

## **Development of components of mathematics in 7-to-11-year-old children: A study using Dynamo Assessment**

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Dynamo Assessment is a computerized assessment that tests children's performance on 14 mathematical components. Four of these components involve number magnitude (visual quantity approximation, ordering numbers, number comparison, estimation); four involve number meanings (counting; single-digit number symbols; multi-digit number symbols; sequencing) and six involve number relationships and arithmetic (number facts; mental strategies; number bonds; problem solving; tens; and multiplication). It has mainly been used to plan interventions. This study aimed to find out more about typically developing children's performance. 2759 children between 7 and 11 underwent the assessment. Key findings are that all tests correlate significantly with one another, and that performance on all tests improves with age. The Number Meaning and Number Magnitude scores correlated negatively with the reaction times to these tests (faster children did better), but the Number Relationships score correlated positively with reaction time (slower children did better). Implications for understanding mathematical development are discussed.

**Key words: Mathematical development; Assessment; 7-to-11-year-olds; Number concepts; Arithmetic.**

### **Background**

Dynamo Assessment is a computer based assessment that takes into account the componential nature of early numeracy. This assessment has so far been predominantly used as a way of diagnosing the components suitable for intervention in children with mathematical difficulties. Dynamo Assessment identifies the mathematical components which the children would be struggling with so that this detailed profile may be used for intervention. Interventions based on the assessment in Malta have shown promising initial results (Zerafa & Dowker, 2016).

The subtests may be grouped into Number Magnitude, Number Meaning and Number Relationships, adding the scores for the tests in each group. Number Meaning includes Visual discrimination and approximation; Counting; Number as Symbols-Single-digit; and Number as Symbols –Double digit. Number Magnitude includes Comparison; Estimation; Ordering Numbers; and Number Sequencing. Number Relationships includes Number Facts; Mental Strategies; Number Bonds; Problem Solving; Time and Multiplication.

The assumption in the diagnostic use of the assessment has been that Number Magnitude and Number Meaning represent aspects of 'number sense' that are

impaired in children with significant mathematical disabilities that may be termed 'developmental dyscalculia'. Number Relationships may represent arithmetical understanding that is more dependent on school instruction, and may be delayed in children with no underlying mathematical disabilities.

In the present study, however, no assumption is made about the underlying causes of differences in performance on these components.

## **Aims**

One key current aim is to standardize the measure, to find age norms for typically developing children. For this purpose, 2385 children between 7 and 11 have been given the assessment. Standardization is still in progress, and will not be the subject of the present report.

The aims that will be discussed here are:

To investigate the extent to which children improve with age in scores and reaction times in the three groups of tests.

In particular, to investigate whether age-related differences exist only on the Number Relationships tests, while showing ceiling effects on the others; or whether there are age-related differences on all groups of tests.

To investigate the extent to which different groups of tests correlate with one another.

To investigate the extent to which scores correlate with reaction times.

## **Method**

Participants were 2385 typically developing children from London primary schools, with which the second author had contact. They included 280 seven-year-olds; 627 eight-year-olds; 594 nine-year-olds; 526 ten-year-olds; and 358 eleven-year-olds. They were all given the Dynamo Assessment described above.

In this study, there were two aspects of the three groups of tests that were analysed:

- (1) Each child's combined scores on the tests in each group.
- (2) The combined mean reaction times of each child to the tests in each group. (Only reaction times for correct answers were included.)

## **Results**

### *Scores*

Pearson correlations were computed between Number Magnitude, Number Meaning and Number Relationships combined scores. All correlations were significant at the 0.01 level.

Table 1: *Mean Number Magnitude, Number Meaning and Number Relationships Combined Scores by age group*

	Mean Number Magnitude Combined Score out of 20	Mean Number Meaning Combined Score out of 20	Mean Number Relationships Combined Score out of 30
7-year-olds	12.18 (s.d. 4.74)	14.04 (s.d. 5.2)	9.54 (s.d. 6.98)
8-year-olds	11.78 (s.d. 4.75)	14.54 (s.d. 1.66)	9.78 (s.d. 7.15)
9-year-olds	12.87 (s.d. 5.18)	18.65 (s.d. 2.11)	10.01 (s.d. 6.74)
10-year-olds	14.04 (s.d. 6.63)	18.99 (s.d. 1.76)	19.41 (s.d. 1.35)
11-year-olds	14.54 (s.d. 5.48)	19.3 (s.d. 1.39)	19.28 (s.d. 7.1)

A Between Participants Analysis of Variance was carried out, with Age Group as the between-participants factor, and Number Magnitude Combined Score, Number Meaning Combined Score and Number Relationships Combined Score as the dependent variables.

There was a highly significant effect of Age Group on Number Magnitude Combined Score ( $F(4,2381) = 24.467$ ;  $p = 0.001$ ). Tamhane 2 post hoc tests showed that there were no significant differences between 7- and 8-year-olds, 7- and 9-year-olds, or 10- and 11-year-olds; but there were highly significant differences between 7- and 10-year-olds, 7- and 11-year-olds, 8- and 9-year-olds, 8- and 10-year-olds, 8- and 11-year-olds, 9- and 10-year-olds and 9- and 11-year-olds. All significant differences were in the direction of older children scoring higher.

There was also a highly significant effect of Age on Number Meaning Combined Score ( $F(4,2381) = 13.26$ ,  $p = 0.001$ ). Tamhane 2 post hoc tests showed that there were no significant differences between 7 - and 8-year-olds, 8- and 11-year-olds, 9- and 10-year-olds, 9-and 11-year-olds or 10-and 11-year-olds. There were, however, highly significant differences between 7 -and 9-year-olds , 7 - and 10-year-olds, 7 and 11-year-olds and 8- and 10-year-olds. All significant differences were in the direction of older children scoring higher.

There was also a highly significant effect of Age on Number Relationships Combined Score ( $F(4,2381) = 12.86$ ;  $p = 0.001$ ). Tamhane 2 post hoc tests showed that there ere no significant differences between 7 - and 8-year-olds, 7 - and 9- year-olds , 8-and 9-year-olds or 10-and 11-year-olds. There were, however, highly significant differences between 7 - and 10-year-olds, 7 and 11-year-olds, , 8- and 10-year-olds, 8- and 11-year-olds, 9-and 10-year-olds and 9-and 11-year-olds. All significant differences were in the direction of older children scoring higher.

To investigate the effect of Number Magnitude and Number Meaning on school-type mathematical learning (Number Relationships), an entry-type multiple regression was carried out on Number Relationships Combined Score. The predictor variables included were Number Meaning, Number Magnitude, and Age in years. Number Magnitude Combined Score was a highly significant predictor ( $\beta = 0.313$ ;  $t = 12.92$ ;  $p < 0.001$ ). Number Meaning Combined Score was also a highly significant predictor ( $\beta = 0.091$ ;  $t = 3.784$ ;  $p < 0.001$ ). Age was also significant ( $\beta = 0.48$ ;  $t = 2.46$ ;  $p = 0.014$ ).

### ***Reaction Times***

Pearson correlation coefficients were computed between Number Magnitude Combined Reaction Time, Number Meaning Combined Reaction Time and Number Relationships Combined Reaction Time. The reaction times were also correlated with the scores for these groups of tests correlated significantly with one another and with the test scores ( $p < 01$  in all cases).

Number Meaning Combined Reaction Time correlated negatively with Number Relationships Combined Reaction Time, but the other reaction time correlations were positive. For Number Meaning and Number Magnitude, the combined reaction times correlated negatively with the combined scores (high performance was associated with speed. Unexpectedly, however, Number Relationships Combined Score correlated positively with Number Relationships Reaction Time.

Table 2 *Mean Number Magnitude, Number Meaning and Number Relationships Combined Reaction Times by age group*

	Mean Number	Mean Number	Mean Number
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	Magnitude Combined Reaction Time	Meaning Combined Reaction Time	Relationships Combined Reaction Time
7-year-olds	291.95 (s.d. 171.19)	103.93 (s.d. 78.46)	690.78 (s.d. 422.62)
8-year-olds	301.53 (s.d. 154.06)	87.18 (s.d. 60.56)	786.57 (s.d. 455.76)
9-year-olds	261.21 (s.d. 147.3)	70.23 (s.d. 47.97)	874.75 (s.d. 433.82)
10-year-olds	250.93 (s.d. 177.97)	61.48 (s.d. 38.34)	931.18 (s.d. 472.88)
11-year-olds	215.8 (s.d. 166.99)	59.11 (s.d. 38.56)	889.31 (s.d. 435.98)

A Between Participants Analysis of Variance was carried out, with Age Group as the between-participants factor, and Number Magnitude Combined Reaction Time, Number Meaning Combined Reaction Time and Number Relationships Combined Reaction Time as the dependent variables.

There was a highly significant effect of Age on Number Magnitude Number Magnitude Combined Reaction Time ( $F(4,2381)= 14.99$   $p = 0.001$ ). Tamhane 2 post hoc tests showed that there were no significant differences between 7 and 8-year-olds, 9 and 10-year-olds, 9- and 11-year-olds, or 10- and 11-year-olds. However, there were significant differences between 7- and 9- year-olds, 7 - and 10-year-olds, 7- and 11-year-olds, 8- and 9-year-olds, 8- and 10-year-olds, and 8- and 11-year-olds., All significant differences were in the direction of older children having shorter reaction times.

There was also a highly significant effect of Age on Number Meaning Combined Reaction Time ( $F(4,2381)= 37.574$   $p = 0.001$ ). Tamhane 2 post hoc tests showed that all differences between ages were significant, except between 10- and 11-year-olds. All significant differences were in the direction of older children having shorter reaction times.

There was also a highly significant effect of Age on Number Relationships Combined Reaction Time ( $F(4,2381)= 14.946$ ;  $p = 0.001$ ). Tamhane 2 post hoc tests showed that there were no significant differences between 9-and 10-year-olds; 9- and 11-year-olds; or 10-and 11-year-olds. However, there were highly significant differences between 7 - and 8-year-olds, 7 -and 9-year-olds; 7-and 10-year-olds, 7 and

11-year-olds, 8- and 10-year-olds and 8- and 11-year-olds. Surprisingly, the significant differences were in the direction of older children having longer reaction times.

## **Discussion**

As regards *scores*, there was a strong improvement with age on all groups of tests. For both Number Magnitude and Number Relationships, the biggest age differences were between 7-to-9-year-olds and 10-to 11-year-olds. For Number Meaning, the biggest age differences seem to be between 7-year-olds and older children, and between 9-year-olds and older children. This could, however, reflect a slight tendency for ceiling effects in the older children for Number Meaning. All test group scores correlated significantly with one another. Both Number Magnitude and Number Meaning scores were strong independent predictors of Number Relationships scores, suggesting that basic numerical abilities and concepts predict more formal arithmetic in a typically developing group and not only when they are impaired.

As regards *reaction times*, older children were faster than younger children at the Number Magnitude and Number Meaning tasks; but older children are slower than younger children at Number Relationships tasks. A related finding was that faster reaction times were related to higher scores for Number Magnitude and Number Meaning, but slower reaction times were related to higher scores for Number Relationships. These are somewhat puzzling results, but perhaps suggests that older and more able children are using more reflective, analytical strategies, that are more effective but slower, for this more formal group of tests. Further research could investigate what these strategies are, and whether these strategies are developed predominantly in response to instruction, or more spontaneously through experience.

There is variability in all the scores, including the Number Magnitude and Number Meaning scores, as well as the Number Relationships scores. There are no ceiling effects, except perhaps for the oldest children with regard to Number Meaning. Thus, Dynamo Assessment is likely to prove a useful measure for the study of individual and developmental differences in typically developing children as well as in those with mathematical difficulties.

## **Reference**

Zerafa, E. & Dowker, A. (2016). Supporting children with mathematics learning difficulties: An intervention programme with primary school children.