EXPERIMENTAL QUESTIONS

The present thesis focuses on four main questions studied in children with and without MD. First, we assess the specificity of the deficit in dyscalculia. The second goal is to test the hypothesis of a deficit of the number magnitude representation in children with MD. The two other questions address the role of the brain regions, especially the IPS, during symbolic number processing. In particular, we investigate the age-related changes in brain activation between children and adults while they compare two Arabic numerals. A second fMRI experiment is conducted in both children with pure dyscalculia and control children to explore possible group differences in cerebral activity dedicated to number magnitude comparisons.

1. Specific retrieval deficit from long-term memory in children with MD

Our theoretical review on developmental dyscalculia has raised several questions. With regard to the possible impact of non-specific factors on numerical abilities, the current findings are inconclusive. The speed of processing is certainly important in calculation, but does not seem to be impaired in dyscalculic children. Indeed, some evidence indicates that children with MD are as fast as age-matched controls to process non-numerical tasks (e.g., Landerl et al., 2004). It is well established that working memory plays a crucial role in executing calculation procedures and learning arithmetic facts. However, the relationships between measures on the three main subsystems and numerical performances are not clear. Some studies showed weaker phonological or visuospatial span in children with MD relative to controls, but these differences were not observed in other experiments. Similarly, while the central executive was found to be closely related to performances on various numerical tasks, recent data showed that this system was unimpaired in dyscalculic children (e.g., Schuchardt et al., 2008). Moreover, it might also be questioned how a deficit in working memory can account for difficulties in more basic numerical tasks like number comparison or estimation. The hypotheses of a potential deficit on number-related spatial processes or finger gnosia in dyscalculia are very interesting given the role of each of these cognitive mechanisms on the development of numerical abilities. However, they suffer from a lack of empirical investigations.

The goal of our Experiment 1 presented in Chapter 4 is to further investigate the extent to which difficulties encountered by dyscalculic children are specific to the number processing. To that aim, performances of 10-year-old children with poor scores on a fluency calculation test and controls were compared on different matching tasks. Participants had to retrieve information conveyed by arithmetic facts, words, object pictures, country-city associations, or verbal proverbs from long-term memory. Moreover, a perceptual task requiring a matching between two similar geometric forms was used as a measure of children's processing speed. In each task, two responses were proposed in order to limit the requirements on working memory. If the deficit is not specifically related to number processing, then children with MD should be slower than their control peers not only in the arithmetical task but also in tasks requiring non-numerical associations. By contrast, a group difference in the arithmetical task only would suggest a specific impairment in cognitive processes engaged in remembering arithmetic facts. Finally, the perceptual task allowed us to discard a general deficit in speed of processing.

2. Symbolic and non-symbolic number comparison in children with MD

Current research focuses on a specific deficit in number processing in developmental dyscalculia. Some authors have postulated that a defective number module (Butterworth, 1999b) or a weak number sense (Dehaene, 1997) could characterise dyscalculic children. In line with this view, it seems that children with MD have problem in identifying small numerosities (Koontz & Berch, 1996) and in estimating the correctness of approximate calculation (Jordan et al., 2003c) or the position of symbolic quantities on a physical number line (Geary et al., 2008). With respect to number/numerosity comparisons, the results are much inconsistent most probably due to the heterogeneity in task requirements, selection criteria, tests, and populations. The apparent conflicts concern (1) a possible slowdown in children with MD relative to controls while they compare number magnitudes; (2) a different slope of the effects related to the number magnitude representation in dyscalculia; and (3) the role of the number format in the two previous points.

Chapter 5 presents an original study that aims at clarifying these issues. The purpose of Experiment 2 is to investigate performances of children with MD and age-matched controls during both symbolic and non-symbolic number comparisons. Participants had to select the larger of two numerical quantities presented in various formats including Arabic numerals, number words, canonical dot patterns, non-canonical dot patterns, or random stick patterns. These tasks were controlled for working memory, attention and selection requirements in order to reduce as much as possible the differences between symbolic and non-symbolic stimuli. Furthermore, the numerical quantities and the numerical distance between them were identical for all formats. This experiment allows us to test whether or not children with MD were impaired in comparing the number magnitudes, and whether this potential deficit is reflected by a general slowdown only or by differences in the slope of distance/size effects relative to typical development. Moreover, previous data are based on the comparison of either Arabic numerals or sets of objects, and yield inconclusive results about the role of these formats. Considering various symbolic and non-symbolic formats enables to test the source(s) of difficulties in dyscalculia. It might be that children with MD have problems in the mapping between a numerical symbol and its magnitude, resulting in poor performances in symbolic comparisons only (Rousselle & Noël, 2007). Therefore, children with MD should be impaired in comparing Arabic numerals, number words, and maybe canonical dot patterns, but not in comparing non-canonical dot patterns or random stick patterns. Alternatively, the number magnitude representation might be less precise (or more imprecise) in dyscalculia, leading to difficulties in comparing numerical quantities irrespective of the format. Yet, one could expect that the deficit affects more strongly symbolic than non-symbolic quantities. Indeed, while even young children are able to discriminate between small numerosities, the learning of numerical symbols appears later during development (see Chapter 1).

3. Age-related differences in brain activity during symbolic number processing

As discussed in Chapter 2, brain-imaging research has underlined the role of the IPS in number processing. Although the question of whether or not this area contains a number module is still debated, the IPS is consistently activated in various numerical tasks. Moreover, it seems that the involvement of regions around the IPS appears very early in the development. Even 3-month-old infants activated a parietal network (along the dorsal pathway) in response to numerosity recovery after habituation (Izard et al., 2008). Furthermore, the great majority of studies favour an increasing brain activation in the IPS with age (e.g., Rivera et al., 2005). However, none of them used (non-numerical) control task which precludes any strong conclusion about the extent to which these developmental changes are specific to number. As pointed out earlier, the IPS is involved in several cognitive processes which improve with age in the same way as numerical abilities. Therefore, one cannot exclude that some of the differences in brain activation come from general rather than number-related mechanisms. Of particular interest is the only one experiment that contrasted numerical comparisons with a control task requiring spatial or perceptual judgments on the same stimuli (Kaufmann et al., 2008). When the numerical task was compared to the spatial task, no positive correlation between age and brain activation was found in any regions around the IPS. On the contrary, some of the parietal areas were more activated for children than adults. Another question concerns the role of frontal lobes during number processing. Some authors have postulated a typical age-related shift from a strong activity of frontal areas to increasing engagement of posterior parietal regions (e.g., Ansari et al., 2005). Once again, it remains unclear whether these changes are related exclusively to numbers or rather reflect general improvement in performances.

In Chapter 6, we conduct a fMRI experiment with both healthy children and adults that addresses these issues. Brain activity was recorded when participants compared either the magnitude of two Arabic numerals, or the colour of two non-numerical symbols. Experiment 3 investigates age-related changes in frontal and parietal areas at the whole-brain level, but also in regions of interest reported in previous studies to be involved in number processing. Our main purpose is to examine which brain region(s) show an increasing activation for numerical relative to non-numerical judgments with age.

4. Neural correlates of symbolic number comparison in dyscalculia

Research on the cerebral bases of developmental dyscalculia is still in its early stages. The current data suggest that the IPS could play a role in the development of numerical abilities. Compared to respective control populations, this area showed less grey matter and structural abnormalities in adults with MD following genetic disturbance (Molko et al., 2003) or prematurity (Isaacs et al., 2001), and in children with pure dyscalculia (Rotzer et al., 2008). Some functional differences also appeared between participants with MD and controls during number processing. Concerning non-symbolic number comparisons, the findings suggested a weak involvement of areas dedicated to the number magnitude representation. The right IPS showed a weaker modulation by the numerical distance in dyscalculic children than in controls (Price et al., 2007). By contrast, no clear evidence of IPS impairment was provided when dyscalculic children processed Arabic numerals. Slight group differences were found in approximate calculation, but not in exact calculation (Kucian et al., 2006). Moreover, any investigation in dyscalculic children tested a possible weak engagement of regions around the IPS during symbolic comparison.

Chapter 7 presents an original fMRI study which aims at further investigating cerebral activity of children with pure dyscalculia and age-matched controls in comparing number symbols. Our purpose is to test whether difficulties encountered by dyscalculic children in manipulating number magnitude could be related to less involvement of the IPS as this area was supposed to hold the core system for numbers. Considering the recurrent co-morbidity with reading, working memory or attention deficit in mathematical disabilities, both groups of children were controlled for all of these factors. In the scanner, they had to perform a simple comparison task on pairs of Arabic numerals separated by either a small or a large numerical distance. If the number magnitude representation is impaired in developmental dyscalculia, children with MD should show less or no modulation of IPS activation with the numerical distance relative to children without MD. A control task on colour comparisons was also used to determine the specificity of differences in IPS activity.