The PRISM studies: improving children's mathematics skills following very preterm birth

Children born very preterm have poorer performance than their term-born peers across all school subjects, with greatest difficulties in mathematics. The Premature Infants' Skills in Mathematics (PRISM) studies, based at the University of Leicester, are led by a multidisciplinary group of researchers who aim to discover the mechanisms that underlie very preterm children's difficulties with mathematics.

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Key points

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1. Children born very preterm are more likely to struggle with mathematics than with other school subjects.
2. Very preterm children's mathematics difficulties stem in part from poor working memory and visuospatial skills.
3. An intervention that provides teachers with strategies to support very preterm children's learning at school is currently under development.
4. Neonatal unit staff may find this information useful when counselling parents about potential long-term outcomes.

Competency in mathematics is crucial for many day-to-day activities ranging from calculating journey times to splitting a bill. Over recent years there has been growing concern about the mathematics skills of children who were born very preterm (<32 weeks' gestation). Although very preterm children have significantly poorer performance than term-born peers across all school subjects, they have greatest difficulties in mathematics.[1]

The risk for mathematics difficulties increases with decreasing gestational age at birth, such that babies born extremely preterm have the poorest attainment at school. Data from the UK EPICure study showed that 44% of children born extremely preterm (<26 weeks' gestation) had mathematics learning difficulties at 11 years of age, compared with just 1% of their term-born classmates. When children with low average scores were included, 70% of extremely preterm children were found to have low attainment in mathematics by the end of primary school compared with 14% of their classmates.[2] Importantly, and in contrast to reading difficulties, mathematics difficulties are not fully accounted for by the generally lower IQ of very preterm children, which suggests that there is something about mathematics that they find especially difficult.

Healthcare professionals in neonatal units should be aware of the risk for later mathematics difficulties to aid them in counselling parents about the potential long-term outcomes for their very preterm child.

Why is mathematics so important?

Understanding how very preterm birth affects children's mathematics skills is of increasing concern as mathematics

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FIGURE 1 The PRISM studies team.

difficulties, even in early childhood, can cast a long shadow over an individual's life chances. Analyses of birth cohort studies have revealed that mathematics skills in primary school are a stronger predictor of a child's future health, economic potential and employment prospects than attainment in other subjects studied at school, and over and above the educational qualifications they go on to obtain later in life.[3] Improving very preterm children's mathematics skills is therefore crucial not only for improving their attainment at school, but for maximising their future life chances.

What are the PRISM studies?

In order to develop strategies to improve very preterm children's attainment at school, we first need to understand the nature of their difficulties with mathematics and what the underlying causes might be. The PRISM studies, based at the University of Leicester, aim to answer these questions (www.prismstudy.org.uk). The studies are led by a multi-disciplinary group of researchers with expertise in developmental psychology, mathematical cognition, neonatology and education who are bringing together emergent research in these fields to discover the mechanisms that underlie very preterm children's difficulties with mathematics (**FIGURE 1**).

Most previous studies in this area have used a single standardised test to assess children's attainment in mathematics. Standardised attainment tests are norm-referenced measures that provide a snapshot of a child's overall mathematical ability, but they do not provide diagnostic information or indicate the exact nature of a child's difficulties. In contrast, the PRISM studies have been designed to provide a more in-depth analysis of mathematical ability by assessing a range of cognitive skills that are known to be important for learning mathematics (**FIGURE 2**). These include 'domain-general' cognitive skills such as working memory, processing speed, visuospatial skills and inhibition (**FIGURE 3**), and a range of 'domain-specific' skills that are important for proficiency in mathematics, such as recognising digits, counting, recalling basic number facts, estimating the location of digits on a number line, applying efficient strategies to solve mathematical problems and understanding mathematical concepts.

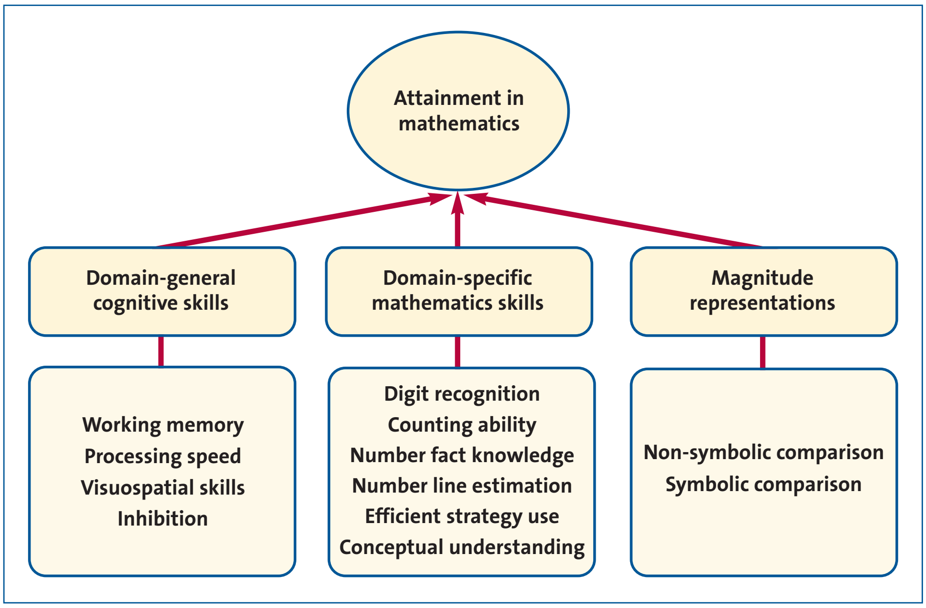

FIGURE 2 Domain-general cognitive abilities and domain-specific mathematics skills assessed in the PRISM studies, in addition to attainment in mathematics.

Working memory The ability to store and manipulate information in the mind for a short period of time. Working memory is different to short-term memory as it requires both remembering information *and* operating on it, such as remembering a list of numbers then repeating the list back in the reverse order. Working memory is involved in multi-step calculations where interim solutions must be held in mind, eg in a multi-digit mental arithmetic problem, calculating the sum of the units and holding it in mind while calculating the sum of the tens.

Processing speed The time it takes a person to perceive, mentally process and respond to stimuli in the environment. It is a measure of how quickly the brain processes incoming information. Faster processing speed means mathematics problems can be solved more fluently and under time pressure.

Visuospatial skills The ability to interpret visual information relating to the location of objects in space. This is also sometimes referred to as hand-eye coordination. Visuospatial skills are important for drawing relationships between objects, eg in mathematics, visuospatial skills are important for reading and interpreting graphs.

Inhibition The ability to respond to relevant information in the environment while ignoring distracting irrelevant information. Inhibition is required not only to ignore distractions at the classroom level (eg noise or chattering in the background), but also to disregard salient mathematical information that is not relevant. For example, when counting we learn that 4 is a larger number than 2, but when using fractions we have to inhibit this information to learn that ¼ is smaller than ½.

FIGURE 3 Definitions of the domain-general skills assessed in the PRISM studies. Domain-general cognitive skills are a range of cognitive processes that allow us to regulate our behaviour in order to achieve goals and to respond flexibly to changes in our environment. Deficits in these core cognitive processes have frequently been associated with low achievement at school.

Recent research in the field of mathematical cognition has also focused on the role of magnitude representations in learning mathematics. Magnitude representations allow children and adults, and even non-human animals, to quickly estimate the quantity of a set of objects without explicitly counting them. This ability is also known as 'number sense'. For example, experimental tests called non-symbolic and symbolic magnitude comparison tasks measure the accuracy with which participants can determine which of two sets of dots, or two digits, presented on a computer screen has a larger quantity without allowing time to explicitly count each set. The accuracy of an individual's responses on these tasks is an indicator of how precise their magnitude representations are, that is, how accurately they can form mental representations of quantity. Poor performance on these tasks has been associated with poor attainment in mathematics in both children and adults. In particular, many studies have shown that individuals with developmental dyscalculia, a learning disorder characterised by specific and severe difficulties in mathematics, have poor magnitude representations.[4]

To date, only the PRISM studies have assessed all of these skills concurrently to try and tease apart the nature and origins of very preterm children's mathematics difficulties. When the first PRISM study commenced in 2011, a key question to be answered to advance both theory and practice was whether very preterm children also have deficits in magnitude representations, similar to children with developmental dyscalculia, or whether other cognitive skills underlie their difficulties with mathematics.

The PRISM-1 study

In 2011, with funding from Action Medical Research, 117 very preterm children were recruited from admissions to neonatal care in University Hospitals of Leicester NHS Trust and University College London Hospital. The children were aged between 8 and 10 years at the time of recruitment and all were in mainstream school, commensurate with the inclusion criteria. To form a control group, 77 classmates who were matched for age and sex where possible, and born at full-term, were also recruited. All of the children were visited by a study psychologist, either at their school or at home, who carried out an assessment of their attainment in mathematics using a standardised attainment test called the Wechsler Individual Achievement Test-II (UK). The psychologist also administered a battery of standardised and experimental tests to assess the skills shown in **FIGURE 2**. In addition to this face-to-face assessment, information about socio-economic status, behaviour, attention and emotions, and special educational needs was collected via questionnaires completed by parents and teachers.

Overall, in line with previous literature, it was found that the very preterm children had significantly poorer attainment in mathematics than the children who were born at term, with a deficit of 12.3 points (95% CI: -17.9 to -6.6), which equates to a 0.8 standard deviation (SD) deficit. This was compared with a deficit of 7.2 points (95% CI: -13.0 to -1.3; 0.5 SD) in non-verbal IQ (**FIGURE 4**).[5] When adjusting for confounders, it was found that their lower IQ or lower socio-economic status did not account for the preterm children's poorer performance in mathematics.

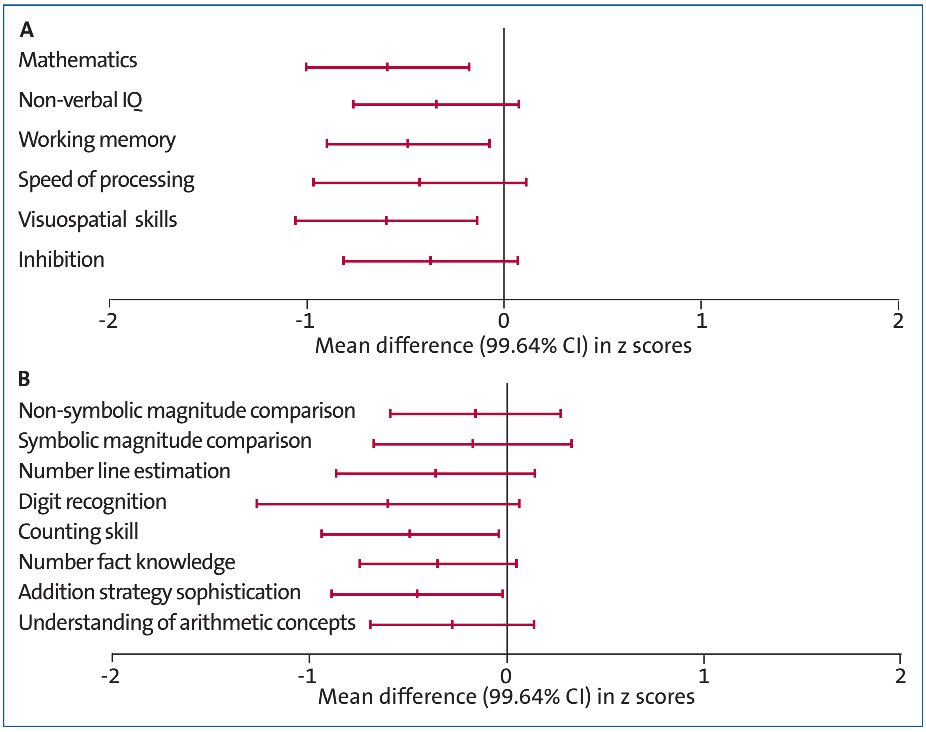

FIGURE 4 Differences between very preterm children and term-born children on tasks measuring mathematics, domain-general cognitive skills and domain-specific mathematics skills. Reproduced from Simms et al. *Pediatric Research* (2015).[5]

It was also found that, after correction for multiple comparisons, the very preterm children had significantly poorer working memory and visuospatial skills than the children who were born at term. In addition, they had poorer counting skills and more often applied immature strategies to solve simple arithmetic problems, such as counting on their fingers rather than retrieving the answer from memory; these deficits were also independent of their lower IQ. Interestingly, however, it was found that the very preterm children did *not* have poorer performance on the non-symbolic and symbolic magnitude comparison tasks. This result was pivotal because it showed that the mathematics difficulties of very preterm children did not stem from deficits in magnitude representations and, therefore, have a different aetiology to those of children with developmental dyscalculia. Instead, the very preterm children's poorer proficiency in mathematics was associated with poorer working memory and visuospatial skills, which accounted for the deficits in their domain-specific mathematics skills and much of their deficit in attainment. This was a significant finding both theoretically, in advancing knowledge of the cognitive bases of neurodevelopmental disorders, and practically, in identifying potential targets for intervention.

The PRISM-2 study

In 2015, further funding from Action Medical Research enabled follow-up of the PRISM cohort at 12-14 years of age. Secondary education imposes greater demands on children's cognitive resources and the mathematics concepts to be learned become increasingly complex. Adolescence also marks an important developmental transition during which domain-general cognitive processes continue to mature. Therefore, the cognitive impairments of very preterm children may become exacerbated in secondary school, cascading into increasing deficits in mathematics. There is a lack of longitudinal research into preterm children's mathematics skills and, as yet, no studies have carried out intensive phenotyping of the mathematics skills of very preterm adolescents.

The PRISM cohort has recently been reassessed at 12-14 years of age using the same methods as in the first study. The aims of this study are to find out how the very preterm children's cognitive and mathematical skills have developed over time and to determine whether mathematics difficulties in secondary school have the same underlying causes as those of very preterm children in primary school. As might be expected, the domain-specific mathematics tests had to be updated to reflect the mathematics abilities of 12-14 year olds, which was done to allow assessment of all of the same aspects of mathematical cognition that were tested in primary school but at a more advanced level. In addition, geometry and algebra tasks were added to the test battery as these subjects form a substantial part of the Key Stage 3 and 4 mathematics curricula. With the help of Dr Stephen Wardle and the neonatal clinical team at Nottingham University Hospitals NHS Trust, an additional cohort of very preterm adolescents was recruited to the second study to increase the statistical power for cross-sectional analyses.

A 72% follow-up rate of children who took part in the first study has been achieved and, together with the new sample, 127 very preterm and 95 term-born adolescents have taken part. The study assessments took place at secondary schools and participants' homes through-out 2016 and the data collection phase has now come to an end. Analysis and dissemination of the study results is ongoing and the findings are eagerly awaited.

From observation to intervention

A further key aim of the PRISM studies is to use the information gained about the nature and origins of very preterm children's mathematics difficulties to develop an intervention to help students who struggle with mathematics at school. As the results of the first PRISM study indicated that very preterm children's difficulties are different in nature to those of individuals with developmental dyscalculia, existing interventions designed to improve magnitude representations that were developed for children with developmental dyscalculia are unlikely to be effective in this population. A number of recent research studies have also focused on the efficacy of working memory training programmes for improving children's performance at school. While these typically show short-term benefits in improving children's working memory, there is as yet no good evidence of transfer to improved performance in mathematics.[6]

Mathematics skills developed in primary school are a stronger predictor of an individual's future life chances than attainment in other subjects studied at school.

Therefore, a different approach to intervention is being taken.

Two children in an average sized UK primary school class are likely to have been born preterm. Despite this, the results of a recent survey conducted by members of the PRISM study team showed that teachers lack knowledge and training about the developmental and educational needs of children born very preterm.[7] Only 16% of teaching staff surveyed had received any training about children's outcomes following very preterm birth, and over 85% reported that they would like more information in this area. Strikingly, the survey found that teachers' poorest area of knowledge related to the risk for mathematics difficulties following very preterm birth, suggesting that very preterm children may not be receiving appropriate support in the area they need it the most. Improving teachers' knowledge of very preterm children's outcomes and providing them with the practical skills they need to adapt the environment to support the learning of very preterm children represents an alternative approach to intervention.

During 2017 a novel, multi-media e-learning programme for use by teachers will be developed and piloted, the content of which will include:

- training about the long-term impact of preterm birth on children's development and learning
- tips on how to identify children with cog-nitive and mathematics difficulties
- information about practical strategies teachers can use to scaffold very preterm children's learning in the classroom.

Although initially targeted at supporting learning in mathematics, the strategies provided may help support learning in other school subjects. The intervention will be designed in collaboration with teachers, educational psychologists and e-learning experts and will be piloted and evaluated in 2018. Ultimately, with further development and evaluation, the study team hopes this will improve not just the academic achievement of very preterm children, but their future life chances.

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