Developing Tasks for Screening Dyscalculia Tendencies[1]

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In mathematics, one of the specific learning disabilities is developmental dyscalculia (DD). It is reported that around 5% of school age children is affected with DD. Diagnosing students with possible dyscalculic tendencies and giving them relevant extra learning opportunities based on their specific difficulties are utmost importance for them to go with their peers. Five systems of human cognition have been determined so far, one of which is number. Two distinct systems of basic numerical capacities have been described: Approximate and exact number systems. Different tasks have been produced to assess the capacity and functioning of these two systems. The purpose of this paper is to determine and explain the major types of tasks used to assess numerical capacity.

Keywords: Core knowledge, Core systems of number, Dyscalculia, ANS, ENS

Developmental Dyscalculia (DD) is a specific mathematics learning disability affecting 3 to 6% of school age population in different countries (C. Mussolin et al., 2010; R. S. Shalev & M. G. von Aster, 2008). We do not know yet the exact reasons behind dyscalculia. As a possibility Butterworth (2005) stated that children inherit DD from their parents since it is a brain-based disorder and probably it has genetic origins. Whatever the reasons, students with DD have considerable difficulties in learning numbers and calculations and they lag at least 2 years behind their peers. In order for these students to continue their education with their peers in regular classrooms they should have additional education relevant to their individual needs. However, they should be diagnosed first for their mathematical learning difficulties.

Diagnosing students with possible dyscalculic tendencies and giving them relevant extra learning opportunities based on their specific difficulties are utmost importance for them to go with their peers. This determination should be done as early as possible because the brain plasticity is very high in early ages (Zamarian, Ischebeck, & Delazer, 2009). The earlier we diagnose dyscalculia the more we have chance to remediate it. Additionally, if early indicators for mathematics learning difficulties (MLD) can be addressed within instructional programs, it may help children to progress and prevent them from falling behind (Desoete, Ceulemans, Roeyers, & Huylebroeck, 2009).

Diagnosing DD has been a measurement problem for researchers. There are different approaches to the problem. The variability of the approaches and the tools used to assess dyscalculia make it difficult to establish a common assessment framework. One approach to the resolution of the problem is to assess basic capacities of human cognition. R. S. Shalev and M. Von Aster (2008) proposed that testing of DD should tap several dimensions of

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human numerical cognition considered to be relevant to the number processing and calculations. Therefore this study attempts to approach the issue from the perspective of basic human cognition systems or basic capacities of human brain. We believe, with others, core deficit in number sense or in the link between number sense and symbolic number representations indicates the existence of certain types of DD (Wilson et al., 2006). It is also clear that if we understand the foundational underpinnings beneath the acquisition of mathematical skills, we would develop better math education and intervention programs for children (Ansari, Price, & Holloway, 2010).

Core systems of human cognition

Spelke and Kinzler (2007) proposed that humans are gifted with a small number of separable systems of core knowledge. According to the researchers, the proposed five systems of human cognition are objects, actions, social partners, number, and space. These core foundations are the bases upon which our new, flexible skills and belief systems operate on (Spelke & Kinzler, 2007). The proposed system is summarized in Figure 1.

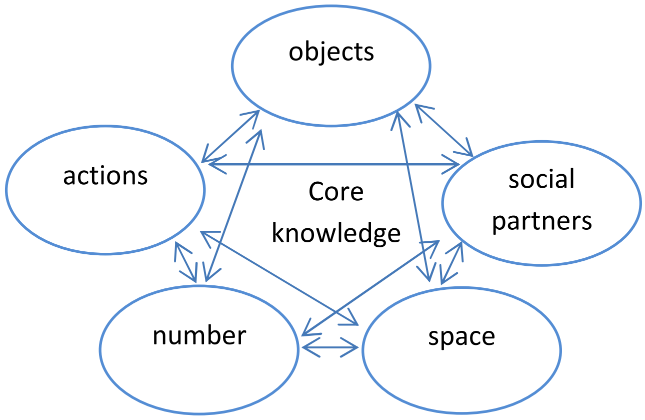


Figure 1. The structure of humans' cognition

Although each system has its signature limits to underlie human reasoning about the world (Spelke & Kinzler, 2007), the five systems are possibly interacting with one another in representing and acting on different types of knowledge. For example actions might have numerical attributes as well as spatial ones such as traces. Similarly, objects may have both spatial and numerical qualities. Further discussions of the core systems are beyond the scope of this paper and can be found in Spelke and Kinzler (2007). Our focus, instead, is on the system that constitutes the construction of numbers, number concepts and relevant calculations.

Core systems of number

The core systems of number proposed by (Feigenson, Dehaene, & Spelke, 2004) consists of two subsystems. One is called approximate number system (ANS) and represents the numerical magnitudes approximately while the other system, called exact number system (ENS) represents the (small) numbers exactly (Izard, Pica, Spelke, & Dehaene, 2008). The two subsystems are considered to be functioning independently (Feigenson et al., 2004).

By its very nature, ANS works based on contextual and/or perceptual estimation while the ENS works on such mental actions as subitizing, counting, and calculations. When and which system engages in solving a numerical problem? Basically, if the numerical magnitude is visually presented and sufficiently small, usually 4 or less, then the ENS is activated. From the birth on, human being, even some animal species, has an innate capacity to determine the number of items in a set at a glance, via a cognitive action called subitizing, (Antell & Keating, 1983) provided that the number of items is 4 or less. For more than 4 items on the other hand, the ANS is activated if the person has a limited time to decide. If there is enough time to decide then counting or other calculation procedures are used to determine exact numerosity of large numbers. Similarly, in daily life if we do not have a calculator or paper and pencil then we use mental, approximate calculations to find the product 12X24=? by substituting the numbers with 10X25=250, which gives us an approximate value that is close enough to the real product. In short, we either treat a number approximately or exactly depending on the circumstances or other external forces and we do have a capacity to do that.

Although mental representation of number seems to be abstract (Brian Butterworth, 2010) it is possible to physically represent a number in different modalities such as sounds, objects, pictures, symbols. These representational modalities have also effect on the recognition of numerical magnitude. Basically, we can put these modalities into two major groups as symbolic and non-symbolic or analog. A number such as 4 is represented either symbolically or non-symbolically. Written forms of number (four), Arabic numerals (4) and canonically represented dot patterns can be considered symbolic representations (Mussolin, Mejias, & Noël, 2010). Random dot patterns and number line on the other hand can be considered as analog representations of number. Core systems of number and relevant tasks are summarized in Figure 2.

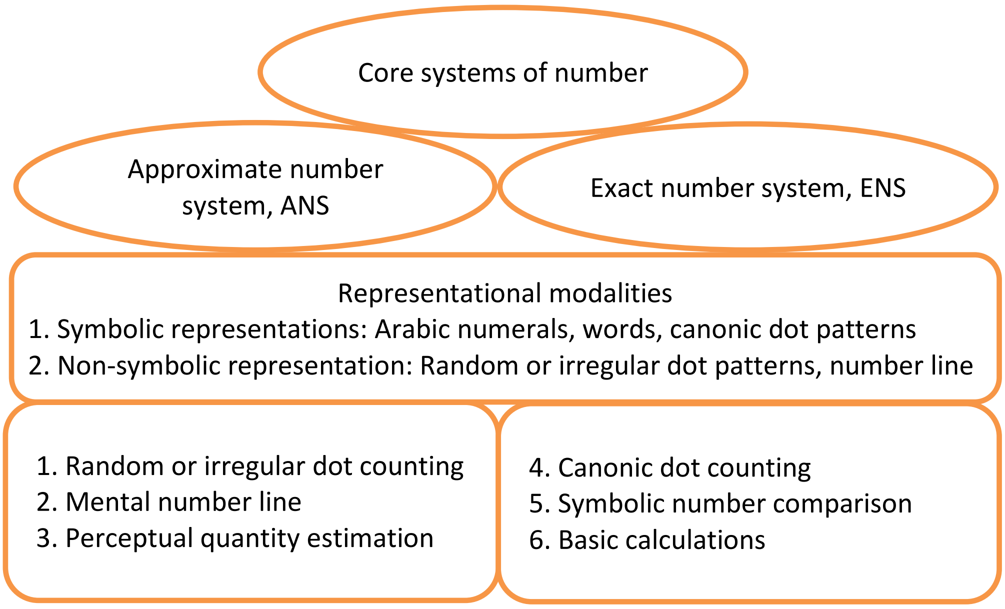


Figure 2. Core systems of number and relevant tasks

Recognition of symbolic representations of numbers beyond 4 is relatively faster than that of analog quantity representations. Since the analog quantities of 4 or less are recognized at a glance the performance is fast and nearly perfect (Feigenson et al., 2004). The readings of symbolic representations depend on education or experience therefore enumeration and comparison of symbolic quantities might be good tasks to differentiate mathematics learning difficulties, specifically dsycalculic tendencies.

Since both ANS (Lipton & Spelke, 2003) and ENS are present in human beings from birth these systems are considered to be inherited as a capacity to learn the concept of number and calculations. According to Feigenson et al. (2004), children and adults integrate the first core system with the symbolic number system for enumeration and computation. At present, however, it is not well explored whether the second core system is engaged in symbolic number tasks. Landerl, Bevan, and Butterworth (2004), on the other hand, found that children showed deficits in very basic numerical capacities such as dot counting and symbolic and non-symbolic number comparisons. They further observed a tendency towards a difference in subitizing. They also believed that the genetic tendency seemed to be the most likely candidate for an underlying cause of dyscalculia when explaining the failure to understand basic numerical concepts, especially the idea of numerosity. Yet, there are conflicting results in the literature. For example; some researchers reported no significant difference between the low achieving and normal achieving groups in any of the approximate tasks (Iuculano, Tang, Hall, & Butterworth, 2008). B. Butterworth (2010) claimed that the major cause for DD is neither the approximate number system nor the small number system but a deficit in numerosity coding.

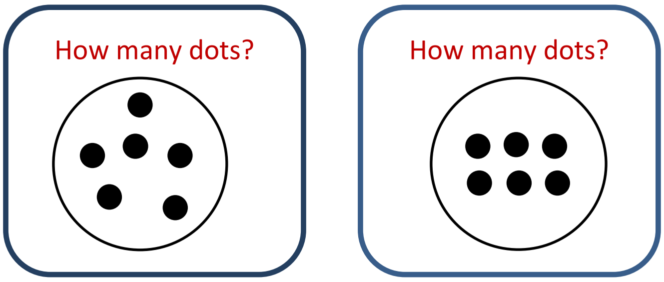
Specific tasks to measure the basic capacities

The tasks that could be used in assessing basic numerical capacities should address both approximate and exact number systems. Considering the difficulties children with DD have in mathematics, R. S. Shalev and M. Von Aster (2008) suggested that in addition to the tasks to measure the knowledge of arithmetic facts and procedures, basic number-processing skills such as subitizing a small number of objects and estimating large number of objects, comparing number magnitudes, counting, and the ability to use different notational formats (eight or 8) and spatially representing numbers on a mental number line be assessed in order to assess DD thoroughly. Now we are going to describe five different tasks in order to assess the dyscalculia tendencies.

Task 1. Dot counting (subitizing)

Even five-days old infants can discriminate 1 from 2 and 2 from 3 in a condition presented as black dots on white background (Antell & Keating, 1983). Similarly, Wynn (1992) found that five-months old infants can discriminate the results of addition and subtraction with small numbers, usually resulting in less than 4. Since these babies are not able to verbally count at that small age they should be using some other mechanism to differentiate small numbers. Landerl et al. (2004) found differences in reaction times (RT) of dyscalculic and normally achieving children especially in the counting range, i.e. enumerating dots from 4 to 10. We believe that these tasks assess the capacity to represent exact numerosities and suitable to measure some aspects of basic numerical capacities.

There would be two types of this task to represent the two modalities. In one type of tasks dots will be arranged randomly to reveal the differences in children’s enumerating speed in this format. In another type of tasks, dots will be canonically arranged in order to detect if there is any processing differences in this format among the children with different levels of mathematical achievement. We are expecting differences in response times since children with dyscalculic tendencies may employ more primitive strategies than normally achieving children. Desoete et al. (2009) suggested that subitizing and counting should be assessed separately, especially in problem solving tasks in mathematics. The mere reason is that subitizing should not be limited to counting only. Students who count all the elements in a set will probably spend more time than the students who use both subitizing and counting, even fast counting based on their previous experiences. One of the indicators of dyscalculia was not responding to education. So the students who employ more primitive strategies than their peers might be dyscalculic tendencies.



(a) Random (b) Canonic

Figure 3. Sample dot counting tasks (in random and canonic arrangement)

Usually, any child can correctly count the dots presented but the difference occur in terms of the time taken to count the dots. Slow math learners tend to count the dots one by one so taking more time to count. So, both latency and accuracy should be taken into consideration in assessing this task.

Task 2. Number comparison (numerical stroop)

Numerical comparison is one of the two basic abilities thought to index numerical magnitude processing (Holloway & Ansari, 2009). Therefore, this task was designed to assess the capacity to order numerosities by magnitude and to understand the numerals (Iuculano et al., 2008). Rousselle and Noel (2007) claim that children with mathematics learning disabilities find accessing number magnitude from symbols more difficult than processing numerosity itself. In other words, they believed that interruptions between numerosity concepts and their symbols result in arithmetical deficiencies. Iuculano et al. (2008) found a significant difference between the normal achievement and low numeracy groups in the symbolic Number Comparison tasks. Similarly, Holloway and Ansari (2009) stressed the importance of efficient mappings between numerical symbols and their quantitative meaning for the development of mathematical abilities.

In this study, we are going to use tasks designed in accordance with the numerical-stroop paradigm. In the stroop tasks, subjects are asked to pick either the numerically or the physically larger of the two numbers. In numerical stroop tasks subjects' decisions are interfered with the use of physically incongruent numerals as shown in Figure 4. Girelli, Lucangeli, and Butterworth (2000) found a size congruity effect in numerical comparison tasks in subjects at different ages from children to adults (i.e., relative to a neutral control, corresponding physical sizes expedited, and different sizes interfered with the numerical comparison).

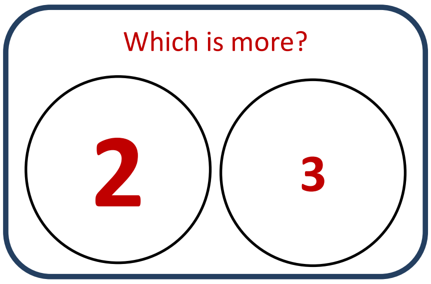


Figure 4. Sample numerical stroop task with small distance

There is another variable that affects the processing speed and accuracy of symbolic number comparison tasks called distance effect (DE). According to Dehaene, Dpoux, & Mehler, (1990), DE is observed when participants are faster and more accurate at making responses when the numerical distance separating two numbers is relatively large, such as 7 (2 vs. 9), than when it is small, such as 2 (3 vs. 5). Later, it is reported that individual differences in the distance effect were related to mathematics achievement and this relationship was found to be specific to symbolic numerical comparison (Holloway & Ansari, 2009). In another study, DD children showed a greater numerical distance effect than control group children, regardless of the number format (Christophe Mussolin et al., 2010). This finding indicates that children with DD display a deficit in their cognitive system when processing the numerical magnitude from symbols. Slow processors of numerical information tend to show larger distance effects. So the task seems suitable for differentiating slow learners from the normal ones. In these tasks latency is more important than accuracy. Any child can decide on which number is larger but it takes longer for the slow learners. According to Iuculano et al. (2008), this situation is a result of poor understanding of symbolic numerals not a poor grasp of exact numerosities. It seems that the speed of processing numerical magnitudes from symbols in an indicator of the efficiency mathematical learning.

Task 3. Perceptual quantity estimation

Another basic ability thought to index numerical magnitude processing is numerical or quantity estimation (Holloway & Ansari, 2009). Different authors pointed out the importance of perceptual quantity estimation in differentiating different levels of number sense or mathematical learning capacity. As children get older and build numerical experience, they develop multiple representations of numerical magnitudes. Consequently, they eventually rely on proper representations. Moreover, their choice of representation is shaped by the numerical context (Siegler & Opfer, 2003). Being able to make near accurate estimations of numbers and visually represented quantities seems to be closely related to mathematical success (Booth & Siegler, 2006).

Task 4. Number line estimation

One of the tasks used to measure approximate number representation is mental number line. In this task, children are given an empty line starting from number 0 at the left end side and ends with a larger number (usually, 10, 20, 100 or 1000). Then, they are asked to indicate the position of the given Arabic numerals on the line (Elida V. Laski & Siegler, 2007). In different studies the linearity of the estimates was found to correlate with mathematical achievement (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010) and arithmetic learning (Booth & Siegler, 2008).

Booth and Siegler (2008) provided extensive evidence for the predictive ability of the linearity of number line estimation on the learning of novel arithmetic problems above and beyond the prediction of the other variables such as prior arithmetic knowledge. So they believed that learning of new arithmetic problems is influenced by numerical magnitude representation. The ability to estimate the relative magnitude of numbers and spatially placing them on a number line seems to be a reliable indicator of mathematical learning.

Task 5. Simple arithmetic

Children with DD have difficulties in remembering number bonds (i.e., 6+4=10) and number facts (i.e., 6x4=24) especially the hard ones (Landerl et al., 2004). Therefore, they usually lag further behind their peers in learning further arithmetic and mathematics involving numbers and numerical procedures. However, the difficulty of learning number facts and arithmetic related calculation procedures may step from other external reasons such as poor teaching, inappropriate learning conditions, poor early learning, or some emotional reasons such as lack of motivation or interest, low self-efficacy, high anxiety etc. (Munro, 2003). Therefore, a failure in learning arithmetic facts could be attributed to either internal factors or external factors. If there is no problem in internal factors then the cause for the poor achievement should be in the learning environment.

Conclusion

This is a small part of a larger project. Up to now, we reviewed the literature to find out what kinds of tasks are used to discriminate dyscalulics, or students with mathematical disorders. It seems that human beings have a basic, may be inherited, capacity to mentally represent or access number in two ways either approximately or exactly. Therefore, we developed tasks to address these two capacities. In the next step, we are going to determine the numerical and other aspects of these tasks.

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