Trends in Neuroscience and Education 2 (2013) 43–47

Contents lists available at ScienceDirect

Trends in Neuroscience and Education

journal homepage: www.elsevier.com/locate/tine

Multiple components of developmental dyscalculia

Wim Fias [a,*], Vinod Menon [b], Denes Szucs [c]

[a] Department of Experimental Psychology, Ghent University, H. Dunantlaan 2, B-9000 Ghent, Belgium
[b] School of Medicine, Stanford University, Stanford, CA, USA
[c] Department of Psychology, University of Cambridge, Cambridge, UK

ARTICLE INFO

Article history:
Received 26 March 2013
Accepted 20 June 2013

Keywords:
Developmental dyscalculia
fMRI
Working memory
Attention
Number representation
Cognitive processing

ABSTRACT

Unresolved controversies regarding the functional impairments at the origin of dyscalculia, including working memory, approximate number system and attention have pervaded the field of mathematical learning disabilities. These controversies are fed by the tendency to focus on a single explanatory factor. We argue that we are in need of neurocognitive frameworks involving multiple functional components that contribute to inefficient numerical problem solving and dyscalculia.
© 2013 Elsevier GmbH. All rights reserved.

1. Introduction

The debate regarding the factors underlying functional impairments at the origin of dyscalculia is longstanding. Whereas developmental dyscalculia (DD) has long been thought to be determined by multiple components, the last decade or so has seen a shift towards the search for a unique underlying factor. This tendency is plausibly related to important new findings in the cognitive neuroscience of number processing: Nieder et al. [34,35] observed number-selective neurons in the monkey brain. Neuroimaging studies suggest a similar type of neural coding in the intraparietal sulcus (IPS) of humans [39,40]. The properties of these neurons can explain human performance in great detail, in populations ranging from young infants to adults. This makes this basic number coding system a plausible phylogenetic precursor of human basic number processing skill. It has also been taken as an ontogenetic starting point for the development of more complex and schooling-induced formal arithmetic. An impaired or inaccurate quantity representation of this type, often referred to as approximate number system (ANS), is taken to be the core deficit of DD [14,27]. Alternatively, others think that DD is a weakness in automatically mapping symbols to their internal magnitude representations, reflecting a specific impairment in symbolic processing that does not necessarily impact non-symbolic processing [19,36,42,43].

This extensive focus on a single core deficit is remarkable because DD is quite heterogeneous [44,30]. Although the prevalence rates vary considerably from study to study, it is clear that dyscaculia has a high comorbidity with other learning and developmental disabilities [45] including dyslexia [5], ADHD, and dyspraxia. This naturally raises questions of how heterogeneity can be reconciled with the homogeneity which is to be expected from a single core deficit. In fact, the heterogenous nature of DD better fits theories which describe it as consequence of impairments of domain-general phenomena including working memory [24,48,12,46,37] and attention [6].

The growing focus on a core impairment in processing numerosity has led to a strong bias towards investigations of number representations as the primary explanatory factor of DD, thereby largely ignoring other critical cognitive functions and processes. Thus, many recent studies have concentrated on measuring the accuracy of number representation and related them to math achievement. Apart from the restricted scope of such a one-sided focus on number representations, it also has inherent risks, namely that representations are hard to measure independently of the attentional and decision-making processes that are involved in specific tasks. For instance, measurements of representational accuracy have been shown to be affected by attention in a number line mapping task [1] and by the decision mechanisms in a number comparison task [50,54]. Conversely, it is also true that those studies that do explicitly address processes often remain at a superficial level of explanation and only vaguely refer to cognitive processes in general terms, such as working memory or executive function, without detailed specification of the underlying neural architecture of how these functions recruit and employ representations of numerical knowledge. This vagueness may be one of the reasons why non-representational neurocognitive processes have been undervalued as key factors that contribute to both “pure” and comorbid DD.

* Corresponding author. Tel.: +32 9 264 64 11; fax: +32 9 264 64 97.
E-mail address: wim.fias@ugent.be (W. Fias).

2211-9493/$ - see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.tine.2013.06.006

2. fMRI studies show that multi-componential neural networks subserve number processing and arithmetic

The neuroimaging literature of number processing has primarily focused on the parietal cortex. Although most studies have reported activity in other brain regions, these activations remained often undiscussed. The recent meta-analysis of Arsalidou and Taylor [4] has highlighted that other key subcortical and neorcortical brain regions, including inferior frontal gyrus, anterior cingulate gyrus, insula and cerebellum are also systematically related to numerical problem solving tasks. As these areas are known to contribute to basic neurocognitive functions like attentional, cognitive control and working memory these activations can be interpreted as reflecting cognitive processes providing dedicated support depending on the nature of the task and on the level of experience and development. Fig. 1 provides a schematic overview how number processing is achieved by a complex system of neural networks, each subserving specific cognitive processes. At a broad level of analysis, a number of subsystems can be distinguised. First, the integrity of visual and auditory association cortex which help decode the visual form and phonological features of the stimulus, and the parietal attention system [17] which helps to build semantic representations of quantity [2]. Second, procedural and working memory systems anchored in the basal ganglia and fronto-parietal circuits create short-term representations [31,51] that support the manipulation of multiple discrete quantities over several seconds. This system also underlies cognitive control systems that optimize performance by monitoring performance, inhibiting undesired responses etc. Third, episodic and semantic memory systems play an important role in long-term memory formation and generalization beyond individual problem attributes. Fourth, prefrontal control processes guide and maintain attention in the service of goal-directed decision making.

More broadly, it is becoming increasingly clear that cognitive skills such as mathematical problem solving depend crucially on interactions within and between large-scale brain networks [11]. Advanced imaging and analysis approaches have confirmed and refined this picture. First, it is becoming more and more clear that the parietal cortex plays multiple roles in numerical cognition. For example, Wu et al. [57] used precise cyto-architectonic mapping to show that specific subdivisions of the posterior parietal cortex make qualitatively different contributions to arithmetic. Moreover, anatomical and physiological connectivity analysis provides insights into the neural processing subserved by these regions and suggests that this functional diversity of posterior parietal cortex regions, such as the IPS and angular gyrus, is determined by distinct functional pathways that link these subregions to other parts of the brain [55].

Developmental studies in children also provide support for multi-component neurocognitive systems and indicate that math skill development is not just a matter of tuning of a single core mechanism. Cho et al. [15] demonstrated strategy-related differences between counters and retrievers in children aged 7–9 in several brain areas, not restricted to parietal cortex, thereby suggesting that the transition from using procedural strategies to skilled memory-based retrieval is mediated by reorganization and refinement in multiple brain areas. Using a cross-sectional design comparing 2nd and 3rd graders, Rosenberg-Lee et al. [41] showed that the neurodevelopmental trajectory of skill learning is accompanied with changes in brain network composition and connectivity, comprising not only parietal but also occipital, temporal and frontal areas. Using a novel multi-pronged neuroimaging approach, Supekar and Menon [47] identified for the first time the dynamic control processes underlying the maturation of arithmetic problem solving abilities. They used a novel multimodal neurocognitive network-based approach combining task-related fMRI, resting-state fMRI and diffusion tensor imaging to investigate the maturation of control processes underlying problem solving skills in 7–9 year-old children and compared it to adults. They found the anterior insula, part of a larger network of regions (related to salience processing and generating influential control signals, see Fig. 1), developed to be a major causal hub initiating control signals during problem solving by the age of 9, but still showing weaker connections to other prefrontal cortex regions, including ventrolateral and dorsolateral PFC and anterior cingulate cortex, when compared to adults. Importantly, measures of causal

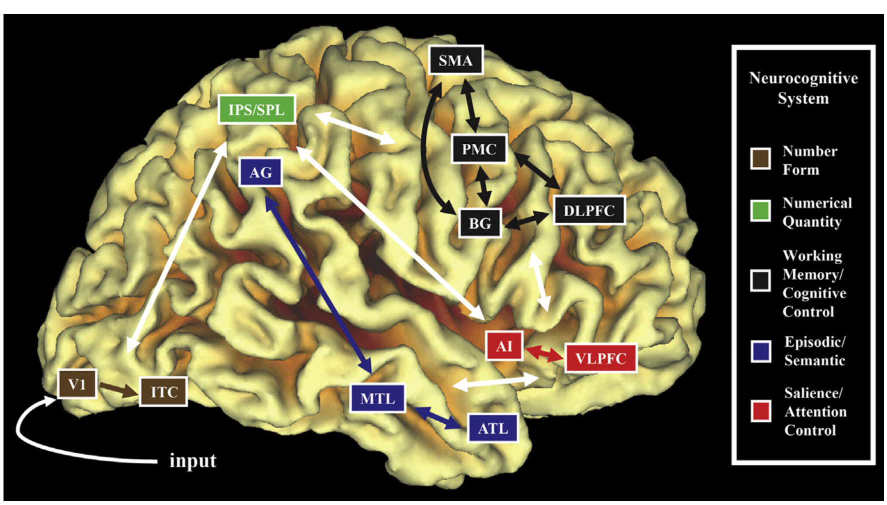

Fig. 1. Schematic circuit diagram of basic neurocognitive processes involved in arithmetic. The inferior temporal cortex (shown in brown) decodes number form and together with the intra-parietal sulcus (IPS) in the parietal cortex helps builds visuo-spatial representations of numerical quantity. Procedural and working memory systems anchored in fronto-parietal circuits involving the IPS and suparmarginal gyrus in the parietal cortex and the pre-motor cortex (PMC), supplementary motor area (SMA) and the dorsolateral prefrontal cortex (DLPFC) in the prefrontal cortex together with the basal ganglia (BG) create a hierarchy of short-term representations that allow manipulation of multiple discrete quantities over several seconds. This system also underlies cognitive control systems that optimize performance by monitoring performance, inhibiting undesired responses etc. Episodic and semantic memory systems anchored in the medial temporal cortex (MTL) and anterior temporal cortex (ATC), and the angular gyrus (AG) within the parietal cortex, play an important role in long-term memory formation and generalization beyond individual problem attributes, allowing storage and retrieval of numerical problems as facts. Finally, prefrontal control processes anchored in the saliency network encompassing the anterior insula (AI) and ventrolateral prefrontal cortex (VLPFC) guide and maintain attention in the service of goal-directed problem solving and decision making. Relative transparency for BG and MTL indicates sub-surface cortical structures. Adapted from [33].

Download English Version:

https://daneshyari.com/en/article/6042899

Download Persian Version:

https://daneshyari.com/article/6042899

Daneshyari.com