

developmental studies, they ignore an important component, which can constrain developmental and cognitive theories: the human brain. Given a decade of advances in understanding the neural basis of number processing, any accounts of numerical development and abilities that do not address the neural instantiation of number processing are necessarily incomplete. Here, to show the limitations of Rips et al.'s view, we consider the parietal lobes, a key area in number processing, with regard to their role in numerical magnitude and their contribution to general magnitude processing. On the basis of evidence from neuroimaging, neuropsychological, and behavioral studies, we challenge Rips et al.'s position that there is no dependency at all between natural number and internal magnitude (target article, sect. 6).

It is indisputable that adults in Western culture have natural number concepts based on symbolic representation of numbers. A great deal of evidence indicates that the parietal lobes, and especially the intraparietal sulcus (IPS), play a key role in numerical cognition (Brannon 2006; Cohen Kadosh et al. 2008; Dehaene et al. 2003; Nieder 2005). In imaging studies, activity in IPS is modulated bilaterally as a function of the distance effect, the numerical priming effect, and the size congruity effect (see Cohen Kadosh et al. [2008] for a review). All these effects stem from numerical representation. The IPS is also active during the processing of other magnitudes, such as physical size, time, space, and luminance (for reviews, see Cohen Kadosh et al. 2008; Walsh 2003). This led Walsh (2003) to suggest that the parietal lobe, especially at the right hemisphere, embodies the basis of a common metric for space, time, and numbers, and many neuroimaging studies have shown that symbolic numbers, non-symbolic numbers, and other magnitudes activate the IPS (see Cohen Kadosh et al. [2008] for a meta-analysis). Notably, the similarity between numbers and other magnitudes is not confined only to the neuronal level but is also observed during behavioural tasks, as indicated by similar effects and response functions (Cohen Kadosh et al. 2008).

These similarities between numbers and other magnitudes, both at the behavioural and neuronal levels, are not mere coincidence; they are indicative of the basic knowledge of magnitude upon which more specific and conceptual representations are built. As Rips et al. (sect. 2.2) have noted, during infancy, numbers do not represent a unique feature. Other dimensions, separately or jointly, can serve as cues in order to detect changes in quantity/magnitude. In our view, this is because of a shared magnitude mechanism that precedes numerical representation. In this scenario, different magnitudes are jointly represented from infancy (Feigenson 2007). Later, the child develops neuronal circuits dedicated to numerical information, and acquires the understanding of natural numbers. This specialized representation, which emerges as we understand natural number concepts, is possible due to interactions between non-tuned neuronal substrates originally dedicated to general magnitude representation, with areas in the left hemisphere involved in language, and ventral occipito-temporal areas involved in symbolic processing (Cohen Kadosh et al. 2007a). This conceptualization of human functional brain development is in line with other fields that have examined neuronal specialization, such as face perception (Cohen Kadosh & Johnson 2007), and is termed the Interactive Specialization Approach (Johnson 2001). The general framework of this theory suggests that some cortical regions that are initially functionally poorly defined are partially activated in a wide range of different contexts and tasks as cortical development proceeds.

The possibility of acquiring the concept of natural numbers via interaction between general magnitude and language is dismissed by Rips et al. Although they suggest why either magnitude or language might not play a role in the formulation of natural numbers, they do not explain why general magnitude and language cannot play an integrative role in shaping the understanding of natural numbers.

As with previous cases of the interactive specialization approach (Thomas & Johnson 2008), the interactive specialization approach

From magnitude to natural numbers: A developmental neurocognitive perspective

doi:10.1017/S0140525X08005621

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Abstract: In their target article, Rips et al. have presented the view that there is no necessary dependency between natural numbers and internal magnitude. However, they do not give enough weight to neuroimaging and neuropsychological studies. We provide evidence demonstrating that the acquisition of natural numbers depends on magnitude representation and that natural numbers develop from a general magnitude mechanism in the parietal lobes.

Rips et al. have provided a considered review, and a theoretical framework for the way in which humans acquire (or do not acquire) natural numbers. However, although they refer to cognitive and

for numerical cognition is supported by investigations of developmental disorders. People with developmental dyscalculia – the inability to process numerical information adequately – have problems not only with automatic processing of numerical quantity (Cohen Kadosh et al. 2007b; Rubinsten & Henik 2005; 2006), but also with other magnitudes (Cohen Kadosh et al. 2007b). Non-dyscalculic adults show similar impairments as developmental dyscalculics when their right IPS (rIPS) is stimulated by transcranial magnetic stimulation (Cohen Kadosh et al. 2007b), thus demonstrating a causal relationship between rIPS abnormalities and developmental dyscalculia. The rIPS plays an active role during infancy and childhood: It is involved in numerical processing as early as 3 months postnatal (Izard et al. 2008), and it is still dominant in numerical tasks at 4 years (Cantlon et al. 2006). After children acquire natural number concepts, via interaction with language, which is mainly left lateralized, the left IPS is also activated (Ansari & Dhital 2006).

The lack of early brain specialization is not the only developmental factor to affect the representation of numerical information. For example, synaesthesia, another developmental atypicality, leads one to similar conclusions. Adults with digit-colour synaesthesia, who experience colour whenever they see numbers (e.g., 2 in red), have a lack of neuronal specialization in the magnitude system (Cohen Kadosh et al., in press). Their symbolic representation of digits is affected by luminance – similar to the tendency shown by children up to two years of age (Cohen Kadosh et al. 2007c).

Rips et al.'s idea, while interesting, does not reflect the current state of neuroscientific knowledge either about numbers or development in general (Johnson 2001), and nor does it accurately represent the link between the cognitive abilities of infants and the development of number concepts. Abnormality in the magnitude processing system or in the language system can lead to developmental dyscalculia – a view that is supported by some of the evidence we present here, as well as by the comorbidity between dyscalculia and dyslexia (Geary 1993).

ACKNOWLEDGMENT

Roi Cohen Kadosh is supported by the Marie Curie Intra European Fellowship.