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# Predicting Mathematical Learning Difficulties Using Fundamental Calculative Ability Test (FCAT)

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## ABSTRACT

**Background** Mathematical learning difficulty (MLD) during school years results from several factors, including dyscalculia. Traditional diagnostic tests for dyscalculia are time intensive and require skilled specialists. This prospective cohort study aimed to reveal that the less time intensive Fundamental Calculative Ability Test (FCAT), administered in first grade, can predict the outcome of mathematical school achievement, which was measured with the curriculum-based mathematical test for second grade (1.2 years after FCAT).

**Methods** A total of 362 Japanese first- and second-grade children participated. A new quick test measuring fundamental calculative abilities, the FCAT, ordinal, radix, addition, and subtraction, was conducted for the first graders (mean age: 7.1 years). Mathematical school achievement was measured during the tests [mathematics curriculum-based test in Tottori Prefecture (MCBT)] for first (MCBT-1, mean age: 7.3 years) and second graders (MCBT-2, mean age: 8.3 years). We analyzed the associations between FCAT and MCBT-1 and 2 using univariate regression analysis, and cutoff values for mathematical learning difficulty (MLD) at MCBT-2 using the rating operation curve and Youden index. MLD was set as a score of lower than 20% on the MCBT.

**Results** The FCAT score was significantly associated with the MCBT-1 (regression coefficient: 0.67, $P < 0.001$) and MCBT-2 scores (regression coefficient: 0.50, $P < 0.001$). A cutoff value of 47 points (deviation score: 47) at the FCAT score predicted MLD at MCBT-2 (sensitivity: 0.77, specificity: 0.73). For 62 participants with MLD at MCBT-1 score, FCAT scores below the cutoff value of 40 points (deviation score: 35) were at high risk of MLD at MCBT-2 (odds ratio: 6.2).

**Conclusion** The FCAT is easily conducted in a short time during regular schools and can predict mathematical school achievement. It can be used for the early diagnosis of children with mathematical problems.

**Key words** early diagnosis; education; dyscalculia; learning disabilities, mathematics; quick test

Mathematical learning difficulty (MLD) during school years results from several factors, including global intellectual disability (ID), dyscalculia, educational environment, and family. Fundamental mathematical abilities include all arithmetic facts of addition, subtraction, multiplication, and division of numbers, accuracy and fluency of calculations, and mathematical reasoning, which are the subitems of disabilities in dyscalculia.[1] These measurements along with accuracy, fluency, and mathematical reasoning can be used to evaluate children's fundamental mathematical ability, and may be applicable for early detection and intervention of MLD.[2, 3] On the other hand, in the Japanese educational system, it is difficult to identify children with MLD until the mathematical curriculum progresses to around the third grade, while there is an attempt to identify children with global ID before entrance into elementary school; most of these latter children receive special educational curriculums from first grade.

Dyscalculia is a learning disorder defined as specific developmental impairments in the acquisition of arithmetic skills such as calculation ability.[4] Several diagnostic tools for testing the fundamental mathematical abilities in dyscalculia have been developed.[5–8] Based on the concept that it results from a defect in numerical concepts, Butterworth et al. developed a diagnostic test comprising addition and subtraction, numerical Stroop task, dot enumeration, and reaction time.[5] Von Aster developed the ZAREKI-R test, which measures the concept of numbers, reciting numbers, reading and writing numbers, easy mental arithmetic, comparison of number largeness, and word problems.[6] Inagaki et al. developed a tool that measures arithmetic, mathematical reasoning, and other problems. This is used in the diagnostic

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Abbreviations: FCAT, Fundamental Calculative Ability Test; ID, intellectual disability; MCBT, mathematics curriculum-based test; MLD, mathematical learning difficulty; ROC, receiver operating characteristic

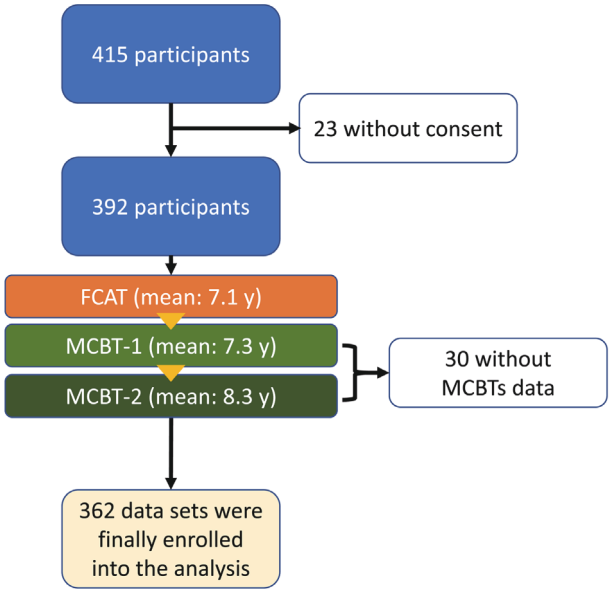


**Fig. 1.** Entry and test flow of the participants. FCAT, fundamental calculative ability test (performed at 1st grade); MCBT-1/2, math curriculum-based test Tottori prefecture at 1st/2nd grades. y, years of age.

guidelines for dyscalculia in Japan.[9] Diagnostic tests for dyscalculia have been applied to predict mathematical school achievement.[10, 11] However, they require long test times and skilled specialists for diagnosis.

Fundamental Calculative Ability Test (FCAT) is a simplified test which evaluates the three elements of basic arithmetic competence of ordinality, cardinality, and computational mechanism of numerical facts, with a time limit to measure computational automaticity, though it is not the complete diagnostic tool for dyscalculia.[12] This test can be performed within 10 min by school teachers who receive short video guidance. We previously conducted a pilot study of the FCAT for first graders.[12] The total score showed an association with the outcomes of mathematical school achievement after 1.2 years.

If early prediction of MLD is possible, the children with high risk of MLD can receive appropriate evaluation and intervention concerning the causes of MLD, including dyscalculia and other problems. If FCAT has the potential to predict MLD, this tool may be applicable for children who need early intervention. In this prospective cohort study, we demonstrated that the FCAT can predict the outcomes of mathematical school achievement in a large population, and confirmed the potential to predict MLD at an early age.

## MATERIALS AND METHODS

### Participants

We initially explained this research to the guardians of 415 Japanese child participants attending regular classes in three elementary schools. The duration of participation in each school was: December 2016 to February 2018, December 2017 to February 2019, and December 2018 to February 2020. In total, 392 guardians agreed to participate and provided written informed consent. After we conducted FCAT on all participants, 30 did not receive the mathematical school achievement tests that are officially provided by the education board in the prefecture, that is, the mathematics curriculum-based test in Tottori (MCBT) for first- or second-graders (MCBT-1 and 2), because of their absence during testing or leaving school during the study duration. Ultimately then, only the datasets from 362 participants were used (Fig. 1).

### Timings of FCAT and MCBTs

In Japan, school begins in April and ends in March the following year. FCAT was conducted in October or December for first-graders. The participants' mean age at the time of the test was 7.1 years. MCBTs were conducted in January or February for first- and second-graders. The mean ages were 7.3 and 8.3 years for MCBT-1 and MCBT-2, respectively (Fig. 1).

### Measurement items in FCAT and MCBTs

#### FCAT

FCAT is a short test comprised of four categories: ordinal numbers, radix, and numerical facts for addition and subtraction. These test concepts were based on the dyscalculia model by McCosky.[13] The test times were set to 1 or 2 min in each category, and the time limitation concomitantly evaluated fluency. The samples of the test items at FCAT are described in Fig. 2, and the test contents are as follows (total: 80 points).

1) Ordinal: The participant wrote a number in the blank space provided in the numerical sequence. The sequences were increased or decreased by one, two, or five. In total, 20 questions were answered within 1 min. One question received one point (total: 20 points).
2) Radix: A line segment is described as the length of a small natural number; that is one, two, or three. The participant selects a line segment that is longer or shorter, corresponding to a certain small natural number from multiple choices. In total, five questions were answered within 2 minutes. One question was scored four points (total: 20 points).
3) Numerical fact (addition): The participant solves

| Category | Example of the question | Test time per a category (min) | Number of questions (score) |
|---|---|---|---|
| **Ordinal** | Write the numbers in the blanks<br>5,__, 7, 8,__<br>2, 4,__, __, 10 | 1 | 20 (20) |
| **Radix** | This is the length of "1"<br>1 ——<br>Check the length of "3"<br>( ) ———<br>( ) ————<br>( ) ————— | 2 | 5 (20) |
| **Numerical facts (addition)** | 5 + 3 = __<br>2 + 7 = __<br>4 + 2 = __ | 1 | 20 (20) |
| **Numerical facts (subtraction)** | 3 – 1 = __<br>8 – 7 = __<br>9 – 8 = __ | 1 | 20 (20) |

**Fig. 2.** Category, examples of questions, test time and numbers of questions in Fundamental Calculative Ability Test (FCAT).

the addition of two single-digit natural numbers without carrying them over. In total, 20 questions were answered within 1 min. One question received one point (total: 20 points).

4) Numerical fact (subtraction): The participant solved the subtraction of two single-digit natural numbers. All answers should be natural numbers. In total, 20 questions were answered within 1 min. One question received 1 point (total: 20 points).

The tests were conducted by the schoolteachers after receiving a lecture on video guidance from the schools. The video guidance included all orders during the test, pre-test training, and guidelines.

### MCBT-1 and MCBT-2

MCBTs measure mathematical skills achievement in elementary schools from grades one to six, officially provided by the board education of Tottori Prefecture, and are compliant with the guidelines of mathematical tests by the Ministry of Education, Culture, Sports, Science, and Technology. MCBTs comprehensively evaluate mathematical skills achievement regarding largeness and smallness of numbers, calculation, amount and measurement of length, dimension and volume, and mathematization from word problems and diagrams. MCBTs were produced for each grade from one to six. We used the results for first- (MCBT-1) and second-graders (MCBT-2) in this study. These tests were conducted at each school attended by participants.

In the pilot study, we referred to previous studies which set MLD as the bottom 20-25% of scores in the curriculum based-mathematical tests[13] and as the bottom 20% in MCBT-1 and 2.[12] Since the FCAT scores showed precise sensitivity and specificity for predicting MLD, we also set MLD as the bottom 20% again. Participants with exact scores of 20% were excluded from MLD.

### Data analyses

We analyzed the associations between FCAT scores and MCBT-1 and 2, using univariate regression analyses, and calculated the correlation coefficient. Then, the cutoff values of the FCAT score for predicting MLD at MCBT-1 and 2 were calculated using the receiver operating characteristic (ROC) curve and the Youden index. We calculated the area under the curve (AUC), sensitivity, specificity, and odds ratio (OR).

This study aimed to identify participants at high risk of MLD at MCBT-2 in those with low MCBT-1 scores. Therefore, regarding the MLD participants at MCBT-1, we analyzed the cut-off value of the FCAT score for the MLD at MCBT-2. For the analyses, we

**Table 1. Results of FCAT and MCBTs (*n* = 362)**

| | Minimum | Maximum | Mean | Standard deviation | Variance |
|---|---|---|---|---|---|
| FCAT | | | | | |
| Total score | 4 | 76 | 44.0 | 13.6 | 184.9 |
| Ordinal | 0 | 20 | 7.2 | 3.9 | 15.4 |
| Radix | 0 | 20 | 8.0 | 6.5 | 42.1 |
| Addition | 0 | 20 | 14.2 | 5.6 | 31.2 |
| Subtraction | 0 | 20 | 12.8 | 5.6 | 31.2 |
| MCBT† | | | | | |
| MCBT-1 | 22.5 | 100 | 85.1 | 13.1 | 170.9 |
| MCBT-2 | 7.5 | 100 | 81.1 | 15.3 | 235.6 |

FCAT, fundamental calculative ability test; †MCBT-1/2, math curriculum-based test Tottori prefecture at 1st/2nd grades.

used the Youden index and ROC curve.

For the analyses, we used IBM SPSS statistical software, version 23.

### Ethics

This study was approved by the local ethics committee of Tottori University Hospital (approval number: 18B016). Informed consent was obtained from all the guardians.

## RESULTS

### FCAT and MCBT scores

We describe each score of FCAT (total, ordinal radix, addition, and subtraction) and the scores of MCBT-1 and 2 in Table 1. Twenty-seven children with MLD at MCBT-1 achieved non-MLD scores at MCBT-2, and 29 children with non-MLD at MCBT-1 entered MLD at MCBT-2.

### Associations between FCAT scores and MCBT scores for 1st and 2nd grade

We describe the associations between the FCAT score and MCBT-1 and 2 scores in Table 2. The FCAT score was significantly associated with MCBT-1 (regression coefficient: 0.67, *P*-value < 0.001) and MCBT-2 scores (regression coefficient: 0.50, *P*-value < 0.001).

We analyzed the cutoff values of the FCAT score for predicting MLD at MCBT-1 and 2. Regarding MCBT-1, 47 points [deviation score (DS): 47.4] was the cutoff with a sensitivity of 0.84 and specificity of 0.73. Regarding MCBT-2, it was also 47 points. The sensitivity was 0.77 and specificity was 0.73. The risks of MLD at MCBT-1 and 2 with scores under the cutoff at FCAT were 14.1 and 9.1%, respectively (Table 3).

**Table 2. Associations between FCAT and MCBT-1/2**

| | Regression coefficients | Correlation coefficients | *P*-value |
|---|---|---|---|
| MCBT-1 | 0.67 | 0.53 | < 0.001 |
| MCBT-2 | 0.50 | 0.49 | < 0.001 |

FCAT, fundamental calculative ability test; MCBT-1/2, math curriculum-based test Tottori prefecture at 1st/2nd grades; We used univariate regression analyses.

### The risk for MLD at MCBT-2 in participants of MLD at MCBT-1

A total of 62 participants with scores lower than the bottom 20% on the MCBT-1 were classified as having MLD. According to the ROC curve and Youden index analyses, those with FCAT scores below the cutoff value of 40 points (DS: 35) were at high risk of MLD at MCBT-2 (positive predictive value: 0.70, negative predictive values: 0.72, sensitivity: 0.86, specificity: 0.5, odds ratio: 6.2), compared to those with FCAT scores over 40 points (Fig. 3).

## DISCUSSION

We performed a large-scale prospective cohort study on the association between mathematical school achievements and fundamental calculative abilities. The FCAT associated with the MCBT-2 scores was predictable for the MLD at MCBT-2 (1.2 years later from FCAT). It was easily conducted in school by the school teachers after the short-time video guidance and completed within 10 minutes. Thus, FCAT may be widely and regularly applied in mathematical education.

We produced the FCAT, which measures the fundamental calculative abilities of first-graders. The

**Table 3. AUC and accuracies of FCAT total scores for MLD† at MCBT-1/2**

| | AUC§ | Cutoff of FCAT total score (DS)‖ | Sensitivity | Specificity | Odds ratio |
|---|---|---|---|---|---|
| MCBT-1‡ | 0.84 | 47 (47.4) | 0.84 | 0.73 | 14.1 |
| MCBT-2‡ | 0.79 | 47 (47.4) | 0.77 | 0.73 | 9.1 |

FCAT, fundamental calculative ability test; †MLD, mathematical learning difficulty; ‡MCBT-1/2, math curriculum-based test Tottori prefecture at 1st/2nd grades; §AUC, area under the curve; ‖DS, deviation score.

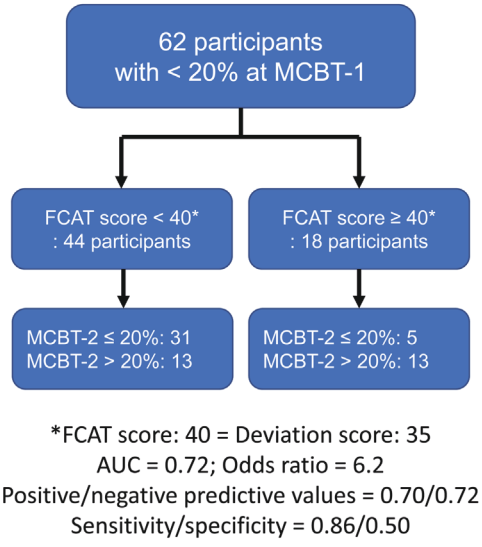


**Fig. 3.** The risks of mathematical learning difficulty with mathematical school achievement tests for the 1st grade by the results of FCAT. FCAT, fundamental calculative ability test; MCBT-1/2, math curriculum-based test Tottori prefecture for the 1st/2nd grades. We used the rate operating curve and Youden index for statistical analyses.

measured items of ordinal, radix, and numerical facts were considered the core abilities of mathematics in the theory of dyscalculia by McCloskey.[14, 15] Fluency in mathematical processing was also associated with MLD in a previous cross-sectional study.[16] These are core abilities for solving mathematical problems and are commonly disrupted in children with dyscalculia and global ID. Children with MLD should have disturbance-mastering mathematical skills in school to address problems with fundamental calculative abilities.[17]

Previous studies have shown that fundamental calculative abilities, measured in the diagnostic steps of children with dyscalculia, can predict MLD. LeFevre et al. reported the associations between the results of a numeracy skill test conducted at 4.5 to 7.5 years of age, and mathematical outcomes after two years.[10] Krajewski et al. revealed that phonological awareness, working memory, and quantity-number competencies at five years can predict mathematical school achievements in third-grade (mean age 8.7 years).[11] However, these studies examined many items in the tests, requiring a long time and evaluations by skilled specialists about dyscalculia.

FCAT can be quickly conducted for first-graders by school teachers through easy steps. The FCAT score showed significant associations with the MCBT-2 scores and could be predicted for MLD with good accuracies for sensitivity of 0.77, specificity of 0.73, and high odds ratio of 9.1. It can be widely applied in school education and does not disturb regular school programs. It is necessary to intervene in dyscalculia or MLD in early school-age children to establish a methodology for early diagnoses of fundamental calculative abilities.[2, 3, 17] Children who were diagnosed with ID or reading/writing disablities received education in special education classes and were excluded from the study. Participants with MLD at MCBTs should include children with dyscalculia. FCAT may contribute to the establishment of early interventions for children with dyscalculia. The low-scoring children at MCBT-1 with low FCAT scores showed a higher risk of MLD at MCBT-1 than those with non-low FCAT scores. Dyscalculia cannot be evaluated using only the mathematical school achievement test.[18, 19] The combination of FCAT and school tests might detect children with dyscalculia with high accuracy and contribute to improving their mathematical skills through special intervention.

This study had some limitations. The participants were from a localized area in Japan. All were Japanese. The language and educational system of Japan may have affected the results. Although MCBTs included tests on geometry, FCAT did not. The duration from FCAT to MCBT-2 was 1.2 years, which was not sufficient. Additional investigations will be necessary in the future. The children were not examined for their intellectual quotient, and we could not accurately distinguish dyscalculia from global ID. We did not evaluate the educational background, familial problems, other developmental disorders and interventions between FCAT and each MCBT test in this study. Those data would give us more meaningful interpretations about MLD, dyscalculia, and other conditions affecting mathematical

achievements in children.

In conclusion, this was a prospective cohort study aiming to reveal the potential of the newly produced fundamental calculative ability test (FCAT) which can predict mathematical school achievement. FCAT is easily conducted quickly during regular school time and could be used for the early diagnosis of children with mathematical problems.

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*The authors declare no conflict of interest.*

## REFERENCES

1 .American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 5th ed. DOI: 10.1176/appi.books.9780890425596.
2 Sella F, Tressoldi P, Lucangeli D, Zorzi M. Training numerical skills with the adaptive videogame "The Number Race": A randomized controlled trial on preschoolers. Trends Neurosci Educ. 2016;5:20-9. DOI: 10.1016/j.tine.2016.02.002
3 Schwenk C, Sasanguie D, Kuhn JT, Kempe S, Doebler P, Holling H. (Non-)symbolic magnitude processing in children with mathematical difficulties: A meta-analysis. Res Dev Disabil. 2017;64:152-67. DOI: 10.1016/j.ridd.2017.03.003, PMID: 28432933
4 .Haberstroh S, Schulte-Körne G. The Diagnosis and Treatment of Dyscalculia. tsch Arztebl Int. 2019;116:107-14. DOI: 10.3238/arztebl.2019.0107
5 Butterworth B. Dyscalculia screener: highlighting children with specific learning difficulties in maths. London: NFER-Nelson Publishing Company Limited; 2003.
6 Von Aster M, Weinhold Zulauf M, Horn R. Neuropsychologische Testbatterie für Zahlenverarbeitung und Rechnen bei Kindern (ZAREKI-R) [Neuropsychological test battery of number processing and calculation in children]. Frankfurt am Main, Germany: Harcourt Publishers Test Services; 2006. German.
7 Jordan NC, Glutting JJ, Dyson N. Number sense screener™(NSS™) User's guide, k-1, research edition. Baltimore: Brookes Publishing; 2012.
8 Peters L, Ansari D. Are specific learning disorders truly specific, and are they disorders? Trends Neurosci Educ. 2019;17:100115. DOI: 10.1016/j.tine.2019.100115, PMID: 31685130
9 Inagaki M, Yoneda R. Specific learning disorder: from a viewpoint of medicine. J Child Adolesc Psychiatry. 2017;58:205-16. DOI: 10.20615/jscap.58.2_205 Japanese with English abstract.
10 LeFevre JA, Fast L, Skwarchuk SL, Smith-Chant BL, Bisanz J, Kamawar D, et al. Pathways to mathematics: longitudinal predictors of performance. Child Dev. 2010;81:1753-67. DOI: 10.1111/j.1467-8624.2010.01508.x, PMID: 21077862
11 Krajewski K, Schneider W. Exploring the impact of phonological awareness, visual–spatial working memory, and preschool quantity–number competencies on mathematics achievement in elementary school: findings from a 3-year longitudinal study. J Exp Child Psychol. 2009;103:516-31. DOI: 10.1016/j.jecp.2009.03.009, PMID: 19427646
12 Ohba S, Koeda T, Maegaki Y. A Numerical Fundamentals Test for the early detection of dyscalculia. Psychiatr Neurologia Paediatr Jpn. 2019–2020;59:199-206. DOI: 10.24782/jsppn.59.2_199 Japanese.
13 Geary DC. Mathematics and learning disabilities. J Learn Disabil. 2004;37:4-15. DOI: 10.1177/00222194040370010201, PMID: 15493463
14 McCloskey M, Caramazza A, Basili A. Cognitive mechanisms in number processing and calculation: evidence from dyscalculia. Brain Cogn. 1985;4:171-96. DOI: 10.1016/0278-2626(85)90069-7, PMID: 2409994
15 McCloskey M, Aliminosa D, Macaruso P. Theory-based assessment of acquired dyscalculia. Brain Cogn. 1991;17:285-308. DOI: 10.1016/0278-2626(91)90078-M, PMID: 1799455
16 Räsänen P, Aunio P, Laine A, Hakkarainen A, Väisänen E, Finell J, et al. Effects of gender on basic numerical and arithmetic skills: pilot data from third to ninth grade for a large-scale online dyscalculia screener. Frontiers in Education. 2021;6:683672. DOI: 10.3389/feduc.2021.683672
17 Price G, Ansari D. Dyscalculia: characteristics, causes, and treatments. Numeracy. 2013;6:2. DOI: 10.5038/1936-4660.6.1.2
18 Kaufmann L, Mazzocco MM, Dowker A, von Aster M, Göbel SM, Grabner RH, et al. Dyscalculia from a developmental and differential perspective. Front Psychol. 2013;4:516. DOI: 10.3389/fpsyg.2013.00516, PMID: 23970870
19 Grigore M. Towards a standard diagnostic tool for dyscalculia in school children. Core Proceedings. 2020;1-16.