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ACCEPTED ARTICLE PREVIEW

Nature and origins of mathematics difficulties in very preterm children: A different etiology than Developmental Dyscalculia

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Abstract

Background. Children born very preterm (<32 weeks) are at high risk for mathematics learning difficulties that are out of proportion to other academic and cognitive deficits. However, the aetiology of mathematics difficulties in very preterm children is unknown. We sought to identify the nature and origins of preterm children's mathematics difficulties.

Methods. 115 very preterm children aged 8-10 years were assessed in school with a control group of 77 term-born classmates. Achievement in mathematics, working memory, visuo-spatial processing, inhibition and processing speed were assessed using standardised tests. Numerical representations and specific mathematics skills were assessed using experimental tests.

Results. Very preterm children had significantly poorer mathematics achievement, working memory and visuo-spatial skills than term-born controls. Although preterm children had poorer performance in specific mathematics skills, there was no evidence of imprecise numerical representations. Difficulties in mathematics were associated with deficits in visuo-spatial processing and working memory.

Conclusions. Mathematics difficulties in very preterm children are associated with deficits in working memory and visuo-spatial processing not numerical representations. Thus very preterm children's mathematics difficulties are different in nature from those of children with developmental dyscalculia. Interventions targeting general cognitive problems, rather than numerical representations, are needed to improve very preterm children's achievement.

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Children born very preterm (<32 weeks gestation) are at high risk for adverse cognitive outcomes including intellectual disability, learning difficulties and special educational needs (1,2). In particular, very preterm children have substantial difficulties with mathematics that are not accounted for by low intelligence (IQ) (see 3 for review). Although mathematics difficulties are especially common, the nature and causes of these difficulties remain unexplained. To elucidate underlying mechanisms it is necessary to consider the influence of both general cognitive skills and specific mathematics skills. A range of executive functions have been found to be important for mathematical achievement (4), including working memory (5), inhibition (6), visuo-spatial skills (7) and processing speed (8). Alongside these, a number of specific mathematics processes are also related to achievement (9) including basic counting skills (10), the ability to apply efficient strategies (11) the accuracy and speed of retrieval of basic number facts (12) and the conceptual understanding of mathematics (9).

Most recently, studies have identified the importance of the Approximate Number System (ANS), a cognitive system that supports the representation and manipulation of quantity information, for mathematical achievement (13). The acuity of ANS representations are measured using magnitude comparison tasks which require participants to quickly compare two quantities presented in either a symbolic or non-symbolic format (Figure 1) (6). Measures of accuracy and reaction time (RT) on these tasks have been shown to correlate with mathematics achievement (13). In particular, individuals with Developmental Dyscalculia, a learning disorder characterized by specific difficulties in mathematics, have poorer ANS acuity compared to those with typical development (14).

While progress has been made in understanding the cognitive mechanisms underlying Developmental Dyscalculia, researchers have yet to undertake a comprehensive evaluation of

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the general cognitive functions and mathematics specific processes which may underpin mathematics difficulties in preterm children. Although the similar behavioural profiles suggest that the same mechanisms may underlie difficulties in both groups, there is reason to believe that their cognitive profile may differ. It is plausible that very preterm children's difficulties may stem from their core deficits in visuo-spatial processing, working memory and processing speed rather than imprecise numerical representations (3). A handful of studies have assessed numerical representations in very preterm children with contradictory results (15,16,17,18). Where imprecise numerical representations have been reported (17,18) the experimental techniques used were unconventional and increased the general cognitive demands of the task making them especially detrimental for preterm children, or mathematical achievement was not assessed. Thus it is difficult to ascertain whether group differences were methodological artefacts *or* were related to poor achievement.

We have previously observed that basic quantity processing explained a small amount of unique variance (2%) in the mathematical achievement of extremely preterm (<26 weeks) children. However, as general cognitive deficits accounted for the majority of variance, this suggests that these may play an important role and that there may be an interaction between the two skill domains (19). Crucially, as no studies have measured general cognitive skills concurrently with numerical representations and a range of specific mathematics skills (18), the cognitive bases of preterm children's mathematical difficulties remain unknown. The aims of the present study were to determine whether mathematical processing deficits in very preterm children are similar to those of children with Developmental Dyscalculia and to identify the specific nature of mathematics difficulties in children born very preterm.

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Results

There were no significant differences between very preterm children recruited (n=115) and not recruited (n=150) in birthweight (mean difference -7.72g; 95% CI -107.26, 91.82, p=0.88) or gestational age (-0.20 weeks, -0.74, 0.34, p=0.46), and there was no association between recruitment and IMD group (χ^2=0.31, p=0.86), demonstrating that the very preterm sample were representative of the total eligible population. In addition, very preterm and control participants were successfully matched for gender, age, mother's age, maternal educational qualification and occupational class. However, there was a significant association between group and area-level socio-economic deprivation as measured by the Index of Multiple Deprivation (IMD) tertile score (20) (Table 1). There were no group differences between very preterm children who did or did not have a matched control in non-verbal IQ (t_{111}=-0.25, p=.247) or mathematics achievement (t_{111}=-0.97, p=.330).

Performance on general cognitive tests and specific mathematics tasks are shown in Table 2. Very preterm children had significantly poorer mathematical achievement than term-born controls ($t(188) = -4.24$, $p < .001$, $d = 0.62$, Figure 2a). This difference persisted after controlling for non-verbal IQ ($F(1, 187) = 11.65$, $p < .001$, $d = 0.61$) and social deprivation ($F(1, 185) = 14.14$, $p < .001$; Table 3a). Very preterm children also had significantly poorer working memory ($t(187) = -3.47$, $p < .001$, $d = 0.55$) and visuo-spatial skills ($t(188) = -3.84$, $p < .001$, $d = 0.57$) which remained significant after controlling for IMD tertile (working memory: $F(1, 184) = 9.80$, $p = .002$; visuo-spatial skills: $F(1, 185) = 11.37$, $p < .001$; Table 3a). As shown in Table 2, we did not observe significant group differences in processing speed ($t(187) = 2.34$, $p = .02$) or inhibition ($t(188) = -2.49$, $p = .014$).

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On tests of specific mathematics skills (Figure 2b; Table 2), very preterm children displayed significantly poorer counting proficiency than term-born controls ($t(188) = -3.21$, $p = .002$, $d = 0.48$) and used less sophisticated strategies when solving simple arithmetic problems ($t(189) = -3.10$, $p = .002$, $d = 0.46$); these differences persisted after controlling for social deprivation (Table 3a). Importantly, group differences in strategy use and counting were negated after controlling for working memory and visuo-spatial skills (Table 3b). There were no other significant group differences in specific mathematics tasks (Figure 2b).

Performance on the tests of basic numerical representations was assessed using accuracy, and response times. All of these measures showed the same pattern of results. For the whole sample, accuracy rates were higher for the symbolic task than the non-symbolic task (M_{sym} = 92.91%. $M_{non\text{-}sym}$ = 73.72%; $F(1, 189) = 645.65$, $p < .001$), but importantly there was no effect of group ($F(1, 189) = 1.82$, $p = .179$) or interaction between group and task ($F(1, 189) = 0.14$, $p = .705$) on accuracy. A similar pattern was observed for response times, overall responses were faster for the symbolic compared to the non-symbolic version of the task (M_{sym} = 0.91s., $M_{non\text{-}sym}$ = 1.27s, $F(1, 189) = 515.58$, $p < .001$). Again there was no effect of group ($F(1, 189) = 0.09$, $p = .771$) and no interaction between group and task ($F(1, 189) = 1.91$, $p = .169$).

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Discussion

Very preterm children had significant difficulties in mathematics and in a number of general and specific skills associated with mathematical achievement. Their deficit in mathematical achievement was of a similar magnitude to previous studies (3) and was not attributed to differences in non-verbal IQ or socio-economic deprivation. Commensurate with previous studies, this performance was indicative of a specific problem with mathematics rather than simply reflecting a difference in general intelligence or socio-economic factors (21).

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Importantly, we have shown that very preterm children did not show evidence of imprecise numerical representations and their poorer performance in specific mathematical tasks was entirely accounted for by their domain-general deficits in working memory and visuo-spatial skills, but not non-verbal IQ.

These results indicate that the aetiology of poor mathematical achievement differs between children born very preterm and those with Developmental Dyscalculia. Deficits in basic numerical representations associated with Developmental Dyscalculia have been linked with structural and functional abnormalities in the bilateral intraparietal sulci (22). In contrast, brain development after very preterm birth has been described as an amalgam of developmental and destructive influences associated with complex neurocognitive deficits (23). Intraparietal sulcal development and function have not been studied in preterm populations, but we would predict that functional imaging during numerical representations tasks would result in different activation patterns between preterm children and those with Developmental Dyscalculia.

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Previous studies that have attempted to establish the potential causes of preterm children's mathematical difficulties have generated conflicting results, largely due to methodological differences. In a previous study we established a small but significant contribution of numerical representations to extremely preterm children's mathematical achievement, explaining 2% of the variance in performance. However, this study used a crude 12-item measure of numerical representations in contrast to the rigorous experimental measures used in the current study. Moreover, general cognitive factors accounted for a substantially larger proportion of the variance (70%) than numerical representations. A recent study has also shown that mathematics difficulties in preterm children are related to deficits in IQ, rather

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than being specific learning difficulties, but this did not include any measures of specific mathematical skills to explore the nature of mathematics difficulties (24).

In contrast, Helgren and colleagues (2013) recently suggested that the causes of preterm children's (unmeasured) mathematical difficulties could be attributed to imprecise numerical representations. However, we suggest that the unusual intermixed presentation of stimuli used in their study placed additional visuo-spatial demands on participants. In fact, in our study we observed that very preterm children had substantial deficits in visuo-spatial processing and these were related to their proficiency in mathematics. This emphasises the importance of the careful creation of experimental stimuli which take into account the known cognitive deficits of the population under study.

In the present study we did not observe any group differences in performance using a standard and carefully controlled magnitude comparison task and thus can conclude that the measured deficits in mathematical performance in our very preterm sample were not attributable to poor numerical representations. This finding corroborates the results of Guarini et al. (2014) who did not find poorer numerical representations in their 8-year-old cohort when compared to control children. However, there is still the potential that these difficulties may be present at an earlier age and longitudinal data are required to confirm this (18). Although children between 8 and 10 years-old were assessed in the present study, the sample size was insufficient to assess the developmental trajectory of these skills within this cohort.

We noted that very preterm children had specific difficulties in working memory and visual-spatial skills, and that these deficits accounted for group differences in strategy use and counting skills. These general cognitive skills have also been identified as being important for mathematical achievement in typically developing children (4,7). Deficits in visuo-spatial

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skills and working memory are frequently reported in preterm samples (41) however this is the first study to identify that general cognitive deficits can explain group differences in specific mathematical skills, which in turn are known to contribute to more complex mathematical performance (4,7,18).

Very preterm children in the present study did not display a significant deficit in inhibition. Although this is in contrast to other studies which have observed deficits in both inhibition and processing speed, there is some inconsistency with regard to the impact of very preterm birth on these skills (25) and, given the task dependent nature of assessment of these skills, there is variation in effect sizes dependent on the measures used (26). In particular, verbal, rather than motor, processing speed has been shown to explain very preterm children's academic deficits (27). Importantly, in the present study we applied Bonferroni Correction to adjust for multiple comparisons. Although this is a conservative approach, this minimises the likelihood of type 1 errors and thus allows us to be sure that group differences observed in the present study are true differences. Differences between our findings and those of others may be explained by the lack of correction for multiple comparisons in previous research.

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Our study has a number of clear strengths such as the unique use of a battery of both standardised and experimental tasks to elucidate the specific nature of mathematics difficulties in preterm children. The dot and digit comparison stimuli were carefully controlled to allow a rigorous assessment of numerical representations, and this is the first study to assess both general cognitive skills *and* specific mathematic skills alongside mathematical achievement in this population. We were also able to recruit a sample of very preterm children who were matched as closely as possible on key factors affecting academic achievement. However, recruitment of control children was lower than that of very preterm

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children resulting in a smaller sample and a significant difference in IMD between the two groups. However, in order to ensure that matched controls were from the same class as each very preterm child this was unavoidable, and analyses were adjusted for IMD scores to account for this difference.

A priority for our research is to inform the development of interventions to improve academic performance in very preterm children. Within the English education system all children are closely monitored and assessed by teaching staff in relation to curriculum benchmarks. Children who have identified learning disorders are provided with an Individual Education Plan, detailing specific educational learning approaches and goals for the child (28). Numerous interventions have been developed for children with mathematical (29) and working memory (30) difficulties. To date, these interventions have had varying success with different populations; however, their efficacy in improving very preterm children's educational achievement has not been established (31). Additionally, in general populations the most frequent co-morbidities with mathematical learning difficulties are dyslexia and ADHD (32). In the present study, 100% (N=11) of very preterm children with standardised mathematics scores <70 (scores < -2SD) had identified special educational needs (SEN) and 78% (N=31) of very preterm children with standardised scores <85 (scores < -1SD) had SEN, compared with 16% (N=9) with scores in the average range. Thus preterm children with mathematics difficulties were clearly recognised by teachers as struggling in the classroom. Further studies are required to investigate specific co-morbidities of mathematical difficulties in very preterm children which may have implications for intervention development.
Our data suggest that rather than relying on existing interventions to enhance numerical representations developed for children with Developmental Dyscalculia (13) alternative interventions targeting both working memory and visuo-spatial abilities alongside

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mathematics-specific skills may be beneficial for children born preterm (33). Simply focusing on only one of these areas of deficits in interventions may have limited or null impact. For example, there has been recent interest in adaptive working memory interventions yet evidence for transfer to academic performance is lacking in children born preterm (33). Alternatively, the development of mathematics teaching methods that place fewer demands on both working memory and visuo-spatial skills may be beneficial; such as breaking complex tasks down into simple steps and the use of concrete manipulatives and structured worksheets to scaffold visual-spatial information. These types of whole-class interventions may have wider benefits for all children in the classroom. Further research is required to develop and assess the efficacy of interventions for very preterm children.

Given the continued rise in global preterm birth rates (34) and the lack of improvement in neurocognitive outcomes for babies born at the most preterm gestations (35) identifying effective intervention strategies will have benefits not only for individual children, but society as a whole. An increasing body of evidence emphasises the importance of early proficiency in mathematics for an individual's future employment and earning potential, in fact mathematics skills are reported as being more important than reading skills in predicting life chances (36). Improving mathematics skills in this population may therefore have far-reaching effects and may contribute to reducing the growing societal and economic burden posed by very preterm birth.

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Method

Participants

All children born <32 weeks gestation from September 2001 to August 2003 and admitted for intensive care in 2 UK neonatal centres (comprising 3 tertiary hospitals) were invited to participate. Of 266 eligible children, the parents of 125 children responded. As the study

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required children to be in mainstream school and to complete psychometric tests, 8 children were excluded (2 lived abroad, 3 attended special school and 3 had severe disability precluding them from participating in study tests). Therefore, 117 (44%) were recruited to the study of whom 115 were ultimately assessed (assessments could not be scheduled for two children). For each very preterm child recruited, his/her teacher identified three classmates of the same age and gender and born at term (37-42 weeks). One of these classmates was then randomly selected to participate. If consent was not received for the first child, one of the remaining children was randomly selected until a matched control participant was identified using standard procedures (37). We were unable to recruit some controls due to teachers being unable to identify a child meeting the inclusion criteria or due to lack of access to the very preterm child's school. As one control child was excluded due to prematurity, a total of 77 term-born controls were recruited.

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Procedure

Ethics approval was obtained from the Derbyshire National Health Service Research Ethics Committee and informed parental consent was obtained for all children. Children were assessed in school (93%) or at home (7%) by one of two psychologists who were blind to group membership. Excellent inter-rater reliability was recorded with an average of 98% agreement on test items between the two psychologists. Parents were sent a feedback letter detailing their child's test results.

Measures

To assess achievement in mathematics, children completed the Wechsler Individual Achievement Test-II (WIAT-II) from which a Mathematics Composite score was derived (mean 100; SD 15).

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General cognitive skills were assessed with standardised tests including (i) Raven's Coloured Progressive Matrices (RCPM) to assess non-verbal IQ from which a standardised score was derived (mean 100; SD 15). (ii) Three working memory tasks comprising a backwards digit recall task, a backwards word recall task and the Mr X visuo-spatial working memory task from the standardised Automated Working Memory Assessment (AWMA) from which a composite working memory score (mean 12.52; SD 3.74; range 5.67-25.00) was calculated. (iii) Rapid Automatised Naming (RAN) to assess processing speed from which an average composite score was calculated (mean 32.33; SD 9.23; range 18.25-74. (iv) Developmental Neuropsychology Test (NEPSY-II) Arrows sub-test to assess visuo-spatial processing and the Inhibition sub-test for inhibition skills; scaled scores were derived for both (mean 10; SD 3).

The accuracy and precision of numerical representations were measured using computerised non-symbolic and symbolic magnitude comparison tasks (Figure 1). Two quantities were presented simultaneously on the screen and children were asked to select the more numerous. In the non-symbolic task quantities were sets of dots and in the symbolic task quantities were Arabic digits. Presentation side of the more numerous quantity was counterbalanced. Quantities ranged from 5 to 30 and the ratio between the quantities varied (0.5, 0.6, 0.7 and 0.8). Dot stimuli were carefully controlled for visual characteristics of the arrays (6). Each task consisted of 80 trials and performance was assessed by accuracy and mean RT (for correct responses only). To measure skills in estimating the position of numbers on a number line, children were asked to mark the position of 22 different numbers on a series of blank number lines with the left end labelled 0 and the right 1000, following similar methods used in previous studies (10). A mean score for percent absolute error was calculated as the average distance between the actual and estimated positions of the numbers. This measure was reversed to indicate performance accuracy.

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To explore the nature of mathematics difficulties and pin-point areas of specific deficit, mathematics skills were assessed using experimental measures adapted from Cowan and colleagues (9). (i) In a digit recognition task, children were asked to name numbers presented randomly on a computer screen as quickly as possible. Response time (RT) was recorded by a key press by the examiner and median RT to name the stimuli was calculated. (ii) Basic counting ability was measured by asking children to count aloud eight series of number sequences from memory (e.g., ascending: 2995-3004; descending: 325-317); overall percentage accuracy was calculated. (iii) To assess number fact knowledge, a series of 12 single-digit addition problems were read out by the experimenter and children were asked to respond with their answer as quickly as possible. Correct answers produced within 3 seconds were recorded as a known fact; the overall percent of known facts was calculated. (iv) Children completed 16 single-digit addition and subtraction problems to assess arithmetic strategy sophistication. For each problem, children were asked to give their answer and then describe how they had reached it. Children were classified as using a mature strategy if they used retrieval (recall from memory) or decomposition (mental calculation e.g. 6 + 9 = 9 + 1 + 5). The percentage of problems completed using mature strategies was recorded. (v) Finally, a series of 12 large-number addition and subtraction problems were used to assess understanding of arithmetic concepts. First, a problem with its answer was presented on the computer screen, and then beneath it a related problem was presented without an answer (e.g. 27+69=96; 96-69=?). These problems were selected so that 8-10-year-olds would be unlikely to be able to solve them within the specified time limit (10 seconds) unless they used conceptual insight, such as applying inverse or commutativity rules. The percentage of correct answers was recorded.

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Parents completed questionnaire items from which three indices of socio-economic status were derived: (i) IMD (20) tertile indicating whether the family lived in the least, middle or most deprived area of the UK; (ii) occupational class defined using National Statistics Socio-Economic Classification (38); (iii) mother's highest educational qualification dichotomised as secondary vs. higher education level.

Statistical analyses

Independent-samples t-tests and chi-squared analyses were used to assess differences in characteristics between very preterm children who were and were not recruited and between very preterm children and controls. Group differences in preterm and control children's performance on all measures were analysed using independent samples t-tests. Bonferroni corrections were applied due to multiple comparisons reducing the alpha value to $p < 0.0036$ (i.e. 0.05/14). Multivariate analyses of covariance (MANCOVA) were conducted to compare performance on primary outcome measures using (i) IMD group and (ii) working memory and visuo-spatial skills as covariates given the group differences observed on these measures. Mixed-design analyses of variance (ANOVA) were used to investigate group differences in basic numerical representations using two metrics (accuracy and RTs).

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Table 1: Sample characteristics

Characteristic	Controls n=77	Very Preterm n=115	p
Gestational age (weeks), median (IQR)	-	28.57 (2.01)	-
Birthweight (g), mean (SD)	-	1213.20 (365.41)	-
Male sex, n (%)	40 (51.9%)	63 (54.8%)	0.70
Age at assessment (years), mean (SD)	9.51 (0.68)	9.70 (0.69)	0.08
Mothers age (years), mean (SD)	40.18 (5.96)	40.32 (5.47)	0.89
Index of Multiple Deprivation tertile:			0.048
High deprivation	37 (49.3%)	43 (37.4%)	
Middle deprivation	18 (24.0%)	21 (18.3%)	
Low deprivation	20 (26.7%)	51 (44.3%)	
Socio-occupational class:			0.51
Professional & managerial	25 (32.1%)	40 (33.6%)	
Intermediate & technical	28 (35.9%)	30 (25.2%)	
Routine and semi-routine	6 (7.7%)	12 (10.1%)	
Never worked/ unemployed	8 (10.3%)	19 (16.0%)	
Not known	*11 (14.1%)*	*18 (15.1%)*	
Maternal highest level of education:			0.83
Less than degree	46 (59.7%)	72 (62.6%)	
Degree or higher	20 (26.0%)	29 (25.2%)	
Not known	*11 (14.3%)*	*14 (12.2%)*	

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Table 2: Children's performance on standardised achievement tests, domain general cognitive tests and specific mathematics tests (before and after Bonferroni corrections).

Measure	N	Control Mean (SD)	N	Very preterm Mean (SD)	Mean difference (95% CI)	p
WIAT-II Achievement test						
Mathematics achievement (stn)	77	103.56 (20.69)	113	91.29 (18.81)	-12.27 (-17.98 to -6.56)	< 0.001[a]
Domain general cognitive skills						
Non-verbal IQ (stn)	77	104.94 (20.83)	113	97.77 (19.42)	-7.17 (-13.00 to -1.34)	0.016
Working memory (raw)	77	13.62 (3.84)	112	11.75 (3.49)	-1.87 (-2.93 to -0.81)	0.001[a]
Speed of processing (crt)	77	30.45 (7.38)	112	33.62 (10.15)	3.16 (0.50 to 5.83)	0.020
Visuo-spatial skills (sc)	77	10.48 (3.10)	113	8.62 (3.40)	-1.86 (-2.82 to -0.91)	< 0.001[a]
Inhibition (sc)	77	9.61 (3.45)	113	8.33 (3.52)	-1.28 (-2.30 to -0.26)	0.014
Specific mathematics skills						
Non-symbolic magnitude comparison (%a)	77	74.61 (9.36)	114	73.11 (9.32)	-1.50 (-4.21 to 1.22)	0.279
Symbolic magnitude comparison (%a)	77	93.46 (5.37)	114	92.53 (6.77)	-0.93 (-2.74 to 0.89)	0.317
Number line estimation (%a)	76	91.30 (6.82)	113	88.84 (8.47)	-2.46 (-4.76 to -0.16)	0.036
Digit recognition (mrt)	77	0.90 (0.17)	113	1.00 (0.31)	0.10 (0.03 to 0.18)	0.008[b]
Counting skills (%a)	77	72.73 (26.96)	113	59.51 (28.46)	-13.21 (-21.34 to -5.09)	0.002[a, b]
Number fact knowledge (%a)	77	46.86 (30.17)	112	36.38 (25.58)	-10.48 (-18.52 to -2.44)	0.011
Arithmetic strategy sophistication (%s)	77	67.45 (34.01)	114	51.92 (33.94)	-15.53 (-25.42 to -5.65)	0.002[a, b]
Understanding of arithmetic concepts (%a)	77	73.38 (24.30)	113	66.67 (22.30)	-6.71 (-13.45 to 0.03)	0.051

Note: [a]Remains significant after applying Bonferroni correction. [b]Remains significant after controlling for non-verbal IQ. stn Standardised scores (Mean 100, SD 15). sc Scaled scores (Mean 10, SD 3). %a Percent accuracy score. raw Raw composite score for verbal and visuo-spatial working memory (range 5.7-25.0). crt Composite reaction time. mrt Median reaction time. %s Percent use of mature strategies.

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Table 3: MANCOVA results for group differences between 115 very preterm children and 77 term-born controls controlling for (a) socio-economic status and (b) working memory and visual-spatial skills. Effect size is reported as partial eta squared.

Covariates	df	F	p	Partial η^2
(a) Socio-economic status (IMD score)				
Mathematics	1,185	14.14	<0.001	0.07
Working memory	1,184	9.80	0.002	0.05
Visuo-spatial skills	1,185	11.37	0.001	0.06
Counting skill	1,185	7.62	0.006	0.04
Arithmetic strategy sophistication	1,186	7.26	0.008	0.04
(b) Working memory and visuo-spatial skills				
Mathematics	1,184	4.41	0.037	0.02
Counting skill	1,184	0.60	0.438	0.003
Arithmetic strategy sophistication	1,184	1.46	0.229	0.008

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Figure legends

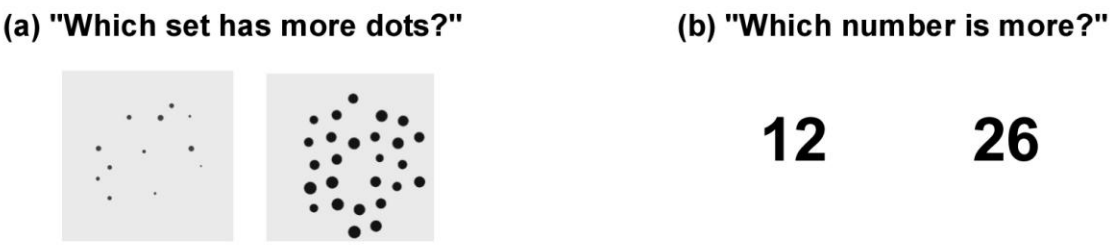
Figure 1: Recent research has highlighted that the precision of an individual's underlying numerical representations can predict current and future mathematics achievement. Experimental methods have been developed to explore various characteristics of these representations. Non-symbolic magnitude comparison tasks (a), in which participants are required to select the more numerous of two arrays of dots, give a measure of the precision of non-symbolic representations within the Approximate Number System. Symbolic magnitude comparison tasks (b), in which participants rapidly select the larger of two digits, index the accuracy of mapping between non-symbolic and symbolic numerical representations.

Figure 2: Mean differences (99.64% Confidence Interval) of z scores between very preterm and full-term children on tasks measuring (a) domain-general cognitive skills and (b) domain-specific mathematical skills.

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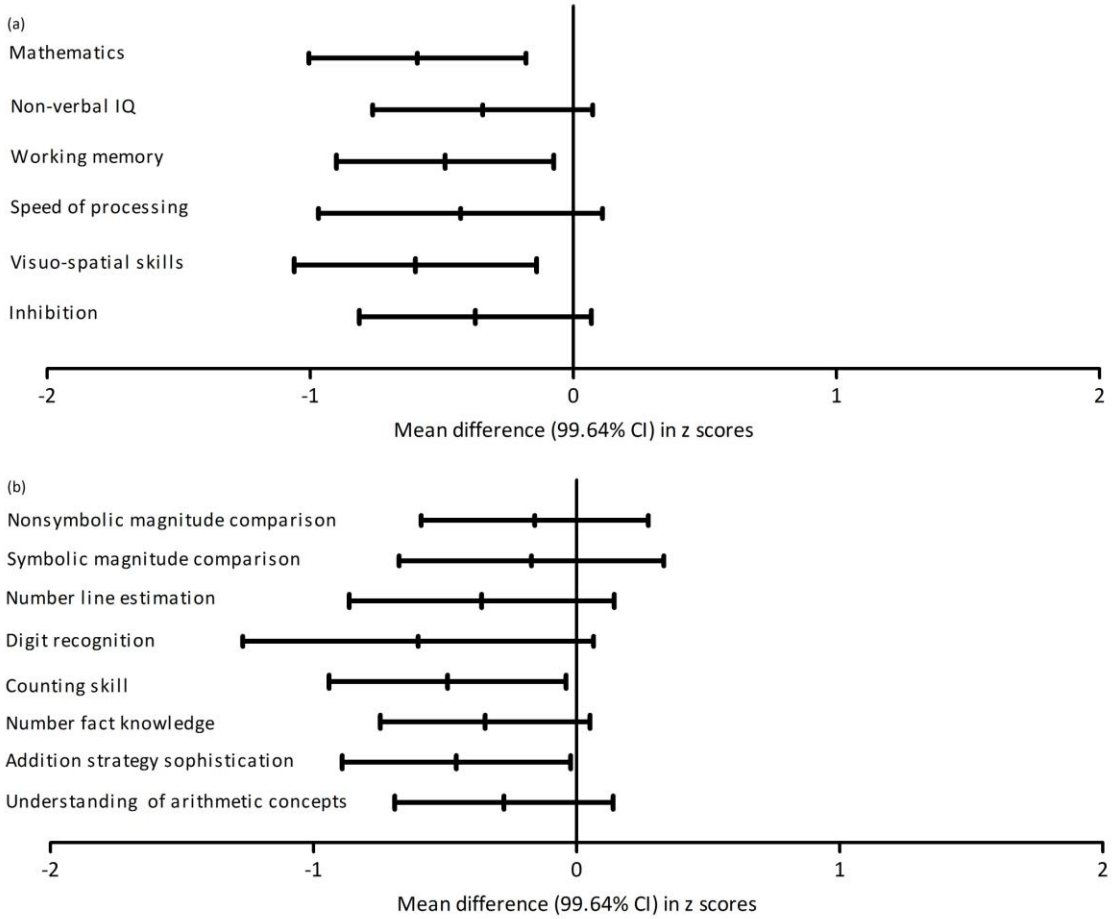
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Figure 1



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Figure 2



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