Basic numerical processes in developmental dyscalculia

Marie-Pascale Noël
Université Catholique de Louvain

**Abstract**

Developmental dyscalculia is a specific learning disorder manifested by a failure to achieve adequate proficiency in arithmetic despite normal intelligence, scholastic opportunities, emotional stability and sufficient motivation. These difficulties do not result from a sensorial deficit and interfere significantly with daily life and/ or school success.
In our talk we will present the results of studies indicating a possible genetic contribution to this trouble. We will then present a study that shows that developmental dyscalculia is due to a basic dysfunction of number processing. However, this dysfunction does not concern the ability to represent number magnitude but merely to access to that representation from symbolic codes. Possible anatomical-functional peculiarities of the cortical bases related to this dysfunction will be evoked.

**Abstract**

La dyscalculie développementale est un trouble spécifique d'apprentissage qui se manifeste par une difficulté d'apprentissage en mathématique malgré un niveau d'intelligence normal, des opportunités scolaires normales et une stabilité émotionnelle et une motivation suffisantes. Ces difficultés ne résultent pas non plus d'un déficit sensorial mais elles interfèrent de manière significative avec la vie quotidienne et la réussite scolaire.
Dans notre exposé, nous présenterons les résultats d'études indiquant la possibilité d'une contribution génétique à ces difficultés. Nous présenterons ensuite des études montrant que la dyscalculie développementale est liée à une dysfonction des traitements numériques de base. Ce dysfonctionnement ne concernerait pas la capacité à représenter la grandeur des nombres mais à accéder à cette représentation à partir des codes symboliques. Enfin, nous évoquerons les études montrant que des particularités anatomico-fonctionnelles pourraient être à la base de ce trouble.

**Personal information**

I am a senior researcher, paid by the National Research Fund of Belgium and also Professor at the Catholic University of Louvain (Louvain-la-Neuve, Belgium). My main interest is numerical cognition. My thesis was on the neuropsychology of acquired acalculia in adults but these last ten years, I have been working on developmental psychology on both normal and abnormal development of numerical skills. I am also the head of a clinic of learning disability.

**Article of the presentation**

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According to the DSM IV (American Psychiatric Association, 1994), three criteria must be met to speak of developmental dyscalculia. In the first place, the arithmetical capacities of the person must be lower than the expected level based on the age, the intelligence and the education of the person. Secondly, these weak arithmetical capacities must significantly interfere with the daily-life and the school success of the person. Thirdly, these difficulties should not be the resultant of a sensory deficit.

Difficulties encountered by dyscalculics are varied (see, for example, the classifications of Badian, 1983, Kosc, 1974 or Temple, 1992). They can concern the mastery of the number symbolic codes and lead to errors in reading or writing numbers or the mastery of the written calculation algorithms but most of the time, they concern also simple calculations. Thus, simple calculations between two one-digit numbers give place to an excessive error rate. Abnormally long response time is also noticed, owed, notably, to a mode of resolution based on immature strategies (for instance, counting on fingers) and a difficulty to retrieve answers from long-term memory (Geary, Brown & Samanarayake, 1991; Kaufman, 2002).

Several hypotheses have been proposed to account for this learning disability. In this talk, we will present the data suggesting a possible genetic contribution. Then, we will develop the research aiming at testing the presence of a very specific deficit concerning basic number processing. Then, we will illustrate possible neuro-anatomical bases of that defect.

Several elements of the literature suggest that there is a genetic contribution to dyscalculia. First, epidemiologic studies of Gross-Tsur, Manor and Shalev (1996) underline the presence of learning disability in mathematics in first-degree parents (both in parents and in siblings) of dyscalculia probands. In a three-year follow-up study, Shalev, Manor, Awerbach and Gross-Tsur (1998) have shown that, for a dyscalculic child, the presence of a parent or sibling showing also learning math disability is associated with a higher risk of showing persistent math disabilities over a three year period. Furthermore, several genetic syndromes are known for leading to very poor numerical skills. This is the case in particular for the fragile-x syndrome (Grigsby, Kemper & Hagerman , 1987), the William syndrome (Paterson & al., 1999) and the Turner syndrome (Rovet, Szekely & Hockenberry, 1994; Temple & Marriott, 1998; Bruandet et coll.; 2004), among others. Yet, the hypothesis of a genetic inheritance of dyscalculia has only been tested in one research (to our knowledge). In this study, Alarcon, DeFries, Light, and Pennington (1997) have tested co-twins to 63 dyscalculic probands, 40 of the being homozygote twins and 23 being 23 heterozygote twins (HeZ), as well as 167 other pairs of twins with no known dyscalculia. They found that the concordance rate of dyscalculia was higher in homozygote twins (.73) than in heterozygote twins (.56). When the same analysis was run on children with pure dyscalculia (with no associated reading disorder), the difference was even stronger (.85 and .46), although still not reaching the conventional level of statistical significance (p=.08). In summary, the hypothesis of a genetic contribution to dyscalculia seems very plausible although strong empirical evidence is still needed.

On a cognitive level, several researches have shown that dyscalculia is not due to general cognitive factor such as weak intelligence (Gross-Tsur & al., 1996), or poor inhibition capacities (Censabella & Noël, 2005; in press). Instead, specific numerical factors must be looked for. In this respect, Butterworth (1999) has suggested that humans are born with an innate capacity to represent numerosities. For him, a defect on that "number module" would be the basis of developmental dyscalculia. To test this hypothesis, Landerl, Bevan and Butterworth (2004) have shown that dyscalculics and dyscalculics-dyslexics children (aged 8-9 years old) are slower than control or dyslexic children in all the numerical tasks proposed, i.e, number reading, verbal counting, enumeration of dot collections and magnitude comparison of two Arabic digits. Furthermore, this slowness appeared to be specific to number processing. For instance, dyscalculics were slower in number naming but not in colour naming; they were also slower in comparing the magnitude of two Arabic digits but not in comparing their physical size. Based on these results, Landerl et al. argued that all the numerical tasks involve the use of the number sense module and, as this module is defective in dyscalculics, it leads to weaker performance.

Yet, all the tasks used in this paper involved symbolic numbers, either Arabic numerals or spoken numerals. Accordingly, an alternative interpretation of the results can be proposed according to which the underlying defects would not be the number sense or the magnitude representation, but the access to that representation from or to symbolic numbers.

In a first exploratory study, Noël (2002) had shown that dyscalculics (8 y.o) were indeed slower than controls on a magnitude comparison task of Arabic digits but they did not differ from controls when comparing the magnitude of two collections of dots.

In a more constrained study, Rousselle and Noël (2007) have compared 46 dyscalculic children (second grade) to 46 controls paired on age, intellectual level and class level. Three magnitude comparison tasks were proposed: (1) on a pair of Arabic digits, (2) on collections of dots and (3) on collections of sticks for which surface area, contour of the collection and other continuous variables, were equated between the two collections. As Landerl et al. and Noël (2002), we found a major difference between the two populations on the magnitude comparison of Arabic digits which involved accessing number magnitude representation from symbolic codes. However, no difference was found between the two groups of participants for the magnitude comparison of the two collections, which indicated that the magnitude representation itself was not defective in dyscalculics. We thus argue that one of main underlying deficit in most dyscalculic children is not a defective number sense but rather a specific difficulty in accessing magnitude representation from symbolic code or vice versa.

Some research suggests that neuro-anatomical peculiarities may be the bases of that defect. It is well-known in the adult literature, that numerical tasks like calculation, number magnitude comparison, or even, Arabic digit detection lead to an important activity at the level of the intra-parietal sulci (see Zago & Pesenti, 2002; Eger & al ., on 2003). More importantly for our purpose, Isaacs, Edmunds, Lucas, & Gadian (2001) have shown that born pre-terms teenagers presented different brain structure according to their mathematical level. In particular, those who had lower mathematical scores than expected on the basis of their intelligence had a weaker grey matter density than the one of good performers in mathematics, at only one spot in the brain structure, i.e., the left intra-parietal sulcus. Further research using functional brain imagery should improve our comprehension of the neuro-anatomical bases of developmental dyscalculia.

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