length may reflect processing strategies have moved from the possibly more efficient holistic strategy of multi-digit magnitude comparison to a more lexicographic component in order to cope with numbers that are less familiar (and therefore stored representations of the integrated number are not so readily accessible) and require more careful sequential processing. The stimuli in the present study were not structured to investigate what processing systems may be in use (e.g. by controlling the position where the first differences between corresponding digits occur and measuring RT) but examining the affect increasing stimulus length has in conjunction with reductions in the transparency of number pairs has provided interesting results concerning the way the different subject groups respond to changes in these parameters.

Reponses to Transparent Number Pairs

A significant interaction occurred between stimulus length and subject group in responses to transparent stimuli, demonstrating the subject groups respond differently to increases in stimulus length, although the main effect of subject group (AC>SLI>LC) still held. There appeared to be an increase in the group effect as stimulus length increased, particularly from two to three digits, so that the LC group were most vulnerable to increases in stimulus length, followed by the SLI group. As language level is matched in the SLI and LC groups, this does not appear to be due to underlying language ability. This suggests the SLI group may be better able to cope with the demands of increasing number length in the comparison task by drawing on more advanced non-verbal conceptual skills or specific non-verbal skills such as visuo-spatial processing (Donlan et al. 2006); Arvedson (2002) had suggested pre-school children with SLI appeared to rely more on their visuo-spatial skills as they were observed to look longer at the arrays in the task than the control groups.

The younger LC group may also perform below the SLI group due to decreased instruction in double-digit numbers. In a slightly younger LC group (mean age 5.5 years), Donlan and Gourlay (1999) found children had not had school experience of double-digits and were unable to master the comparison task containing them. Although Sowder (1992) proposed place-value knowledge was not expected to be understood until around age eight, Cowan et al. (2005) and the current study demonstrate that the LC group (mean age 6.0 years) could perform multi-digit comparisons at levels well above chance. The decreased exposure to multi-digit numbers that they have, however, may affect the type of processing strategies available. It may be expected that for transparent stimuli children predominantly use holistic processing of number pairs (Donlan & Gourlay 1999; Dehaene et al. 1990; Nuerk et al. 2001) but it is possible that lexicographic processing may be utilised more by the younger group to cope with the reduced familiarity of multi-digit numbers (Poltrock & Schwartz 1984; Dehaene et al. 1990), as there will not be ready access to symbolic representations of integrated numbers.

Nuerk et al. (2004) did find that the processing strategies used in the multi-digit magnitude comparison task did appear to change throughout childhood. The study made predictions based on three models: if processing were solely holistic there would be no compatibility effect when overall distance between number pairs was matched; if processing were lexicographic with corresponding digits compared in parallel then incompatible pairs were predicted to be processed more slowly and less accurately than compatible pairs; and if processing were lexicographic but digits were compared sequentially then an inverse compatibility effect would be seen with incompatible pairs being processed faster as they have the largest decade difference (e.g the incompatible pair 47 vs. 62 has a larger decade difference than the compatible pair 42 vs. 57, although the absolute difference is equal).

Their results suggested the youngest age group (mean age 7.6-years) processed multi-digit magnitude comparisons sequentially and then gradually moved toward a more parallel lexicographic processing strategy that was seen in results from children aged 11-years and adults. They proposed an in-between stage occurred where both parallel and sequential processing could be used. As in their earlier study (Nuerk et al. 2001), they found no evidence that holistic processing is used in isolation although it may be a predominant component. Donlan and Gourlay (1999) also found evidence against a purely holistic or lexicographic processing of double-digits when SLI and AC groups underwent the comparison task. Therefore, at any one time different strategies could be used by any one child (Nuerk et al. 2004). The LC group in the current study are younger than the youngest tested group in the Nuerk et al. (2004) study, so it may follow that they would be predominantly using sequential lexicographic processing. The SLI and AC groups fall nearer the middle of the age range tested and so according to the

Nuerk et al. (2004) study could be using holistic processing alongside sequential or parallel lexicographic processing strategies. It is possible that this development of strategies available for use could affect the accuracy responses between the subject groups. The current study is not designed to systematically infer which processing systems are being utilised by each subject group but it would be interesting to study this further by examining RTs to the comparison task with stimuli controlled for unit distance, compatibility and absolute distance between number pairs. This could be done for each stimulus length and type and so perhaps determine whether the presence of language impairments affects the processing strategies available and in what circumstances.

The SLI group still score significantly below the level of their typically-developing peers with transparent stimuli; the AC group had no difficulty with increasing stimulus length. The possible causes for the discrepancy between the SLI and AC group will be discussed further on.

Responses to Incompatible/Conflicting Number Pairs

A significant interaction was also seen between subject group and stimulus length for number pairs that were incompatible, where the smaller number of the pair contained the highest individual digit (Type 3). In general, the AC group still performed above the level of the SLI group but the SLI group now do not score significantly differently from the younger language-matched group. However, as the amount of trials using Type 3 stimuli was somewhat limited, and the difference between the SLI and LC group was very close to significance ($p = 0.054$), it is likely that with larger trial size a significant difference would have been noted. Indeed, it can be seen that although floor effects were exhibited by some children in both groups at higher stimulus lengths, the SLI group did score significantly higher once the number pairs exceeded double digits ($p < 0.001$) and a greater number of LC children responded at chance level. Therefore, the SLI group appear to be better able to cope with conflicting information in the task due to their more advanced understanding of the place-value concept. Again, the difference between the SLI and the younger LC group could reflect reduced exposure to multi-digit numbers and fewer processing strategies being available to the LC group in comparison to the older SLI group. The AC group initially performed above the level of the SLI group but the two groups scored similarly once the highest stimulus length was reached. Donlan and Gourlay (1999) showed that children with SLI could respond as quickly as age-controls to double-digit comparisons of Type 3 stimuli, suggesting that at this level they may be using the same processing strategy, but that children with SLI were more inaccurate in their responses. They found that the difference between the SLI and AC groups could be accounted for once reduced school exposure to double-digits had been taken into account. It may be that the increased familiarity of double-digits aids the AC group by extending their ability to use holistic processing, even if in conjunction with lexicographic processing.

The low scores at the highest stimulus length for all subject groups reflects the increased demands of the task from the combination of high stimulus length and presence of conflicting information. This pinpoints the limits of performance in all groups, and that in certain circumstances the SLI group can perform as well as their peers. As lexicographic processing is thought to take over at number lengths over three digits (Poltrock & Schwartz 1984) and become more involved with the processing of incompatible number pairs (Nuerk et al. 2001), as before it would be interesting to do a further study to investigate whether the different subject groups move to, or use, different processing strategies at differing points, e.g. do the AC group have extended use of holistic processing in comparison to the other groups due to more exposure to multi-digit numbers and greater mapping of verbal and Hindu-Arabic number forms?

Responses to Transposed/Reversible Number Pairs

In contrast to the other stimulus types, there was no significant interaction between stimulus length and subject group for number pairs in which digits were reversed/transposed (Type 2). This is due to the fact that the SLI and LC groups now performed equally at all stimulus lengths ($p=1.0$), demonstrating the SLI group have particular difficulty with this stimulus type and suggesting that their language impairment may now be contributing to their reduced performance in the multi-digit magnitude comparison task for this stimulus type. This provides evidence that although other studies have shown magnitude comparison tasks are essentially non-verbal and do not require verbal skills (Donlan et al. 1998; Donlan

& Gourlay 1999; Cowan et al. 2005), in certain circumstances multi-digit comparison may be hindered by impaired language ability. Interestingly, Donlan et al. (2006) found count aloud performance was a significant predictor of multi-digit comparison (the study included number pairs with reversible digits) and that this correlation could explain the difference between the SLI and AC groups, although this relationship is not necessarily causal. The finding that children with SLI have more difficulty with transposed digits could be in line with this correlation, although further investigations are required to explore this issue.

Nuerk et al. (2004) discuss the idea that number word syntax may influence access to magnitude representations through mapping between verbal number forms and Hindu-Arabic digits, exhibited through transcoding tasks. Children with SLI have deficits in transcoding skills (Cowan et al. 2005) but this deficit does not seem to affect development of place-value understanding itself as Donlan and Gourlay (1999) described a child that could perform magnitude judgement tasks but could not transcode spoken to written Hindu-Arabic numerals. However, it is possible difficulties in transcoding may disrupt the multi-digit magnitude comparison task if information from verbal and Hindu-Arabic representations seem to conflict. Nuerk et al. (2005b) found a greater compatibility effect was seen with German speakers in comparison to English speakers, which they attributed to the fact that German contains more inversion properties in number words than English (although English does also contain inversions), e.g. 'einundzwanzig' represents 'one and twenty' for 21. They suggest this linguistic element can interfere with multi-digit magnitude comparison in adults with no impairment. Therefore, children with phonological processing difficulties[3], affecting their ability to map between verbal and Hindu-Arabic number forms, may have more difficulty dealing with the place-value task and more demands may be placed on their working memory and attention (Nuerk et al. 2004), especially if number pairs contain transposed digits.

Children with dyslexia have major difficulties in phonological processing (Snowling 1987) and often have numerical difficulties, especially in making

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[3] Difficulties categorising speech sounds and relating them to orthography.

sequential/reversible errors (Lewis et al. 1994). Children with SLI can also often have phonological processing difficulties (Bishop & Snowling 2004); could this be a common feature that may affect performance in the multi-digit magnitude comparison task when transposed digits are present? Unfortunately, a limitation of the current study is that reading ability was not tested so it is not possible to correlate reading ability and performance with Type 2 stimuli. Cowan et al. (2005) did find the SLI group had phonological processing skills below that of the LC group, so it is possible this contributes to their difficulty with stimuli containing transposed numbers.

The present study could be repeated to include subgroups of children with SLI with varying degrees of phonological impairment, assessed for reading ability, and a group of children with dyslexia to investigate this issue further. Studies that have investigated the understanding of place-value in children with only reading difficulties are difficult to interpret as Landerl et al. (2004) found children with dyslexia performed as controls on the magnitude comparison task (although only single-digit comparisons were tested), whereas Jordan et al. (2003) found deficits in understanding of place-value (using tasks other than magnitude comparison). In addition, not all children with SLI have phonological processing difficulties and as Bishop and Snowling (2004) point out, children with dyslexia whose difficulties are predominantly restricted to phonological processing form a distinct group from children with SLI whose difficulties can be diverse and include impairments in semantics, syntax and discourse.

Therefore, it is difficult to make any conclusions about the underlying impairment that may cause children with SLI to have difficulty with this particular stimulus type and whether a component of their language impairment is influencing performance, although it appears verbal counting skills are correlated and may contribute in some way to the differences in performance between the SLI and AC groups (Donlan et al. 2006). Cowan et al. (2005) also found other factors that contributed to the group difference in these children.

What Factors may contribute to the Discrepancy in Performance between the SLI and AC groups?

In the present study, the SLI group perform consistently below the level of the AC group, suggesting some underlying component of their impairment is contributing either to the development of conceptual place-value knowledge or to the demands of the task. As discussed, language ability may be involved via deficits in verbal counting skills but deficits in oral language comprehension do not seem to contribute to reduced performance as Cowan et al. (2005) found no correlation between them (although it is correlated to decreased performance in other number tasks). It is always possible that variations in unassessed language skills may also be contributing to differences seen between SLI and AC groups (Cowan et al. 2005).

Cowan et al. (2005) also found that the children with SLI performed below the AC group in all aspects of working memory[4], central executive function[5] and non-verbal skills such as visuo-spatial functioning and that all these contributed to the differences between the two groups but could not completely account for them. It is also difficult to know whether impaired ability in these areas contribute to reduced understanding of place-value or merely impact on the demands of testing. Reduced performance in the multi-digit magnitude comparison task could also reflect the use of less efficient processing strategies in the presence of intact conceptual knowledge, e.g. if children with SLI are relying more on visuospatial skills than the AC group the accuracy may reduced in response to increasing stimulus length for example. The 'Martian maths' task in the Donlan et al. (2006) study demonstrated that when the task was particularly designed to circumvent their language impairment, the performance in children with SLI equalled that of the AC group, revealing an intact grasp of conceptual principles underlying simple arithmetic. It can also be difficult to accurately assess certain abilities in

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[4] System for temporarily storing and managing the information required to carry out complex cognitive tasks such as learning, reasoning, and comprehension.

[5] System that controls and manages cognitive processes, thought to be involved in processes such as planning, cognitive flexibility, abstract thinking, rule acquisition, initiating appropriate actions and inhibiting inappropriate actions, and selecting relevant sensory information.

children with SLI, e.g. there is no non-verbal test of central executive function in children (Cowan et al. 2005).

Environmental factors are unlikely to exert much influence as although some children with SLI were recruited from special language schools (11/55) most attended either the same schools as the control groups or schools nearby in the same catchment area. As mentioned previously, it is more likely the levels of instruction will affect performance in the comparison task, which may influence the processing strategies used between children with SLI and the AC group. For these children, a teacher questionnaire confirmed children with SLI had not been taught to the same level as the AC group on any aspect of number (Cowan et al. 2005). Although Donlan and Gourlay (1999) found levels of instruction could account for the difference in accuracy scores between SLI and AC groups, in the larger study instruction levels could only account for some of the difference between them (Cowan et al. 2005). It is also not clear whether lack of instruction results in decreased numerical knowledge or whether instruction is reduced because of lower levels of achievement (Donlan & Gourlay 1999).

This analysis, in conjunction with the Cowan study, raises various aspects of impairments seen in SLI that may contribute in some way to performance of the multi-digit magnitude comparison task, although there was still a difference between the SLI and AC groups after these had been taken into account (Cowan et al. 2005). It can be particularly problematic to identify specific processing areas that predominantly affect performance due to the diverse nature of the range of impairments and underlying causes present in children with SLI.

Clinical Implications

This study demonstrates that although children with SLI generally perform the multi-digit magnitude comparison task above their language level, including being able to more readily cope with reductions in transparency due to conflicting information, they perform below the level of their typically-developing peers in all but the hardest test condition, and in certain circumstances perform at the same level of younger language-matched children. This is despite the fact that children with SLI have been shown to be able to develop good conceptual skills and ability to infer logical numerical principles (Donlan et al. 2006). Therefore, they are at risk for reduced mathematical development of both procedural skills (Fazio 1999; Cowan et al. 2005; Donlan et al. 2006) and some conceptual skills, suggesting instruction is not capitalising on their strengths. This would seem to be in part due to the decreased instruction they obtain, which may be due to the focus and extra work needed on the remediation of their language skills, and also due to standard teaching methods not being tailored to exploit their strengths. Numeracy is an essential life skill and as such it would be beneficial for children with SLI to attain their full potential in this area, requiring teaching methods to capitalise on their strengths while reducing the demand placed on language. This could support the development of their conceptual and procedural skills in an attempt to limit the impact of accumulating deficits over the years.

Conclusion

This study has replicated the general finding that children with SLI appear to have conceptual knowledge of place-value principles in advance of their language abilities, and that this holds true for more complicated comparisons where conflicting information is present. It has shown that in certain circumstances, where transposed digits are present, the SLI group perform the task at the same level as the younger language-matched children, suggesting an element of their language disorder could impact on their ability to use place-value knowledge even in an essentially non-verbal task. Studies at present have not been able to pinpoint what exact processing components cause the discrepancy in performance seen between children with SLI and typically-developing peers, although contributing factors have been identified. The study has demonstrated that different subject groups respond differently to variations in task parameters and suggests some further areas for study, such as whether SLI and control groups use different processing strategies as task demands increase; answers to which may provide further insight into the role of language in the development of numeracy skills and suggest ways in which the numeracy skills of children with SLI can be optimised.

Word Count: 9609

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