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Differences in Working Memory Profiles amongst Children with Low versus Average Academic Performances

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Previous studies showed working memory span predicted mathematical performance. However, it was unclear whether working memory span differed amongst children with poorer performances in mathematics (PM), English literacy (PL), or in both areas (PML). 150 Primary 5 pupils participated in the study. Assignment to performance groups was based on two standardised literacy measures and a mathematical problem solving task. Children scoring at or below the 25th percentile were classified as having performed poorly in that area. Working memory capacity was measured using the Working Memory Test Battery for Children. PML had similar working memory profiles as PL, but had lower scores than PM. Children classified as PM had similar profiles as did normally achieving children. These findings suggest children with difficulties in different topic areas may not benefit equally from working memory based intervention.

Working memory refers to systems involved in the temporary maintenance and manipulation of information. Research conducted with both preschoolers and older pupils showed that working memory span is associated with academic performance (e.g., Gathercole & Pickering, 2000; Gathercole, Pickering, Knight, & Stegmann, 2004). In a previous study, we extended these findings and examined the contributions of working memory to a complex algebraic task (Lee, Ng, Ng, & Lim, 2004). Children, 11 year olds, were asked to solve a set of ten algebraic problems and were administered a set of working memory, literacy, and non-verbal IQ tasks. When both direct and indirect effects were taken into account, working memory was found to have a greater total effect on algebraic performance than did either literacy or non-verbal IQ.

Although working memory capacity has been found to predict performances in both mathematics problem solving and reading comprehension (for reviews, see Alloway, 2006; Daneman & Merikle, 1996), it is not clear whether there are differences in working memory profiles amongst pupils who are not doing well in specific academic areas. This information would be useful for determining the causes of performance difficulty and for designing topic specific remedial programmes.

In this study, we were particularly interested in differences amongst children doing relatively poorly in mathematics versus those doing poorly in both mathematics and English. To examine this issue, we extracted data from a larger study (part of which

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was reported in Lee et al., 2004), and re-analysed them together with new data from a mathematical task that contained a comprehensive set of arithmetic and algebraic problems. We used performances in the mathematical task and in tests of English literacy as grouping criteria and examined differences in working memory profiles amongst children doing poorly in English literacy (PL), mathematics (PM), or in both subject areas (PML). Children with normal achievement in the two subjects provided baseline measures.

Working Memory and Academic Performance

Our work was guided by a working memory model first described by Baddeley and Hitch (1974). The model consisted of three components: central executive, phonological loop, and a visuo-spatial sketchpad (see Baddeley, 2000, for a recent revision to the model). Both the phonological loop and the visual-spatial sketchpad are short-term storage systems. Traditional tests of short-term memory capacity, e.g., digit span, are believed to measure the storage capacity of the phonological loop. The central executive is a resource manager and controls the allocation of attentional resources. Like most cognitive accounts of thinking processes, Baddeley and Hitch's model postulates an upper limit in attentional capacity. Performance deteriorates when task demands exceed this capacity. Other higher cognitive functions, e.g., ability to inhibit unwanted information, switching between problem solving strategies, and activating information stored in long-term memory, have also been attributed to the central executive (Baddeley, 1996).

A number of recent studies have shown working memory capacity predicted performances in school based examinations. Gathercole and Pickering (2000), for example, examined the relationship between performances on a set of 13 working memory tests and the UK national curriculum assessments for 7 year olds. Comparing children with difficulties in English or mathematics versus those without difficulties, the former exhibited lower central executive and visuo-spatial capacities. In a follow-up study, Gathercole et al. (2004) examined differences in working memory profiles amongst 7 and 14 year olds. Children were divided into three ability groups (low, average, and high) based on results from the UK national curriculum assessments. Only central executive and phonological measures were administered. Data from the younger children were generally consistent with findings from Gathercole and Pickering (2000): higher working memory scores were associated with better achievement. Phonological scores were higher in the high ability group but did not differ across the low and average groups. For older children, both the phonological and central executive measures differed across the three ability groups in mathematics, but not in English.

Although Gathercole and Pickering (2000) showed performances on the working memory battery were associated with academic difficulties, small sample sizes precluded a more detailed examination of differences across academic subject areas. The present study provides an extension to their study. In particular, we examined the working memory profiles of children with weaknesses in mathematical problem solving with or without weaknesses in English literacy.

Working memory, English literacy, and mathematical performance.

A number of studies have examined the relationship between different components of working memory and mathematical performance (e.g., Bull & Johnston, 1997; Bull & Scerif, 2001; Furst & Hitch, 2000; Heathcote, 1994; Klein & Bisanz, 2000; Lee et al., 2004; Rasmussen & Bisanz, 2005). A finding common to many of these studies is that correlation between working memory and mathematics is greatly reduced when reading comprehension or literacy is taken into account (Bull & Scerif, 2001; Kail & Hall, 1999; Lee et al., 2004; Swanson, Cooney, & Brock, 1993). What is the relationship between literacy, working memory, and mathematical achievement? One possibility is that pupils' difficulties with mathematics are largely due to difficulties with literacy. Inability to surmount the linguistic demands of classroom instructions, test instructions, or test questions may be largely responsible for poor performance in mathematics. If this is the case, the preponderance of pupils poor in mathematics should also be poor in English. Yet, inspection of school examination results suggests this is not always the case. Although some students are poor in both English and mathematics, there are sizeable numbers of students who are poor in mathematics but not in English. Similarly, there are those poor in English but not in mathematics.

Apart from work conducted by Gathercole and her colleagues (2000; 2006), few studies have examined the working memory profiles of children with different patterns of performances in school based assessment. However, there are related findings from the disabilities literature. Geary et al. (2000), for example, examined the working memory profiles of first-graders who had disabilities in mathematics versus mathematics and reading, but found no significant group difference. Instead, children with reading or reading and mathematics disabilities were found to have lower articulation speed than did children with mathematics disabilities only. Focusing on executive functioning, van der Sluis, de Jong, and van der Leij (2004) found no difference amongst arithmetically disabled 4th and 5th graders and their reading plus arithmetically disabled peers on measures of shifting and inhibition.

Rourke (1993; 2004), in contrast, found children with only arithmetic disabilities showed a wider range of difficulties than did those with both arithmetic and reading difficulties. These included problems with spatial organization, visual details, graphomotor skills, perseveration, and reasoning. Children with disabilities in both arithmetic and literacy had problems that were mainly verbal in nature. These problems were manifested in errors in remembering mathematical tables and sub-routines in mathematical procedures. Others found children with only mathematical disability performed better than did children with mathematical and reading disability on mathematical tasks mediated by language and speech (Geary, Hoard, & Hamson, 1999; Geary, Hamson, & Hoard, 2000; Hanich, Jordan, Kaplan, & Dick, 2001).

In this study, our grouping criteria and expectations were guided by findings from the disability literature (e.g., Rourke, 1993; Rourke, 2004). However, children in the PL, PM, and PML groupings were all drawn from average ability classrooms. At the time data were collected, all pupils in Singapore sat for a streaming examination at the end of Primary 4 (~ 10 year old). Depending on their performances in English, mother tongue, and mathematics, they were assigned to one of three ability streams in Primary 5. The lowest stream catered to children with noted difficulties in both mathematics and the languages (~ 5 - 7% of each cohort). To qualify, children had to fail all three academic subjects. We selected our children from the two higher ability groups for practical reasons. The bulk of students are enrolled in these classes. Although classified as average ability, there still existed large individual differences amongst children in these classes. Because of the importance of academic standing in Singaporean society, it was important to find out whether patterns of deficits, found in children with more severe difficulties, are also apparent in these children. In the long term, it was important to ascertain whether intervention designed for children in the lowest stream would also benefit children from higher streams.

Regarding working memory profiles, if Rourke's (1993; 2004) findings were to generalise to the present sample, we could expect children in the PML grouping to have lower phonological memory capacity. Children in the PM grouping would have a wider set of deficits, including lower visual spatial memory capacity. Our expectation is, however, tempered by findings from a recent study suggesting relationship between working memory and mathematical performance differs, depending on whether participants are drawn from normally functioning or disabled populations (Henry & MacLean, 2003).

METHOD

Participants

Children in this study took part in a larger study that examined the relationship between working memory and mathematical problem solving. The sample contained 150 Primary 5 pupils (77 boys, average age = 10.7 years, *SD* = 0.65) from five public schools in the western districts of Singapore. All children participated with parental consent. Given our interest, children were recruited from the middle and upper ability streams. Apart from mother tongue classes, all school lessons were conducted in English. Mother tongue was generally defined by cultural origins. At present, roughly half of all pupils spoke English at home. All pupils who participated in this study were functionally bilingual with a minimum of five years of schooling in English, most had seven.

Participant assignment procedure

Children were assigned to one of four groups based on their performances in an English literacy and in a mathematical task. The mathematical task focused on problem solving. Ability to solve word problems, especially those requiring algebraic thinking, is a key area of the curriculum (Curriculum Planning and Development Division, 2000) and is examined at semestral examinations. Literacy was measured using the reading component of the Wechsler Objective Reading and Language Dimensions, Singapore (WORLD, Rust, 2000) and the vocabulary subtest of the Wechsler Intelligence Scale for Children, third edition (WISC III, Wechsler, 1991).

A variety of grouping criteria and cut-off levels can be found in the literature. McLean and Hitch (1999), Wilson and Swanson (2001) used a 25% cut-off, but Hanich et al. (2001), Geary et al. (2000) used a more lenient 35% cut-off. Here, we used a slightly more stringent cut-off: Children who scored at or below the 25^{th} percentile on either the literacy or the mathematical test were classified as doing poorly in English literacy (n = 22) or mathematics (n = 23) respectively. Children below the 25^{th} percentile on both subjects were classified as being poor in both areas (n = 15). The remaining 90 children were classified as normal achievers. Based on a harmonic mean of 19, this sample has 75% power to detect differences with a large effect size.

Instruments and Procedure

The reading component of WORLD had three subtests: reading, spelling and reading comprehension. The reading subtest consisted of a series of words and children were asked to pronounce each word aloud. In the spelling subtest, the examiner dictated a series of words and asked the children to spell and write each word. The children were given as much time as they needed to spell each word. For both tests, administration was terminated when a child failed on six consecutive items. The reading comprehension subtest consisted of a series of printed story passages. Children were asked to read each passage and to answer a question based on the story. No reliability data was provided with the test manual. However, the UK edition of the test cited split-half reliability of .76 - .92 (Spies & Plake, 2005). In the WISC III vocabulary subtest, children were presented with individual words and were asked to explain their meaning (Spearman-Brown $r = .88$, Wechsler, 1991). For both the reading comprehension and vocabulary subtests, testing was terminated when a child failed four consecutive items. For the WORLD subtests, one mark was awarded for each correct response. For the vocabulary subtest, a correct response attracted two marks but one mark was awarded for a partially correct response.

The various literacy related measures were highly intercorrelated (rs > .55). To provide a broader based measure that is more reflective of abilities tested in school based assessment, a composite literacy score was computed by submitting scores from the four tests to a principal component analysis. The resulting score had an eigenvalue of 2.96 and captured 74% of total variance. Variable loadings for vocabulary, reading, spelling, and reading comprehension were .87, .87, .87, and .81 respectively. We also collected the children's scores from a school based English examination. It correlated reliably with the literacy score (r = .81).

Two sets of mathematics problem solving tasks were administered. Findings from the first set were reported in Lee et al. (2004). The present analysis is based on a second set administered several weeks after the first set. This second set contained a larger number of arithmetic word problems, which children found easier ($M = 5.3$, maximum = 10, SD = 2.78. in comparison, $M = 2.81$, $SD = 2.39$ for the first set). This set contained two versions. Each version contained 10 word problems. In one version, children were asked to use the model method: a heuristic that helps pupils visualise and centralise information presented in the word problem. This method is taught in all public schools. In the other version, children were asked to use a heuristic other than the model method. Both versions had good internal reliability (Cronbach $\alpha = .84$ for both versions) and were highly correlated with a school based mathematics examination ($r > .84$, higher than the first set of questions). Question selection was based on the national curriculum. Because testing was conducted during the middle of the academic year, we selected 2 questions from the Primary 4 curriculum, 6 questions from the Primary 5 curriculum, and 2 questions from the early Primary 6 curriculum. The first two questions were arithmetic in nature. The remaining questions were algebraic in nature and tested children's understanding of relational concepts: specifically, more than, less than, as many as, older than, and concepts involving proportional reasoning. Children were administered both versions on two separate occasions and were given one hour to finish the questions each time. We used an accuracy score, averaged over the two versions, to assign children to groups. One child could not attend the mathematical test; her score was estimated from her working memory and school examination scores.

In addition to the literacy and mathematical tasks, children were administered the Working Memory Test Battery for Children (WMTB-C, Pickering & Gathercole, 2001). It assessed children's working memory capacity in three domains: phonological loop, visuo-spatial sketchpad and central executive.

Phonological loop. The Digit Recall, Word List Matching, Word List Recall, and Non-word List Recall tasks were used to measure phonological capacity. In the Digit Recall task children listened to sequences of digits and were asked to recall them in the same sequence. The sequences increased in length and contained one to nine digits. In the Word List Matching task, children listened to a sequence of one syllable words (e.g., cat, book, jug, lawn). After a brief interval, the same words were repeated, either in the same order (e.g., cat, book, jug, lawn) or with the position of two words reversed (e.g., book, cat, jug, lawn). Children had to decide whether words in the two sequences were of the same order. Sequences contained two to nine words. In the Word List Recall task, children listened to a sequence of one syllable words (e.g., turn, pen, bill, dart) and were asked to recall them in the same sequence. Sequences contained one to seven words. The Non-word List Recall task was similar with the exception that non-words were used (e.g., loob, kell, tam, dorg). Sequences contained one to six non-words. Because of the structure of the test and the use of discontinuation rules, participants were exposed to different number of questions. As a result, internal reliabilities statistics cannot be meaningfully calculated. Pickering and Gathercole (2001) reported test-retest reliabilities of .42 to .82.

Visual-spatial sketchpad. In the Block Recall task, the examiner tapped a sequence of blocks and asked children to reproduce the same sequence by tapping the same blocks. The blocks, nine in total, were arranged in a fixed position on a rectangular board. The number of blocks used in each trial ranged from one to nine (test-retest reliabilities = .43). For the Mazes Memory task, the examiner traced specific routes on a series of rectangular mazes. Although alternative routings were available, children were instructed to remember the route demonstrated by the examiner and to reproduce it in a response booklet. The mazes increased in complexity and involved two to eight boundary walls (test-retest reliabilities = .53).

Central executive. For the Listening Recall task, children listened to a sequence of sentences and had to decide whether each sentence was true or false. After all sentences in a trial were presented, children were asked to recall the last word of each previously presented sentence; in the order the sentences were presented. Trials began with one sentence verification and progressed to six sentences. In the Counting Recall task, children were asked to count arrays of dots presented on a series of cards. Similar to the Listening Recall task, children recalled the number of dots on each card at the end of each trial. One to seven cards were presented in each trial. In the Backward Digit Recall task, children listened to spoken sequences of digits and were asked to recall them in the reverse order. Span length increased from two to seven (test-retest reliabilities, .38 to .71).

The WMTB-C, WORLD, and WISC were administered on a one-to-one basis. The mathematical problem solving task was administered several weeks afterwards. Due to school scheduling constraints, approximately half of the subjects were administered these tests on the same day. For the remainder, administration was conducted on separate days.

RESULTS

To ensure that the use of a 25^{th} percentile cut-off resulted in four groups that differed in performances on both the literacy and the mathematical tests, we conducted a multivariate analysis of variance (MANOVA). Test scores differed reliably across groups, $F(6, 292) = 58.89$, $p < .01$, partial $\eta^2 = .55$ (given the unequal sample sizes across groups, Pillai's Trace was used in all tests). Tukey's Honestly Significant Difference test showed that, on the literacy test, children classified as PL had similar scores as did those classified as PML. On the mathematics test, children classified as PM had similar scores as did those classified as PML.

As children were assigned to groups based on whether their scores fell below the 25^{th} percentile in relevant subjects, children classified as PM were, by definition, better in literacy than those classified as PL. The literacy scores of PM children was reliably poorer than those of normally achieving children, but was within one standard deviation of the sample mean. A similar pattern was found on the mathematics test with PL children. They performed better in mathematics than did their PM counterparts. However, their performance in mathematics was reliably poorer than normally achieving children, but was within one standard deviation of the sample mean (see Table 1 for means and standard deviations).

Table 1

Means and Standard Deviations of Literacy, Mathematics, Working Memory, and IQ Scores by Group

	Literacy	*Maths*	*PL*	*VS*	*CE*	*Vocab.*	*BD*	*IQ*
Poor in both (n = 15)	-1.14 (.30)	1.93 (1.08)	90.47 (16.27)	84.47 (13.35)	92.33 (19.94)	18.53 (4.79)	35.91 (13.09)	82.21 (16.36)
Poor in literacy (n = 22)	-1.35 (.49)	4.82 (1.34)	95.45 (11.74)	93.00 (13.54)	96.41 (14.92)	15.73 (4.52)	41.50 (7.70)	82.60 (7.80)
Poor in mathematics (n = 23)	-.25 (.44)	1.61 (1.12)	109.35 (16.77)	95.96 (14.54)	106.39 (13.55)	19.00 (3.93)	38.96 (9.46)	86.38 (10.72)
Normal Achievement (n = 90)	.58 (.73)	6.86 (2.02)	115.89 (15.50)	103.52 (14.17)	113.32 (18.29)	29.06 (7.26)	48.18 (8.24)	106.38 (14.49)
Sample average (n = 151)	0 (1.00)	5.26 (2.78)	109.35 (17.88)	98.91 (15.30)	107.68 (18.91)	24.51 (8.42)	44.56 (9.99)	97.41 (17.30)

Note. Values in parentheses are standard deviations. PL = component scores from the phonological loop measure of the Working Memory Test Battery for Children (WMTB-C); VS = component scores from the visuo-spatial measure, WMTB-C; CE = component scores from the central executive measure, WMTB-C; Vocab. = raw scores from the vocabulary subtest, from the Wechsler Intelligence Scale for Children- Third Edition (WISC-III); BD = raw scores from the block design subtest, WISC-III.

A MANOVA showed that the four groups differed reliably on the working memory measures, $F(9, 438) = 7.20$, $p < .01$, partial $\eta^2 = .13$. Follow-up univariate analyses showed that the difference is reliable on each of the three component measures.

Inspection of effect sizes showed that differences across groups were greatest on the phonological measure, partial η^2 = .28, followed by the central executive and the visuo-spatial components, partial η^2 = .17 for both scores. Two sets of planned comparisons were of specific interests: (a) PML versus PM, and (b) PML versus PL. These contrasts examined whether there are differences in working memory profiles amongst children performing poorly in one area versus those performing poorly in both subject areas. As there are three degrees of freedom associated with the main group effect, both contrasts were evaluated using uncorrected t tests with a critical α of .05.

Findings across the three working memory domains bore the same pattern. PML children had lower scores than did their PM counterparts. Confidence intervals (CI, 95%) for differences across the two groups are as follows: phonological (8.85, 28.92), visual spatial (2.27, 20.71), executive (2.67, 25.45). These differences were reliable at or below the .016 probability level. Differences between children classified as PML versus PL were not reliable. In addition to the planned comparisons, post-hoc Tukey's Honestly Significant Different (HSD) test was used to evaluate differences across other groupings. PM children were found to have a similar working memory profile as did normally achieving children. Although the former achieved lower span scores in all three working memory domains, differences were not reliable. In all three domains, normally achieving children obtained higher span scores than did children classified as PL, 95% CI: phonological (13.24, 27.63), visual spatial (3.91, 17.13), executive (8.75, 25.08). They also obtained higher scores than did children classified as PML, 95% CI: phonological (16.99, 33.85), visual spatial (11.31, 26.81), executive (11.42, 30.56). On both the visual spatial and central executive measures, children classified as PL or PM did not differ. On the phonological measures, children classified as PL had lower span scores than did children classified as PM, 95% CI (4.88, 22.91).

In some studies, the influence of IQ on natural group differences in working memory or neuropsychological profiles are controlled by using analysis of covariance (ANCOVA) or by sampling from within a restricted IQ range. Miller and Chapman (2001) argued that results from such analyses were likely to be misleading. In a natural group design, the presence of group differences on a covariate can produce spurious group differences on the dependent variable when ANCOVA is performed. Sampling from within a restricted range results in non-representative samples and can result in regression-to-the-mean problems. For these reasons, differences in IQ were examined in a separate analysis of variance. Using an estimated IQ score computed from performances on the vocabulary and block design subtests of the Wechsler Intelligence Scale for Children (using the conversion formula from Sattler, 2001), reliable differences were found, $F(3, 146) = 33.98$, $p < .01$, partial η^2 = .41. Normally achieving children obtained higher IQ scores than did children in all other groups, 95% CI: PML (16.78, 31.56), PL (17.48, 30.08), PM (13.80, 26.19). There were no reliable differences amongst children with poor performances in either or both areas.

It is possible these findings were biased by the way in which children were assigned to groups. One of the assignment criteria, literacy score, was computed using vocabulary scores from the WISC as a contributing variable. To address this possibility, we examined the children's performances on the block design subtest. The same pattern of findings was found.

DISCUSSION

The present analyses revealed findings that were not apparent from the data and analyses presented by Lee et al. (2004). In that study, the central executive component score was found to correlate positively with performances in both English literacy and algebraic problem solving. The present findings show differences in working memory profiles amongst different groups of children with poorer performances in mathematics.

Children classified as PML had lower span scores than did both normally achieving and PM children. Given that children classified as PML had the lowest span scores, a possible contributor to their poorer mathematical performances is that they were hampered by their lower working memory capacity. Previous studies showed that working memory resources are needed in computation requiring carrying operations, mental storage of interim solutions, and other operations requiring simultaneous processing and remembrance (e.g., Furst & Hitch, 2000; Heathcote, 1994).

Though this interpretation is consistent with the data, it seems unlikely. First, PM children performed as poorly as their PML counterparts in mathematics, yet their working memory scores did not differ reliably from those of normally achieving children. Second, children classified as PL had similar working memory profiles as did those classified as PML, but their mathematical performance was reliably better (though still poorer than normally achieving children). If limitation in working memory capacity is primarily responsible for poorer mathematical performance, children classified as PL should have similar difficulties with mathematics.

An alternative explanation, similar to that suggested by Lee et al. (2004), is that, deficits in working memory has a largely indirect effect on mathematical performance. Deficits in working memory result in poor literacy that, in turn, produces detriment in mathematical performance. Thus, only in the presence of poorer performance in literacy is working memory capacity associated with deficits in mathematical performance. Previous studies showed that both phonological and central executive spans predicted performance in reading comprehension (Daneman & Merikle, 1996). Recent works also suggest that the phonological loop plays a causal role in vocabulary development and the acquisition of a second language (Baddeley, Gathercole, & Papagno, 1998; Baddeley, 2003). With poor English literacy, children will have difficulty understanding mathematical lessons, texts, and homework; all of which are conducted or presented in English in local schools. One caveat to this explanation is that poor literacy will not necessarily result in poor mathematical performance. As is evident in data from the PL grouping, deficits in literacy can occur with relatively well preserved mathematical performance. Other factors such as experience with mathematics in the children's mother tongue may operate in a compensatory manner.

For children classified as PM, their working memory scores did not differ reliably from those of normally achieving children. This finding may be partially affected by power considerations. Given the sample size, we have 75% power to locate a difference with a large effect size. Indeed, when differences were examined using uncorkrected t tests rather than Tukey's HSD, children classified as PM did exhibit lower visuo-spatial working memory span than did normally achieving children. However, on other measures, point estimates are suggestive of lower spans for PM, but differences failed to attain reliability even with uncorrected t tests. These findings suggest that even if PM children's working memory spans are smaller than those of normally achieving children, the magnitude of these deficits are small. These findings are not consistent with Rourke's (1993; 2004) findings, which showed that children with only arithmetic disabilities showed a wider range of difficulties than did those with comorbid disabilities in reading. A possible explanation of this variation is that our children may not be as severely disabled as those in Rourke's. Another possibility is that some of the visual spatial deficits found by Rourke may not be highly correlated with visual spatial working memory capacity (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001).

Working Memory, IQ, and Academic difficulties

A contribution of this study is to show that working memory measures are more sensitive to group differences than are IQ measures. The working memory measures showed that children classified as PM have higher spans than did those classified as PML. The former also exhibited higher phonological memory span than did children classified as PL. Despite moderate to strong correlations between estimated IQ scores and each of the working memory scores (*r*s > .44), these differences were not apparent on the IQ measures.

The relationship between working memory and IQ is controversial. In an earlier study, Kyllonen and Christal (1990) argued that working memory capacity is synonymous with fluid intelligence. Their findings showed that correlations between the two ranged from .80 to .90. This finding is replicated in a more recent finding in which the loading of intelligence over working memory was found to have an average value of .98 (Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004). Other recent works showed that despite high correlations between the two constructs, each predicted uniquely to academic performance. In Bull and Scerif (2001), for example, measures of different aspects of executive functioning predicted performance on the Group Mathematics Test (Young, 1980), despite having controlled for IQ. Although our present findings are based on an abbreviated IQ test using only the vocabulary and block design subtests, they are in keeping with the proposition that working memory and IQ measures are not synonymous (see Ackerman, Beier, & Boyle, 2005 for a recent meta-analytic study on this issue).

CONCLUSIONS

There are three findings of particular importance. First, the data show clear differentces in working memory spans amongst children classified as PML versus PM. The former consistently obtained lower span scores. Second, having a smaller working memory capacity will not necessarily result in poor mathematical performance. This is consistent with previous findings showing that working memory has a reliable but modest effect on academic achievement. Third, working memory measures are more sensitive to differences amongst the various groups examined here than are IQ measures.

Regarding interpretations, several caveats should be borne in mind. First, the present findings are obtained from children who exhibited relative difficulties in mathematic or literacy, rather than clinically diagnosed learning difficulties. Second, mathematical performance was assessed using word problem task. We used this because it is an important component of the curriculum and is a major connector of mathematics taught in primary and secondary school. A previous study conducted by Hanich et al. (2001) showed that in younger children at least, language mediated mathematical tasks are much more difficult for PML than for PM children. Fewer differences were found amongst the two groups on tasks requiring only numerical understanding. These findings suggest that results may differ if other mathematical tasks were used for group assignment. Third, our findings are based on a literacy score that includes measures of reading, spelling, comprehension, and vocabulary. Using an assignment criterion that includes only measures of reading and spelling will more closely approximate the existing literature on dyslexia. We did not do so because our primary interest was to investigate working memory differences amongst normally functioning children with relatively poor performances rather than children with more severe difficulties.

From a pedagogical perspective, the present findings suggest the two groups of children may benefit from intervention with different emphases. Although both groups have poorer literacy than normally achieving children, those with problems in both areas have more severe deficits and are more in need of remediation. Both groups have poorer visuo-spatial skills than normally achieving children and may benefit from further exposure to manipulatives and shape construction tasks. However, it is in working memory capacities that children poor in both areas exhibited the most distinct deficit. Because of the hypothesised relationship between working memory, literacy, and mathematics (Lee et al., 2004), improvements in working memory may improve performances in both areas. However, some non-trivial problems remain. First, it is not clear whether working memory capacity is responsive to remediation. Furthermore, whether an increase in working memory capacity will result in better academic achievement has not been studied. In the absence of specific training for capacity improvement, children may benefit from explicit scaffolding that teaches them how to delineate capacity intensive tasks into more manageable segments.

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.

Alloway, T. P. (2006). How does working memory work in the classroom? *Educational Research and Reviews*, 1, 134-139.

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

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

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

Baddeley, A. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology*, 49A, 5-28.

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

Bull, R. & Johnston, R. S. (1997). Children's arithmetical difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology*, 65, 1-24.

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.

Colom, R., Rebollo, I., Palacios, A., Juan-Espinosa, M., & Kyllonen, P. C. (2004). Working memory is (almost) perfectly predicted by g. Intelligence, 32, 277-296.

Curriculum Planning and Development Division (2000). *Primary mathematics syllabus*. Singapore: Ministry of Education.

Daneman, M. & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin and Review,* 3, 422-433.

Furst, A. J. & Hitch, G. J. (2000). Separate roles for executive and phonological components of working memory in mental arithmetic. *Memory and Cognition*, 28, 774-782.

Gathercole, S. E. & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *British Journal of Educational Psychology*, 70, 177-194.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology*, 18, 1-16.

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., & 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.

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.

Heathcote, D. (1994). The role of visuo-spatial working memory in the mental addition of multi-digit addends. *Current Psychology of Cognition*, 13, 207-245.

Henry, L. A. & MacLean, M. (2003). Relationships between working memory, expressive vocabulary and arithmetical reasoning in children with and without intellectual disabilities. *Educational and Child Psychology*, 20, 51-64.

Kail, R. & Hall, L. K. (1999). Sources of developmental change in children's word-problem performance. *Journal of Educational Psychology*, 91, 660-668.

Klein, J. S. & Bisanz, J. (2000). Preschoolers doing arithmetic: The concepts are willing but the working memory is weak. *Canadian Journal of Experimental Psy-chology*, 54, 105-116.

Kyllonen, P.C., & Christal, R. E. (1990). Reasoning ability is (little more than) working memory capacity? *Intelligence*, 4(4),389-433.

Lee, K., Ng, S. F., Ng, E. L., & Lim, Z. Y. (2004). Working Memory and Literacy as Predictors of Performance on Algebraic Word Problems. *Journal of Experimental Child Psychology*, 89, 140-158.

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

Miller, G. A. & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology*, 110, 10-4.

Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuo-spatial working memory, executive functioning, and spatial abilities related? A latent variable analysis. *Journal of Experimental Psychology: General*, 130, 621-640.

Pickering, S. J. & Gathercole, S. E. (2001). *Working Memory Test Battery for children*. Kent: The Psychological Corporation.

Rasmussen, C. & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of Experimental Child Psychology,* 91, 137-157.

Rourke, B. P. (1993). Arithmetic disabilities, specific and otherwise: A neuropsychological perspective. *Journal of Learning Disabilities*, 26, 214-226.

Rourke, B. P. (2004). Neuropsychological and psychosocial subtyping: A review of investigations within the University of Windsor Laboratory. *Canadian Psychology*, 41, 34-51.

Rust, J. (2000). *Wechsler Objective Reading and Language Dimensions (Singapore)*. London, UK: The Psychological Corporation.

Sattler, J. M. (2001). *Assessment of children: cognitive applications.* (4th ed.) San Diego: J.M. Sattler.

Spies, R. A. & Plake, B. S. (2005). *Mental measurements yearbook* (16 ed.) Lincoln, NE: University of Nebraska Press.

Swanson, H. L., Cooney, J. B., & Brock, S. (1993). The influence of working memory and classification ability on children's word problem solution. *Journal of Experimental Child Psychology*, 55, 374-395.

van der Sluis, S., de Jong, P. F., & Van der Leij, A. (2004). Inhibition and shifting in children with learning deficits in arithmetic and reading. *Journal of Experimental Child Psychology*, 87, 239-266.

Wechsler, D. (1991). *Wechsler Intelligence Scale for children* (3rd ed.). San Antonio, TX: Psychological Corporation.

Wilson, K. M. & Swanson, H. L. (2001). Are mathematics disabilities due to a domain-general or a domain-specific working memory deficit? *Journal of Learning Disabilities,* 34(3), 237-248.

Young, D. (1980). *Group mathematics test.* Kent: Hodder and Stoughton.

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