# Developmental dyscalculia

School resources

**Developmental dyscalculia (hereafter just dyscalculia) is a lifelong cognitive difference that affects a person's ability to understand and manipulate quantities, numbers, and their representations. People with dyscalculia therefore have difficulty accessing and applying standard mathematical tools.**

## What is dyscalculia?

Dyscalculia is a form of innate neurodivergence, which means that it is present from birth. Genetics play a role in the likelihood of a child being born with a predisposition to dyscalculia, with twin studies showing between 32% and 38% heritability. Premature birth and environmental factors while the foetus' brain develops also play a role, particularly exposure to drugs or alcohol in the womb[1].

Dyscalculia affects between 3.5% and 14% of all people, and diagnosis requires a consistently low achievement in maths (at least one or two years below the expected level for the student's age) that is not explained by generally low IQ scores or other conditions. It occurs at similar rates as other learning differences and often co-occurs with them[2]. However, compared to dyslexia, for example, dyscalculia is under-researched and less well-understood, particularly from a neurodiversity-affirming perspective[3]. For this reason, adequate interventions are more difficult to obtain for dyscalculics, and they often miss out on specific teaching that could help them access the curriculum[4]. This is a problem, as maths skills have been shown to have at least as much, if not more, impact on the person's success as an adult than reading skills, and studies in the UK show that more than four times as many adults struggle severely with maths than with reading[5].

Characteristics of dyscalculia vary between individuals, with each person having their own profile of strengths and difficulties. Studies focus primarily on three areas:

1. Non-symbolic number sense, or the intuitive ability to judge quantities. Non-symbolic number sense is present from birth in typical humans and several animal species. When it is impaired, individuals have no basis onto which they can later project a number. This means that they can have difficulty estimating magnitudes and durations, or figuring out the order of sequences.
2. Symbolic number sense, or the ability to link Arabic numerals and number words with quantities. Symbolic number sense is culturally transmitted and is most closely associated with formal maths skills. It forms the basis of number processing, so when it is impaired, individuals have to use often slow and effortful compensation strategies.
3. Cognitive differences unrelated to maths, which combine to make the execution of mathematical processes difficult[6]. Visuospatial working memory is the most researched of these differences. It allows us to keep bits of information on a mental sketchpad for a brief period of time. When it is impaired, individuals can have difficulty performing mental calculations and solving mathematical word problems[7].

## Neurocognitive theories of dyscalculia

Dyscalculia presents differently in every individual, a fact that led researchers to suggest multiple neurocognitive theories for the condition. Recent consensus has landed on a hybrid theory that incorporates previous ideas. This theory, supported by neuroimaging studies, suggests that multiple brain regions across both hemispheres are involved in creating the phenomenon of dyscalculia, with both structural and functional differences[8]. Depending on the task performed, functional differences involve hypo- and hyperactivation, and hypo-and hyperconnectivity. In other words, mathematical tasks activate different parts of the brain to different degrees in dyscalculic people compared with typical learners. The hyperactivation found across multiple brain areas related to maths reflects the extreme effort dyscalculics exert to solve problems relative to the effort put in by their peers[9].

## How can dyscalculia affect students?

Many core experiences of dyscalculia are similar to those associated with dyslexia, as many of the same brain regions are involved. These experiences include difficulty with verbal comprehension, poor working memory, and slow processing and information retrieval[10]. The constant struggle to keep up with the class despite these difficulties can lead to frustration when students are confronted with repeated failure despite extreme effort, especially if they perceive success in maths as crucial to their success overall. Their self-image, academic self-efficacy, and social status in school can be affected negatively, causing social isolation, a loss of self-esteem, dread, shame, and a decrease in general wellbeing[11]. In other words, the student's sense of what they are capable of across subjects can be lowered even if their achievements are the same as those of other children. Studies have found that the earlier the diagnosis comes, the better the child's self-image is, as it gives them access to an explanation of their difficulties, as well as to positive feedback and support[12]. Training in socio-emotional, cognitive, and self-development skills has been found to increase self-confidence and self-efficacy in those students[13], and teacher perception can influence social acceptance of the student by setting an example for the rest of the class[14]. Finally, teachers' acknowledgement of relative cognitive strengths in each individual also has a major impact on their students' motivation and engagement, as well as promoting those strengths[15].

In dyscalculic students who care about their success in maths, or about how their loved ones will judge them as a result of their performance in maths, anxiety can also result. While maths anxiety can occur in all students, it is twice as common in dyscalculics. Research shows that a vicious circle may be created between maths anxiety and poor maths performance, where anxiety leads to avoidance and impaired short-term memory, which leads in turn to declining performance, with each reinforcing the other[16]. However, research also shows that teachers have a substantial influence on the development of maths anxiety in their students, and can act either as a circuit breaker (by being supportive, strengths-based, and positive, framing errors as opportunities to learn, and making learning fun and playful) or as a reinforcer (by demanding high performance and embarrassing the student in front of their peers). Parents and families can also help lessen maths anxiety in their children by supporting them at home with assignments, being mindful of how their children can absorb the parents' anxiety or self-image regarding maths, and playing mathematical games[17]. Finally, interventions aimed at improving maths skills can also have the 'side effect' of reducing maths anxiety. For example, a study that used the programme MathWise with third-graders demonstrated a change in brain activity post-invention, with fMRI scans of high-anxiety children resembling those of low-anxiety children after the training but not before[18].

## What teachers might notice

In early childhood, one of the first signs of dyscalculia is often difficulty judging the number of items in a small set, a skill called subitising. For example, when looking at dice, dyscalculics may have to count the number of dots on each side rather than seeing three dots and immediately recognising that they have rolled a three. In school, teachers may observe difficulty learning arithmetic facts and difficulty estimating or comparing amounts and values. The latter, called magnitude comparison, is one of the most reliable signs of dyscalculia. Dyscalculic children will take significantly longer to decide which of two single-digit numbers is larger[19]. In addition, although most children initially learn to count using their fingers, dyscalculics may continue to use this strategy well into their school years, even when performing easy calculations. This is due to difficulty with working memory. For the same reason, they may also count out loud rather than doing so silently or mentally[20].

Specific difficulties teachers may observe include:

- Difficulty assigning place values in multi-digit numbers; for example, when comparing 65 and 72, they may suggest 65 is larger.
- Difficulty recognising the equivalence of mathematical operations like multiplication and multiple addition (for example, that 3x2 = 2+2+2).
- Difficulty understanding fractions and percentages.
- Difficulty counting money.
- Difficulty telling the time from analogue clocks, and with time management in general.
- Difficulty solving maths problems that are presented verbally[21].

## Evidence-based strategies for supporting dyscalculic students

Practice-based research into strategies to support dyscalculic learners from a neurodiversity-affirming perspective is scarce, with a 2022 literature review only finding two studies that involved dyscalculic learners[22]. Evidence-based strategies for dyscalculia from the traditional deficit-based perspective are also not yet well-researched, and there is lively debate on the best approaches. Proponents of the different approaches can be roughly divided into two camps: those who support interventions targeting only general cognitive skills such as working memory and executive function, and those who support interventions targeting only numerical skills through the practice of specific maths problems. Other researchers fall between the two camps, showing the best improvements when interventions target a variety of general *and* maths-related skills[23]. The difference in effect sizes for these approaches likely stems from the difference in cognitive profiles between dyscalculics, suggesting that different interventions are suited to different individuals.

Researchers agree on some points: that interventions are more effective when individualised, intensive, presented one-on-one or in small groups, and delivered as early as possible, preferably at preschool age[24]. Teachers should notice and verbally reward every success of the learner to increase motivation[25], and it is important that intervention strategies not only focus on remediation of specific weaknesses but take into account the whole learner[26]. Interventions should reduce the load on working memory (for example, by providing explicit, sequenced instructions)[27]. Finally, dyscalculic students benefit from explicit instruction in maths[28].

Maths-specific instruction is found to be most successful when it is motivating and fun, includes verbal and visual strategies, student verbalisation, immediate, explicit teacher feedback, practice on multiple examples, and multisensory resources such as Numicon. Schema-based strategies (which use visual schematic diagrams to represent operations) are more effective than keyword-based strategies, particularly when applied to identifying the relevant maths operations in word problems. In young children, adding a kinaesthetic aspect to interventions increases their effectiveness. For example, in a study with 5-year-olds, some children were allowed to handle the marbles involved in an arithmetic exercise, while others only watched a teacher handle the marbles. The children who handled the marbles themselves had better learning outcomes than those who did not[29].

The use of technology such as apps and computer games also appears to enhance maths instruction for dyscalculic students, providing motivation and routine. However, in some studies, teachers were still involved in facilitating use of the software. Evidence-based interventions for maths skills included the adaptive number line game Calcularis, which has been linked with significant improvement of number processing and neuronal changes in dyscalculic children[30]. Evidence-based interventions for visuospatial working memory included Cogmed for young children and Jungle Memory[31] for primary school children. Both interventions provide immediate feedback while children are working on training tasks, which reduces stress, motivates them, and supports understanding. The children who participated in these interventions improved their maths performance in the short term, although long-term impact has not been measured[32].

Due to the neuroplasticity of the brain, successful interventions for dyscalculia have the power to reshape dyscalculic children's neural responses to maths. For example, when researchers implemented a computer-based intervention aimed at automating number processing, the intervention also decreased previous hyperactivation and hyperconnectivity in the frontal and parietal lobes. This shows that children were expending less energy to complete the same mathematical tasks than before the intervention. In another study, the brains of dyscalculic children who participated in an intensive eight-week intervention led by expert tutors underwent such dramatic changes that activation patterns during maths tasks resembled those of neurotypical children after the eight weeks[33]. However, it should be noted that neither of these studies conducted follow-up brain scans with their participants after more time had elapsed. As other studies have shown that improvements in maths performance often cannot be maintained by the child for an extended period post-intervention, it is likely that brain activation patterns also revert back if support is not maintained long-term[34].

## Critiques of the research

Due to the lack of research regarding dyscalculia in general and effective interventions in particular, much of the existing intervention research has been critiqued as being of poor methodology, questionable impact, and uncertain transferability[35]. One of the main issues has been the fact that researchers have used different cut-off points for inclusion of participants, with some using cohorts that fell in the lowest 25th percentile of maths achievement and others using cohorts in the lowest 10th percentile. As a result, strategies identified as effective in meta-analyses may only be effective for a subsection of students with dyscalculia[36].

In view of these critiques, teachers should always individualise interventions, tailoring them to the student and carefully monitoring progress in case adjustments are needed. Crucially, the success of dyscalculic children does not depend on interventions delivered by teachers and tutors alone. Family support also plays a role, with studies showing that the wider environment around the child should also be considered to sustain long-term gains, such as by providing community-based initiatives and psycho-educational programmes for parents, as well as embedding number activities playfully and indirectly at home[37].

## Endnotes

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