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DOES KNOWLEDGE OF MATHEMATICAL LANGUAGE PLAY A ROLE IN MATHEMATICAL ABILITY? -A PRELIMINARY STUDY

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Mathematics has always been associated with knowledge of digits and number words. Limited thought is given to the language system that binds digits and number words for meaningful computation. The lexicons of mathematics such as series of alphabets, numbers and digits become meaningless unless semantics or the meaning component is loaded into mathematical problems. Therefore, language skills related to reading, writing and comprehension are linked to performance in mathematics. In order to understand the role of language in mathematical lexicons, tests were developed for math vocabulary reading and math language incorporating general language vocabulary and syntax. The tests were administered on 47 children studying in IV Grade with Kannada as the medium of instruction. Results indicated poor performance by children on tasks where the general language vocabulary terms are shared between math and language. The study emphasizes the importance of teaching meaning of the mathematical lexicons in the classroom.

INTRODUCTION

Mathematics is often characterized as the language of science. As early as 1975, the superiority of mathematics as a language system is supported by the views of Beilin, supported by Lamb (1980) who attribute successful performance in mathematics to the ability to represent abstract ideas using symbols. Mathematical text reading requires two salient components of language of mathematics- *understanding mathematical* *technical vocabulary* and *specialized symbols*. These components are facilitated by the knowledge of language. Children acquire knowledge of mathematical terms through arithmetic processes such as counting, problem solving strategies, working memory, that are necessary for both their daily functional living as well as academic activities. Vocabulary understanding is a major contributor to overall comprehension in many content areas, including mathematics. Effective methods for teaching vocabulary in all content areas are diverse and long standing. Teaching and learning the language of mathematics is vital for the development of mathematical proficiency. Mathematical vocabulary learning by students is an important part of their language development and ultimately mathematical proficiency (Riccomini, Smith, Hughes & Fries, 2015).

The human brain must contain mental representations and processes for recognizing, understanding and producing various notations of numbers for the purpose of translating it from general language to the language of mathematics. The number domain, therefore, provides an interesting dimension to study the representation of symbolic information in the human brain and the interplay between language (verbal) and number symbols (non-verbal) forms. The study of organization of number system in human brain would possibly throw light on the organization of linguistic domains related for processing number symbols.

The relationship between language and mathematical symbols has been documented for English language and Arabic numerals consequent to which several models have been proposed. The architecture for mental representation of numbers and their interconnections are detailed in McCloskey's modular model of number processing (1992) in which a single central abstract quantity representation interfaces with notation-specific input and output modules. On the other hand, the triple-code model (Dehaene and Cohen, 1995) describes both the functional architecture and the neural substrates of number processing accounting for many types of numerical deficits, widely known as acalculia / dyscalculia, generally defined as a developmental arithmetic disorder leading to failure to develop arithmetic competence. Children with dyscalculia may make a variety of errors during math performance due to difficulties in understanding numbers, counting skills, computational skills and solving problems. Kosc (1974) suggested that dyscalculia could occur in different combinations and also with other impairments. Owing to the significance of number processing, there is greater awareness in the past few decades that difficulties in mathematics frequently occur concurrently with language difficulties (Chinn and Aschroft, 1993). In general, the neuropsychological models of number processing attempt to explain manipulation of numbers using Arabic notation, spelled-out numerals or as an abstract quantity representation accounting for certain inabilities manifested by children with dyscalculia.

While literature is available for English language and Arabic numerals, similar studies in non-English languages are scanty. Kannada, a Dravidian language has terms that are borrowed as its origin is from Sanskrit. For example, the specific lexicon of mathematical terminology such as '*dashaka*' in Kannada language means 10's; terms used for general language purpose, such as '*hadi*' indicating the teen numbers which is also symbolically used to represent the meaning of 'teen age' (*hadi haraya)*; the bilingual lexicon (the term 'bilingual' is used here to indicate words that cut across general language and mathematical language as explained in the examples) such as '*kaalu*' meaning 'quarter' (specific mathematical lexicon), and '*leg*' (general language lexicon) in Kannada language has not been studied till date. There is a need to understand its relevance to develop suitable tests and remedial programs for children with dyscalculia. The origin of mathematical symbols, the semanticity of abbreviations used in mathematics and the bilingual nature of numerals is language specific and therefore, is an important area of study to evaluate the relationship among language-reading-mathematical symbols.

The relationship among language, reading and mathematics can also be drawn from several other examples. Reading numerals is similar to reading alphabets or letters (2, 3, 4 as numerals as against a, b, c as alphabets); reading combinations of mathematical symbols that form mathematical lexicon (for example, 2x) is similar to reading words; need to interpret words with differential meaning in general language compared to mathematical language based on the context (for example, square, root, point, slope, etc.,) is closer to the semantics of language. For example, in Kannada, /*hattu*/ meaning 'climb' is used to denote number 'ten'(10); /*elu*/ meaning 'get-up' to denote number 'seven'; words with multiple meanings in mathematics ('square' would mean 'a geometric figure' or a 'mathematical operation') is used as /*chouka*/ in general language meaning 'square' as well as 'towel'. Common mathematical root words in English with different suffixes such as multiply, multiplier, multiplication and multiplicand for which the equivalent words in Kannada are also confusing (/*gunaka*/ 'multiplier'; /*gunya*/ 'multiplicand'; /*gunalabdha*/ or /*shesha*/ 'answer') as it requires morphosyntactic knowledge; Further, the mathematical sentences (for example, 3+3=5) that do not conform to traditional sentence patterns pose additional challenges. The above examples suggest that there is a need for children to develop the ability to derive context specific meaning since communication in mathematics is primarily a linguistic behavior. Schleppegrell (2007) conducted a review of research by applied linguists and mathematics educators that highlighted the pedagogical challenges of mathematics. The review suggests that since the mid-1980's researchers have been pointing to ways that language is implicated in the teaching of mathematics. A key influence has been the discussion by Halliday (1978) on the 'mathematical register'. Halliday pointed out that counting, measuring, and other 'everyday' ways of doing mathematics draw on 'everyday' language, but that the kinds of mathematics that students need to develop through schooling use language in new ways to serve new functions, such as mathematical performance (Schleppegrell, 2007).

The different aspects of language involved are indicated by the summary of key linguistic features of the mathematics register. There are a few studies examining mathematical ability among children with learning disability (Geary, 2004) reading disability (Jordan, Hanich & Kaplan, 2003; Fuchs & Fuchs, 2002), and specific language impairment (Fazio, 1994) as well. However, there are not many studies on the knowledge of language of mathematics in typically developing children. Thus an effort is made to explore the language of mathematics and its relation to mathematics performance.

While the bilingual lexicon of general language and mathematical language as explained earlier for Kannada language offers certain challenges for learning, there are also specific challenges within the domain of the language of numbers. When a child is learning in a bilingual medium with English as a second language (ESL learners), s (h) e has to learn two representations for each number, the digit as well as the number word. For example, while the notation using the Arabic numerals would be (4, 40), the spoken number is (/four/, /forty/) and the written or spelt number is (FOUR, FORTY). Whereas in Kannada, the numbers are spoken and written the way it is expressed (*/mu:ru/* = 3) since the orthography is direct (transparent, with letters and not alphabets). Children receiving education of Kannada medium are taught Arabic numerals even though digits in Kannada are available since Arabic numerals are used as standard notation across the world. Therefore, the bilingual children's brain must contain mental representations and processes for recognizing, understanding and producing these various notations of numbers and for translating across the notations that highlight the complexity in learning mathematical language. This calls for an understanding of the lexicon of mathematical terminologies in the context of children learning in Kannada medium with mathematical symbols being represented using Arabic numerals that is in practice not only in Karnataka State but also across several schools in other States of India.

OBJECTIVES OF THE STUDY

The main aim of the study was to examine the relationship between knowledge of terms in general language as well as mathematical language and mathematical ability in children. Hence, the study was designed with the following objectives:

To construct a math vocabulary reading test in Kannada for children in Grade IV.

To construct a math language test in Kannada for children in Grade IV.

To determine the relationship between reading math terminology, mathematical language and performance on mathematics by Grade IV children.

METHODS

The study was designed with a purposive sample of IV Grade children studying in Kannada medium. 50 children in the IV Grade (only one section per Grade) were screened for intellectual deficiency if any, using *Gessel's Drawing Test (GDT,* Verma, Pershad & Kaushal, 1972) standardized on mentally retarded children and revalidated on clinical population (Venkatesan, 2002). For ease of administration and scoring, selected drawing test items were arbitrarily classified into:

Preliminary domain that consists ten items at or / below 36 months mental age level.

Intermediate copying domain that consists of 25 items for mental age equivalence between 36 to 120 months.

Advanced three dimensional drawing domain that consists of 10 drawing items with three dimensional perspective at or / above 120 months mental age.

Since the children were in grade IV (approximate age range 9-11 years), the preliminary sections of GDT with simple drawings were not administered. All the children were seated comfortably in a chair with a writing table. Paper and pencil were supplied to draw the picture. The GDT was administered as a group test, for which thirty two picture cards were projected on the wall one by one by using an over head projector (OHP) in the classroom. Children were instructed to draw the picture projected on the wall. The pictures drawn by them were rated as average, above average or below average in intellectual functioning but not quantified (for more details on scoring, please see Venkatesan, 2002). 47 children whose performance was in the average and above average range were selected for the study.

Further, the adequacy of sampling was also examined by setting the confidence level at 95% based on Raosoft sample size calculator (http://www.raosoft.com/samplesize.html). The suggested sample size was 45. However, a total of 47 (28 M; 19 F) children were selected for the study. Children who had minimum of three years of formal schooling with exposure to textbook terminologies were selected. Ethical formalities were followed to avail permission, informed consent and cooperation from teachers, parents and children. Data collection was done for a period of two months in the initial term of the academic year.

Test materials

A battery of tests for math vocabulary, reading math terms, test of arithmetic ability were developed / adopted for the study. Screening test of intelligence was administered to rule out intellectual disability. Table I shows the list of tests.

Table 1
List of Tests

Skills	Test	Developed
Knowledge of Math Language concepts	Test of Math Language (TML)	By the investigators in the project
Math Vocabulary Reading	MathVocabulary Reading Test (MVR)	By the investigators in the project
Arithmetic performance	Arithmetic Diagnostic Test (ADT)	Ramaa (1994)
Intelligence screening	Gessel's Drawing Test (GDT)	Venkatesan (2002)

i) Description of tests and administration procedure

a) Test of Math Language (TML)

TML was developed based on the review of vocabulary in the textbooks of Grades I to IV. Vocabulary used in the textbooks was selected to test knowledge of language concepts related to mathematics in participants of Grade IV. The basic concepts which are prerequisites for mathematical skill such as symbol decoding were included in the TML along with technical terms used in math books such as synonyms in math vocabulary and language vocabulary (for example, /*hattu*/ meaning number 'ten' as well as 'to climb' in Kannada language), terms having different meaning in general language usage (for example, /*biDi*/ means units in mathematical context while in language usage, it means both 'request to leave' as an honorific term and also to represent meaning of 'single', 'free'). A total of 60 items were classified into sub sections to assess math vocabulary in TML

The TML comprised of questions with multiple choices, fill-in the blanks and matching tasks. Small groups of 5-6 participants were made to sit comfortably and the TML was administered as a group test. The participants were able to complete the test in one sitting taking approximately 30 minutes. Each correctly answered item was given a score of 'one'. Total score was 60.

b) Test of Math Vocabulary Reading (MVR)

MVR test was developed based on the math textbooks of Karnataka state syllabus (Kannada) of Grade I through IV. The books were extensively reviewed and a list of words was prepared. All the words in the text that either explained the concept (for example, concept of addition) or used to give instructions to solve problems (for example, addition) were collected. The test was short-listed to sixty words and arranged based on the complexity as per the Graded books.

MVR was administered individually to all the forty-seven participants. They were informed that the test was not for allotting marks and/or grades, but only to note how they read. Each participant was asked to read aloud as many words as possible in the list. They were Approximate time taken by each participant was about 10 minutes. Each correctly read word was given a score of 'one' and the total score was 60.

An item analysis with biserial correlation was carried out for the words in TML and MVR to ensure that the words chosen from the Grade IV text books may be incorporated as test items. Table 2 shows the components and number of items chosen for TML & MVR tests.

Table 2

TML & MVR test components and the number of items

Type of math vocabulary	No. of items
Prerequisite concepts	16
Math terminology	17
Terms with both math and language lexicon	7
Symbol decoding	12
Synonyms	8
Total	60

c) Arithmetic Diagnostic Test (ADT)

ADT was developed by Ramaa (1994) to identify the specific difficulties encountered by the primary school children (Grades I-IV) in solving arithmetic problems. The test covers three major areas of arithmetic namely, number concept, arithmetic processes and arithmetic reasoning. Since the test facilitates diagnosis of arithmetic disability, it includes problems that represent each type and subtype of task to solve arithmetic problem that fall under each major area. Each subtype of the task is represented with two items to examine the difficulties faced by the children in solving arithmetic problem. The sub item and items are arranged in the order of increasing level of difficulty within and between the subsections. The test was administered in small groups. A score of 'one' was given to each correct response. The scores of the addition and subtraction sections of the test were further split into numerical, verbal numerical, verbal-spatial and numerical test scores based on the nature of the task. Table 3 shows the number of items in ADT for Grade IV.

Table 3
Total number of items for Grade IV in ADT

Concept/Operations	Total No. of Items
Number Concept	47
Addition	56
Subtraction	86
Multiplication	46
Division	40
Total No. of Items	275

ii) Content validity, Item analysis and Reliability of the tests

Content validity was established by giving the test items to six experienced teachers and four experts in the field to judge for its appropriateness. . Based on their suggestions suitable modifications were done. The assessment of test reliability was based on the correlations between the individual items or measurements that make up the scale, relative to the variances of the items. Owing to the time constraint (project was run for a period of 6 months only due to want of qualified research officer) and in view of the literature support (http://www.statsoft.com/Textbook/Reliability-and-Item-Analysis#index), other methods of reliability were not executed. Since Item Analysis aids in the design and evaluation of sum scales, that is, scales that are made up of multiple individual measurements (e.g., different items, repeated measurements, different measurement devices, etc.) through which a researcher can evaluate scales following classical testing theory model the items were subjected to Biserial Correlation. Validity index of each item of TML and MVR was determined by the extent to which a given item discriminates among the examinees on the function measured by the test. In order to carry out item analysis the number of participants who responded to the items correctly in selected upper and lower subgroup was noted. The discriminative power of the item, its consistency with total score on the test is gauged by the correlation of the item with the total test score. The biserial is read from a standard table. As a general rule, items with validity indices of 0.20 or more are regarded as satisfactory, and that items with validity indices lower than 0.20 are discarded. Thus, in TML, two items were re-structured to remove ambiguity. In the MVR the validity index for all the items was 0.20 and therefore all the items were retained in the final version. The test was administered individually to a group of 47 participants of Grade IV.

RESULTS AND DISCUSSION

The data obtained from the Test of Math Language (TML), Math Vocabulary Reading Test (MVR), Arithmetic Diagnostic Test (ADT) was analyzed. Descriptive tests of statistics were employed to examine the performance of participants. Table 4 & Figure 1 indicate the mean scores and SD of boys and girls on each of the tests in the battery with p value derived using ‘t’ test.

Table 4

Mean, SD & 't' test scores in MVR, TML, & ADT

Test	Max. Score	Mean score (Boys)	Mean score (Girls)	t test
MVR	60	36.07 (23.85)	43.84 (24.19)	1.08
TML	60	23.18 (14.11)	27.95 (13.27)	1.16
ADT	120	53.79 (34.93)	62.79 (35.75)	0.86

MVR (Math Voabulary Reading); TML (Test of Math Language); ADT (Arithmetic Diagnostic Test)
N=47 (28 Boys; 19 Girls); $p>0.05$

a) Comparison of performance of boys and girls on TML, MVR, and ADT

Descriptive statistics was used to compare the mean scores on Test of Mathematical Language (TML), Math Vocabulary Reading Test (MVR) and Arithmetic Diagnostic Test (ADT). The results indicated that the girls performed better than the boys on all the three tasks (Figure 1). However, there was no significant difference on 't' test when the performance of boys and girls was compared.

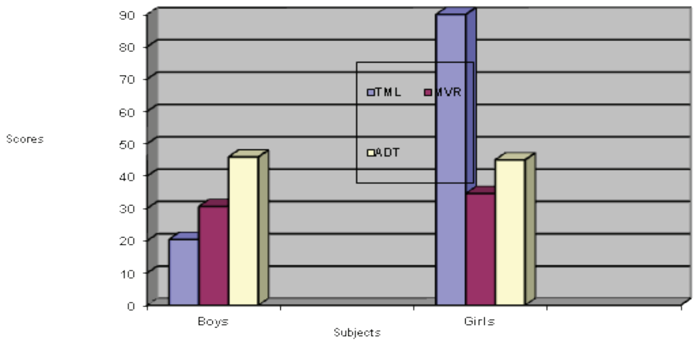

Figure1: Performance of boys and girls on TML, MVR & ADT

b) Comparison of performance of boys and girls in different subtests of TML

The data obtained on the subcomponents of TML was analysed to compare the performance of boys and girls on pre-requisite skills, math technical vocabulary, common terms in both math & language usage, symbol decoding and synonyms. Table 5 shows the details. The mean score difference between boys and girls on subtests of TML shows that girls have performed fairly better than the boys in all the categories of the test, except on synonyms. However, the difference was not significant ($p>0.05$).

Table 5
Mean, SD & 'p' values on sub-tests of TML

Subtests and no. of items	Mean scores (Boys)	Mean scores (Girls)	p value
Pre-requisite skills (16)	8.71 (4.49)	10.32 (4.97)	0.27
Math Technical Vocabulary (17)	3.54 (3.21)	4.47 (3.08)	0.32
Math and language terms (7)	3.00 (1.92)	3.89 (1.82)	0.12
Symbol reading (12)	5.04 (3.98)	6.26 (4.05)	0.31
Synonyms (8)	2.39 (2.70)	2.32 (1.92)	0.92

N=47 (28 Boys; 19 Girls); $p>0.05$

Correlational analysis

The raw scores obtained in the Test of Mathematics Language (TML), Math Vocabulary Reading (MVR) test, and Arithmetic Diagnostic Test (ADT) were analyzed to check for correlation among language, reading and mathematics for the entire group as well as for boys and girls separately. Table 6 shows high correlation among the three tests suggesting interrelationship among the skills necessary to perform on all the three tests.

Table 6
Correlation among TML, MVR, and ADT

Test pairs	Correlation	Significance
TML-MVR	0.88	0.00
MVR-ADT	0.78	0.00
TML-ADT	0.88	0.00

* df = 46; $P<0.05$

The data was also analyzed qualitatively to examine the pattern of errors on items of MVR, TML and ADT. It was observed that the errors were seen on all the domains under study-prerequisite concept, math reading vocabulary, math and language terms. The errors were often related to spatial terms such as short vs. long (3%), up vs. down (4%), right vs. left (6%), More vs. less (7%), first vs. last (8%), before vs. after (16%), , horizontal vs. vertical (16%). In addition, when there were common terms used in both general language as well as in math, the percentage of errors was observed to be more than the terms indicating spatial relationship. For example, percentage of errors ranged from 12 to 18 for terms such as /*hattu*/ meaning 'ten' as well as 'to climb', /*yeLu*/ meaning 'seven 'as well as 'to get up', /*aaru*/ meaning 'six' as well as 'to cool down'.

DISCUSSION

The study was conducted with the objective of understanding if there is relation between language knowledge and mathematical ability. Therefore, the study was designed to explore the relation among language, reading and mathematical abilities in Grade IV children with Kannada as the medium of instruction. The results on correlation analysis indicated that the ability to read math vocabulary, understanding of math language and performance on arithmetic diagnostic test is highly correlated with each other. The scores of ADT, MVR and TML showed a high positive correlation. The correlation among these constructs support the view point proposed by Riccomini, et al., that students' mathematical vocabulary learning is important for their mathematical ability. While average performance was observed on prerequisite concepts and symbol decoding of TML, performance on math technical vocabulary was poor by IV Graders indicating that they are yet to align their general language skills with mathematical language skills. Qualitative analysis showed more number of errors on the basic language terms which act as prerequisite lexicon to math learning concepts (terms like above, below, latter, middle, and so on). The results emphasize the need to incorporate mathematical language teaching in the early Grades at schools. However, there was no significant gender difference in the performance in the study population.

Percentage of failure was observed to be the highest in the category of TML in which there are linguistic terms that are shared between math language and general language. Among the items that required to decode symbolic representation, majority of participants failed in greater than and lesser than item (>&<) which could be either due to poor concept of direction (left-right confusion) or confusion with size adjectives. In general, the results support our premise that language, reading & mathematics are closely related to each other and therefore, any child with mathematical learning disability should be evaluated for general language skills also and supported, if necessary during remedial education. The findings are in support of the findings from Chinn and Aschroft (1993).

The results of the preliminary study emphasize the need to pay particular attention to the linguistic features of the 'mathematical register' as proposed by Halliday (1978) in the process of teaching math to school children in the earlier grades. Teaching prerequisite language concepts before teaching formal classroom math is essential for success in math performance by children. Therefore, language teacher as well as math teacher should make an effort to teach the dual meanings of terms that cut across general language and math language in order to facilitate math-ability. Since majority of children perform better on problem solving when it is in oral mode than in written mode, they should be encouraged to read and understand questions before solving math problems. In general, the results of the study emphasize the relationship among language, reading and mathematics supporting Beilin (1975), Lamb (1980) among others. The results indicate that an adequate foundation in language skills along with the necessary thrust given to build up mathematical language in the early Grades is necessary to develop adequate ability in mathematics in young children.

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