Dyscalculia: issues for practice in educational psychology

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Dyscalculia has been described as a specific learning difficulty affecting the ability to acquire arithmetical skills. In recent years, it has become a topic for discussion in the popular media, yet there has been little research undertaken by educational psychologists. This paper provides a summary of neuroscientific research into the development of early number skills and considers the neurological and behavioural features of dyscalculia. Two fundamental questions are then discussed: Is one able to accurately assess for and identify dyscalculia?; Is it of benefit to children and young people to do so? The paper concludes by considering implications for practice.

Keywords: dyscalculia; arithmetic; maths development; educational psychology practice

Introduction

Dyscalculia has been described as a specific learning difficulty affecting the ability to acquire arithmetical skills (Department for Education and Skills [DfES], 2001). It is estimated that it affects between 3 and 7% of the population (Bishop, 2010; Butterworth, Varma, & Laurillard, 2011; Kaufman, 2008) although until recently it has received relatively little research interest compared with its literacy counterpart, dyslexia (Bishop, 2010; Wilson & Deheane, 2007).

This article considers educational psychologists’ (EPs’) engagement with dyscalculia. It provides a summary of recent neurobiological research and discusses issues relevant to assessment and identification.

The difficulty with dyscalculia

Writing an article about “dyscalculia”, rather than “difficulties in maths”, has proved a difficult task. Firstly, because in common with “dyslexia”; “autism” and “attention deficit hyperactivity disorder (ADHD)”, dyscalculia is a label. EPs’ primary focus when they work with a child is the nature of their strengths and difficulties, the learning environment in which they find themselves and how their difficulties could be resolved. Providing a label for a child’s difficulties is often of secondary importance and the consequences of doing so are an ongoing concern for the profession. Lauchlan and Boyle (2007) provide a balanced account of the arguments for and against the use of labelling in Special Education. They conclude

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that labels are generally “more unhelpful than helpful” (p. 41) but acknowledge their position in UK legislation (for example, Special Educational Needs and Disability Act, SENDA, 2001) and suggest that “for individual cases there may be positive opportunities to be gained from the application of a label” (Lauchlan & Boyle, 2007, p. 41).

Secondly, when trying to provide an explanation of a child’s maths difficulties, EPs are likely to consider a range of data relating to environmental and social factors, for example: home learning environment and parental attitudes to maths, the appropriateness of maths teaching to the child’s needs, the child’s motivation and attitude to school and their self image as a mathematician, as well as their ability and attainment. In contrast, the term dyscalculia is commonly used to describe an exclusively within-child impairment.

Finally, much of the evidence base for dyscalculia comes from neurobiological studies. Understanding and evaluating this evidence requires engagement with a paradigm and discourse which may fall outside of the daily practice of EPs.

Yet despite these anxieties, a paper considering EPs’ practice regarding dyscalculia seems overdue. To date, Educational Psychology in Practice, the theory, research and practice journal of UK Educational Psychologists, has published five articles for which the primary focus has been maths, none of these reference dyscalculia. This compares to twenty articles focusing on Literacy, four of which have dyslexia as their focus. This relative paucity of dyscalculia literature lags behind developments elsewhere.

In 2007, a special edition of Educational and Child Psychology was published on the topic of arithmetical difficulties. In the editorial to the edition, Munn and Reason (2007) suggested that one reason why EPs should be interested in arithmetical difficulties was the “migration of the term ‘dyscalculia’ from neuropsychology to education” (p. 5). Four years on, the term has now entered the popular corpus. Academic papers on dyscalculia have provided content for broadsheet newspaper articles (Connor, 2011), internet magazines (Beladi, 2011) and radio programmes (Naughtie, 2011).

Increased public awareness of dyscalculia does not provide reason for EPs to abandon formative assessments of children’s difficulties in maths in favour of diagnostic assessments for dyscalculia. The two are very different. It does, however, provide impetus for EPs to take account of neurobiological evidence. Modern EPs work as scientist-practitioners (Fallon, Woods, & Rooney, 2010; Munn & Reason, 2007; Woods et al., 2006), and so occupy a privileged position between academic psychology and the practical arena of education. It is, therefore, reasonable for children, parents and teachers to expect EPs to provide a view with regard to dyscalculia.

**Current understanding of dyscalculia**

Neuroscientific research identifies brain structures which are involved in specialised areas of number processing (Organisation for Economic Cooperation and Development, OECD, 2007) and it has been demonstrated that temporarily impairing the function of these structures can induce specific number difficulties in adults with normally good number skills (Cohen Kadosh et al., 2007). Whilst there is some debate over the type of mechanisms through which the impaired functioning of these structures impacts upon number skills (Kaufman, 2008), there is broad
agreement that some of the core neurological causes for number difficulties have been identified (Butterworth et al., 2011; Dehaene, 2009). The term “dyscalculia” is, therefore, used by neuroscientists to describe a neurological difficulty that affects number skills.

It is, however, possible to imagine cases where children experience difficulty with maths, but not with number. For example, a child may have good mental arithmetic skills and be able to fluently recall their times tables, but struggle with the symbolic reasoning used in algebra or find it hard to get to grips with rotational symmetry.

It is also possible to conceive of instances in which children experience difficulties with number caused by reasons other than neurological impairment. They may, for example, experience a high level of anxiety when asked to complete maths tasks, or have missed a substantial part of their early schooling.

In both cases, a valid conclusion may be that the child is experiencing difficulties with maths, but not that they have dyscalculia. The remainder of this section considers the mechanisms through which neurological impairment may impact upon number skills.

**Dyscalculia and numerosity**

The range of mathematical tasks with which students are asked to engage is wide, as is the range of cognitive processes they employ when working on them. Fluid intelligence (Blair, Gamson, Thorne, & Baker, 2005), working memory (Bull, Andrews, & Weibe, 2008; Raghubar, Barnes, & Hecht, 2010) and conceptual and computational skills (Mabbott & Bisanz, 2008) have all been associated with the development of mathematical ability. In contrast, recent neurobiological studies of dyscalculia have focussed on one specific process; numerosity or “number sense” (Kaufman, 2008).

Butterworth (2005) describes numerosity as “the cognitive counterpart to the term ‘cardinality’…” (p. 3). It is the intuitive ability to recognise the quantity of a set without needing to count all its members. For example, imagine that you are presented with a covered dish, in which there are either 1, 2, 3 or 4 marbles. You are then told that the cover will be briefly removed and your task is to say how many marbles you can see. In performing the task, it is unlikely that you would count the marbles one by one. Instead, your sense of numerosity would tell you how many marbles you saw in the same way that your sense of size might tell you whether someone is about 4, 5 or 6 feet tall, or your sense of colour might tell you whether a key fob is blue, green or red.

Numerosity is regarded as a key factor in the profile of dyscalculia. It is, for example, implicitly referenced in the DfES’s definition (DfES, 2001), which suggests that dyscalculic learners “lack an intuitive grasp of numbers” (p. 2) and in a recent review of literature by the OECD (2007), which concludes that “dyscalculia is most likely caused by an impairment of number sense – the early understandings of numerical quantities and their relations” (p. 104).

Studies referencing numerosity are prevalent in dyscalculia research and there is general agreement regarding its role as a major contributory factor. However, Kaufman (2008) suggests that to conclude that numerosity is the sole cause of dyscalculia may be moving beyond the available evidence. She cites Wilson and Dehaene (2007) who point out that although numerosity could be a direct cause of
number difficulties, an alternative explanation is that people with dyscalculia experience difficulty mapping quantities onto symbolic codes; they can easily recognise, but not name or code quantities.

Furthermore, there is a higher than expected co-morbidity of diagnosis of dyscalculia with dyslexia and ADHD (Landerl, Fussenegger, Moll, & Willburger, 2009; Von Aster & Shalev, 2007). Wilson and Dehaene (2007) argue that further investigation of this relationship may lead to the identification of new subtypes of dyscalculia.

**Dyscalculia and the brain**

Neurological research into dyscalculia and numerosity is spread across multiple experimental paradigms. It suggests that core number skills are evident from a very early age, that they are dissociable from other cognitive abilities and that they are linked to specific brain structures.

The research does not imply that humans are born fully numerate nor does it suggest that numeracy is isolated to specific areas of the brain. Numeracy is regarded as a complex process that involves multiple neural structures and which develops as a result of interaction between a person and their environment (OECD, 2007; Von Aster & Shalev, 2007). It does, however, suggest that neural architecture imposes constraints on numerical development. There are some areas of the brain which are predisposed to processing number. In cases where the functioning of these areas is impaired, numerical development takes an atypical route.

One such area is the horizontal intraparietal sulcus (IPS), located on the lateral surface of the parietal lobe (Neider & Deheane, 2009). It is this area which has been associated with numerosity. In a recent study, Cohen Kadosh et al. (2007) found that by using transcranial magnetic stimulation to temporarily impair the function of the IPS they could induce, in otherwise maths-typical adults, symptoms normally displayed by adults with dyscalculia. Studies of adults with specific brain injuries and evidence from neuro-imaging studies likewise implicate the IPS in basic number processing (Neider and Deheane [2009] and Butterworth [2005] provide accounts of this evidence).

Developmental studies show that even very young children have a sense of quantity. For example, Xu and Seplke (2000) found, using the preferential looking method, that 4–6 month olds were able to discriminate between an array of eight and 16 discs. In subsequent work (Xu & Arriaga, 2007; Xu, Spelke, & Goddard, 2005) researchers found that for large quantities, infants’ ability to discriminate (on a 1:2 ratio) persisted even when other variables, such as the total surface area occupied by the discs, were controlled for. Dehaene (2009) provides a comprehensive account of developmental studies of early mathematical development.

Also of relevance is data gathered through ethnographic studies (for example, Butterworth, Reeve, Reynolds, & Lloyd, 2008; Pica, Lemer, Izard, & Dehaene, 2004) which suggests that basic numerical processes exist even in people from cultures with a very limited number vocabulary and no formal education system.

**What questions should EPs ask of dyscalculia research?**

There is a growing neurological evidence base regarding number skills and dyscalculia. It is important to note, however, that this constitutes only one strand of
research into maths difficulties. Research undertaken from developmental and instructional perspectives has for some time provided information which is not only theoretically informative, but readily applicable to learning contexts (Munn & Reason, 2007).

In contrast, the application of neurological research to teaching and learning in maths is more recent. Examples include, Butterworth (2003), who provides an electronic screening tool for dyscalculia; Kaufman (2008), who gives a neurological account of the effectiveness of finger-based counting strategies and Wilson, Revkin, Cohen, Cohen, and Dehaene (2006), who describe how computer software could be used to support children experiencing difficulties with numerosity.

An important implication of neurological research into dyscalculia is that it potentially allows for a new dissection of mathematical ability. Rather than dividing maths skill into component functions at a behavioural level (for example, counting skills, addition and subtraction, multiplication and estimation) it allows maths skill to be split on an underlying neurobiological basis (for example into numerosity and the ability to effectively map magnitudes onto number symbols). Butterworth et al. (2011) suggest that this, in turn, may lead to more effective intervention.

In the future, then, it is possible that the distinction between dyscalculia and other forms of maths difficulty may become an increasingly important one. Given this possibility, coupled with the increasing body of neuroscientific research into maths development and the popularisation of the term “dyscalculia”, EPs may ask two basic, but fundamental questions. Firstly, “Can one identify dyscalculia?” And secondly, “What is the benefit of doing so?”

Can one identify dyscalculia?

Butterworth et al. (2011, p. 1053) suggest that neurological evidence allows for the scientific categorisation of dyscalculia as “reduced ability for understanding numerosities and mapping number symbols to number magnitudes”. Based on the available neurological evidence, it does indeed seem appropriate to include a measure of numerosity in an assessment for dyscalculia. However, there is some debate regarding how best to define dyscalculia; whether the term should be limited to describing a single deficit (numerosity) or whether a broader definition is needed to account for other types of mathematical difficulty. This debate brings into question whether considering numerosity alone can provide sufficient evidence upon which to base a decision about diagnosis.

Assuming that neuroscientific research is, in the future, able to delineate the cognitive outlines of dyscalculia, any would-be assessor is still faced with the task of selecting valid and reliable assessment tools. McKensie (2007) describes formative assessments available to EPs wishing to investigate children’s maths difficulties. The range of diagnostic tools for the assessment of dyscalculia, however, is much more limited. Aside from internet-based behavioural checklists, Butterworth (2003) provides one of the few such examples, the Dyscalculia Screener. This is a computer programme designed to assess children’s mathematical attainment and numerosity by measuring their response times in a selection of number-based tasks. The programme may represent a useful step forward in diagnostic assessment and provides a method for investigating core number competencies. However, some limitations have been highlighted.
An underlying assumption of the Screener is that children’s response times to sets of test items provide an indication of their level of numerosity. Voutsina and Ismail (2007) question this assumption by describing the behaviour of some children during completion of the Screener:

many children enthusiastically started an activity and responded promptly to the tasks but after several of the same type of tasks they either slowed down in their speed of response or got distracted. (p. 88)

Alternative explanations for slow response times on the Screener could be provided by examining the child’s level of anxiety during the assessment, or their motivation to complete the task. It is important that these factors are taken into account by test users.

Even if these concerns are addressed and it is assumed that, in the future, it will be possible to agree upon a shared definition of dyscalculia together with valid and reliable assessment tools, the role of environmental factors on a child’s maths development must still be considered. Gifford and Rockcliffe (2008) present the findings of a research project in which they attempted to identify “pure” cases of dyscalculia. They were unable to do so, but instead identified several children with “complex patterns of learning difficulties and compensatory strategies” (p. 21). In their discussion, they highlight the large volume of factors that can be implicated in maths difficulties, drawing particular attention to environmental factors such as pre-school experience. It will be necessary, then, to consider how best to integrate information about neurological and environmental influences.

EPs seeking to determine whether or not a child has dyscalculia may, then, feel that they are faced with a difficult task. Although it is possible to conceive of “clear-cut” cases where poor numerosity and, by extension dyscalculia, provide the best explanation of a child’s difficulties, there remain questions which are likely to present themselves in more complex cases, for example:

- Does current assessment practice provide evidence which is sufficiently valid and reliable upon which to base a diagnostic decision?
- If a child has good numerosity, does it mean that they do not have dyscalculia?
- At what point does a child’s numerosity pass from being considered “typical” to “atypical”?
- How can one effectively control for test variables (such as heightened anxiety or reduced concentration) when assessing numerosity?
- Should diagnosis be made in cases where the child has poor numerosity and significant environmental risk factors are identified?

In seeking answers to these questions, it may be useful as a starting point to consider the approach advocated by Yin (2009) for case study research. Yin argues that the validity of real world case studies is improved by the use and triangulation of multiple sources of evidence. This view is echoed by Woolfson, Whaling, Stewart, and Monsen (2003) in their presentation of a problem-solving framework to guide educational psychology practice. Within this way of working, EPs could choose to undertake broad assessments of numerosity, mathematical attainment and cognitive ability and then, through observation and consultation, compare the information gained with the views of students, parents and teachers. After
triangulating information from all these sources, EPs may feel more able to provide a valid and reliable description of a child’s maths difficulties.

**What is the benefit of identifying dyscalculia?**

In addition to considering whether or not assessment for dyscalculia can be undertaken, EPs should consider whether it brings any benefit to the child, and conversely whether not identifying dyscalculia places children with “dyscalculic-type” difficulties at a disadvantage. Elliott and Gibbs (2008) provide an informative account of the “meaningfulness, purpose and effect of the dyslexia construct” (p. 476). To do so, they ask three pertinent questions, which are discussed briefly here in relation to applying a similar conceptual framework of the term “dyscalculia”.

**Question 1: Is dyscalculia a clinically or educationally meaningful term for differentiating between children with maths difficulties?**

If a neurological definition is used (such as that presented by Butterworth et al. [2011]) then dyscalculia can be defined as a specific neurological impairment (numerosity) in a specific area of maths (number processing). The definition allows differentiation from other types of number difficulties (for example, fact retrieval, and the naming of numerals) and other types of difficulty in maths (for example, difficulties with algebra or shape and space).

The current neurological definition of dyscalculia is not, however, widely shared outside of academic discourse, nor is it agreed by all neuroscientists to be sufficient. The DfES definition makes implicit reference to numerosity but is broader in its conceptualisation. It defines dyscalculia as “A condition that affects the ability to acquire arithmetical skills” (DfES, 2001, p. 2) and goes on to describe the characteristics of dyscalculic learners:

> Dyscalculic learners may have difficulty understanding simple number concepts, lack an intuitive grasp of numbers, and have problems learning number facts and procedures. Even if they produce a correct answer or use a correct method, they may do so mechanically and without confidence. (p. 2)

Making a meaningful distinction between dyscalculia and other maths difficulties using this definition may prove more difficult.

**Question 2: To what extent would the dyscalculic diagnosis guide the educator in devising appropriate forms of intervention?**

Butterworth and Laurillard (2010, p. 527) note that “one of the central problems in educational neuroscience is how to coordinate the disciplines of education and neuroscience”. They suggest that doing so will likely require conversation between neuroscientists, psychologists and educators: a task which is perhaps complicated by the different languages, epistemological standpoints and research methodologies that are present within and across these groups. They also suggest that there is no linear relationship between neuroscientific research and educational intervention. Instead, they argue that “the science informs the design of the intervention, as the science of materials informs, but does not determine the design of a bridge” (p. 527).
Despite this, research into neurologically informed interventions has already begun. Neuroscientists have designed and piloted computer programmes to develop numerosity (Laurillard, Baajour, British Educational Communications, & London Knowledge Lab, 2009) and neurologically informed pedagogical approaches are being discussed.

**Question 3: To what extent should the dyscalculic diagnosis result in the differential allocation of resources or other forms of special arrangement?**

Identifying children with difficulties in numerosity may prove a meaningful way of differentiating between types of maths difficulties. In the future, it may also provide a basis for planning effective targeted intervention. There is a subtle but important difference, however, between identifying a child’s difficulties and applying to them a label.

If a “narrow” definition of dyscalculia (such as that presented by Butterworth et al. [2011]) is applied, it follows that only a proportion of those children who experience a difficulty in maths will be assigned the label. Given the relationship between the receipt of a label and the allocation of resources (see Lauchlan & Boyle, 2007), it is possible to imagine a situation in which children with dyscalculia access resources that those with “un-labelled” maths difficulties, perhaps in algebra or shape and space, do not.

If a “broad” definition of dyscalculia (such as that proposed by the DfES [2001]) is applied then a greater proportion of children experiencing difficulties in maths could be assigned a label and, as a result, there is likely to be less homogeneity within the labelled group. In this instance, concern may also be raised about the utility of a general dyscalculia label in deciding what resources are needed to meet a child’s individual needs.

It is important to note that the allocation of resources based on diagnosis does not necessarily create a situation of inequality. Diagnosis could, for example, lead to the allocation of different rather than additional resources. Furthermore, if numerosity is found to be an essential skill upon which the development of other mathematical skills is contingent, then screening for dyscalculia may provide an effective way of targeting early intervention. However, given the concerns around labelling children, some EPs may prefer a system in which tailored resources are allocated based on children’s individual strengths and difficulties, rather than labels. The issue of labelling needs to be considered carefully and with specific reference to dyscalculia.

**Conclusions: where next for EPs?**

Neurological studies have provided robust evidence for the existence of a specific, fundamental, number processing skill, which is present in very young children and which employs a specific area of neural architecture. The absence of this skill, in neuroscientific discourse, been labelled as “dyscalculia”. Yet the clarity of this definition is perhaps less evident in definitions from outside of the domain of neuroscience. Also, questions remain regarding the identification process for dyscalculia.

For those who strongly adopt a social view of disability, this, along with the negative implications of labelling children, may provide reason to dismiss the possibility that identifying dyscalculia could be of benefit to children and young people.
For those who adopt a more interactive view, it may provide motivation for increased involvement with research. Three ways in which EPs could develop their engagement with neurological research into dyscalculia and maths difficulties are suggested here.

Firstly, given the range of cognitive skills that are required to engage fully in the maths curriculum and the multiple factors that may impact on the development of mathematical ability, it seems appropriate for EPs to undertake broad-based assessments when considering a child’s maths difficulties. Given the amount of neurological evidence which implicates numerosity as a fundamental maths skill, it would also seem appropriate for EPs to include an assessment of numerosity as part of any such assessment.

Secondly, EPs could work more closely with neuroscientists to develop the tools that are available for assessing children’s numerosity. Having the ability to triangulate information from multiple sources will strengthen the evidence base upon which diagnostic decisions are made. Developing more naturalistic and interactive assessments may also help reduce the impact of confounding variables such as anxiety, tiredness and boredom on assessments of numerosity.

Finally, and perhaps most importantly, EPs should consider how best to integrate the increasing body of educational-neuroscientific research into their case formulations. EPs will be acutely aware of the complexity of children’s special educational needs and the interplay between biological and environmental factors. Yet, in the UK, “within-child” labels such as dyslexia, autism and dyscalculia are a part of modern popular discourse and are likely to stay so. The challenges, then, are to:

- interrogate the evidence base upon which such labels are based,
- ensure that diagnostic assessments are robust,
- outline to children, parents and teachers the important distinction between a neurological label and a young person’s observed special educational needs, and
- given the implications of diagnosis, make sure that labelling a child or young person is of benefit to them.

The author stated earlier that writing an article about “dyscalculia”, rather than “difficulties in maths”, has proved a challenging task. The task ahead for EPs is perhaps more so, but it also exemplifies an exciting and important new area for educational psychology work in educational neuroscience.

References


