Chapter

Neural Correlates in Learning Disabilities

Misciagna Sandro

Abstract

In recent years, researchers have done significant advances on the study of learning disabilities in particular in terms of comprehension of cognitive and anatomical mechanisms. The understanding of neural mechanism of learning disabilities is useful for their management and cognitive treatment. The advent of functional neuroimaging methods has also identified anatomical networks and neurological learning systems that have contributed to knowledge of neurobiology of learning deficits. On the other side, neuropsychological assessment, with comprehensive test or specific cognitive tasks, has proved to be useful to analyze specific cognitive deficits to find potential targets of intervention for cognitive compensation. In this chapter the author summarizes major scientific advances in particular in the study of neuroanatomical mechanism based on structural and functional neuroimaging of children with learning disorders, developmental disorders, and language impairment, in particular with dyslexia which is one of the most common learning disabilities.

Keywords: learning disabilities, learning deficits, learning disorders, dyslexia, reading disorders, dyscalculia, math disorders, dysgraphia, text generation disorders, anatomical mechanism, neurobiology, neural mechanism, functional neuroimaging, anatomical networks, learning systems

1. Cognitive bases of learning disabilities

Learning disabilities have been studied by neuropsychological researchers over the past 50 years, so many scientific articles have been published on this topic.

The understanding of learning disorders has relevant implications both for assessment and cognitive interventions.

Early cases of children with learning disorders were described by an ophthalmologist who studied children with reading difficulties without brain lesions, so they considered these children as affected by "word blindness" [1].

Subsequently medical researchers used the term "dyslexia" to describe children with troubles in reading and spelling isolated words; they attributed dyslexia to a disorder of cerebral dominance for language [2]. Other authors used the term "learning disabilities" to refer to children with unexpected difficulties secondary to language disorders, differentiating learning disabilities from behavioral disorders and intellectual disabilities [3].

In the 1970s, neuropsychologists started a period of research to identify the cognitive bases of learning disabilities. They emphasized in particular the importance of profile interpretations for inferring brain dysfunction in learning disabilities [4].

Other researchers identified neuropsychological correlates of reading difficulties including finger agnosia [5], right–left confusion, auditory–visual integration [6], color-naming difficulties [7], or other language problems.

Some scientists hypothesized that learning disabilities could be related to a parietal lobe disorder [5] or to a developmental Gerstmann syndrome [8].

Some authors attributed reading difficulties to a maturational lag in brain development [9] or to language difficulties [10].

Other researchers criticized theories based on group comparison of single variables in favor of multivariate approaches [11]. This led to researches in which profile of neuropsychological tests were identified to better study the cognitive deficits of learning disabilities [12].

One of the most significance influences on the scientific understanding of learning disabilities was the "theory of speech processing" as a segmented signal of phonological representation [13]. According to this theory, phonological awareness is a metacognitive understanding of the sound structure of speech. The children learning to read must link the orthographic patterns of written language to the internal structure of speech to access the developing lexical system. This theory has been verified across languages that vary in the transparency of orthography and phonology [14].

These discoveries were important in the understanding of learning disabilities since a specific phonological awareness and cognitive skill was considered linked to decoding a specific academic skill, explaining success and failure in reading.

The differentiation of learning disabilities into academic domains produced an expansion of base researches about cognitive correlates and neurobiological factors related to cognitive domains of learning disabilities [15].

Thus learning disorders were separated into three principal domains and six subdomains:

1. Oral reading domains that occur at the level of word (*dyslexia*) and the level of text (*reading comprehension disorders*)

2. Math domains that could be computational (*dyscalculia*) or involve executive mathematical functions (*math problem-solving disorders*)

3. Written language domains that could involve basic skills needed for transcription (handwriting and spelling *dysgraphia*) and generating text in essays or stories *(text generation disorders*)

According to Pennington and Peterson, problems in these cognitive domains generate higher-order language, attentional, and executive disorders that affect oral and written language [16]. In other cases, these cognitive disorders are often comorbid with other behavioral traits, such as attention-deficit/hyperactivity disorders (ADHD) [17] or developmental language disorders [18].

Over the years, international researchers have mapped the framework of different sources of variability that influence learning disabilities [19] to help to establish the bases for effective interventions (**Figure 1**).

According to this framework, learning disabilities are related with neurobiological factors (brain structure and function, genetic factors) [15], cognitive processes (e.g., phonemic awareness), psychosocial factors (e.g., attention, anxiety, motivation), and environmental context (socioeconomic conditions, schooling, instruction, home environment).

Researchers have showed that intellectual quotient (IQ) is not predictive of learning disabilities [20], while processing speed deficits and working

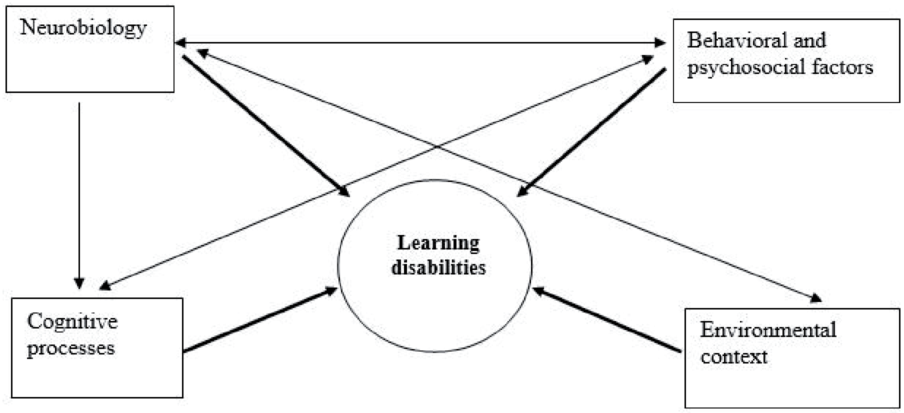

Figure 1.
Framework of different sources that influence learning disabilities.

memory are linked to learning disorders as well as comorbidity with ADHD [21]. Phonological awareness is also a strong predictor of failure or success in reading acquisition [22]. Time reading and spelling assessment could be used in the identification of dyslexia in more transparent languages [23], while vocabulary tasks, listening comprehension, and attention/executive function tasks could be used to study text-level disorders [24]. The learning abilities of individual with dyslexia have been examined using serial reaction time measures, revealing a moderate effect that indicates that automatization of learning is impaired in this disorder [25].

Neuropsychological studies have also suggested neurological and functional distinction between different types of learning: procedural learning system is involved in implicit learning and impaired in individual with specific language impairments [26], while declarative learning system were argued to be relatively intact. Children with dyslexia appear to have difficulty extracting structure from novel sequences in artificial grammar learning paradigms [27] and difficulties in making judgments about grammaticality, confirming that implicit learning processes are involved in dyslexic patients. Prominent difficulties in procedural learning in sequence-based tasks and relative preservation on declarative and nonsequential procedural learning may explain why individuals with learning disabilities have more difficulties in language tasks in which they have to extract and produce sequential information.

Math disabilities without reading difficulties are very common as comorbidity in children with learning disabilities [28]. Attention, working memory, and phonological processing are also overlapped with math problem-solving disorders, even if less studied than computational skills [29]. These findings support the view that mathematical abilities involve multiple cognitive processes and that math disorders reflect more generalized cognitive difficulties [30]. Executive functions that affect self-regulation are relevant for text generation disorders [31].

2. Neurobiological bases of learning disabilities

In recent years, research on brain structure and cerebral function of children with learning disabilities has taken advantage of new noninvasive structural and functional technologies.

Most studies have been focused on the study of dyslexia using neuroimaging studies (magnetic resonance imaging (MRI)) or functional studies (electroencephalography, event-related potentials, functional magnetic resonance imaging, positron emission tomography) [32].

Studies based on functional neuroimaging have identified a network of three regions localized in the left hemisphere mediating word reading:

1. A sublexical dorsal stream localized in temporoparietal areas

2. A lexical ventral stream localized in occipitotemporal region

3. A cerebral area in the left inferior frontal lobe underactivated or overactivated by temporoparietal or occipitotemporal regions (**Figure 2**)

This network, universal across different languages and orthographies [33], consists of a dorsal and ventral component that operates in parallel, connecting to the inferior frontal gyrus. The dorsal stream is associated with sublexical route to word meaning, consistent with word reading, while the ventral stream is specialized for visual processing of orthographic patterns [34]. The fusiform gyrus is considered an area that mediates word recognition with direct access to semantic regions in inferior temporal regions [35].

Researches based on functional MRI have demonstrated that the development of ventral system is dependent on exposure to print and that in children this system shows reorganization with explicit instructions in reading [36].

Quantitative analyses of MRI have shown reduced volume of the network of pre-scholars before the onset of formal reading instructions [37].

The dorsal and ventral pathways have resulted similar pattern of activation in children with word-level learning disabilities when compared with children developing reading comprehension learning disabilities (RCLD). In contrast the group of children with RCLD showed reduced deactivation of the left angular, left inferior frontal, and left hippocampal and parahippocampal gyri [38]. In other structural studies conducted on adolescent with RCLD, researchers found reduced gray matter in the right frontal regions, explaining their executive function disorders [39].

Functional MRI studies in adults have found that language learning also implicates corticostriatal and hippocampal systems. These structures are connected to each other as well as to the cortex and to other subcortical structures (**Figure 3**).

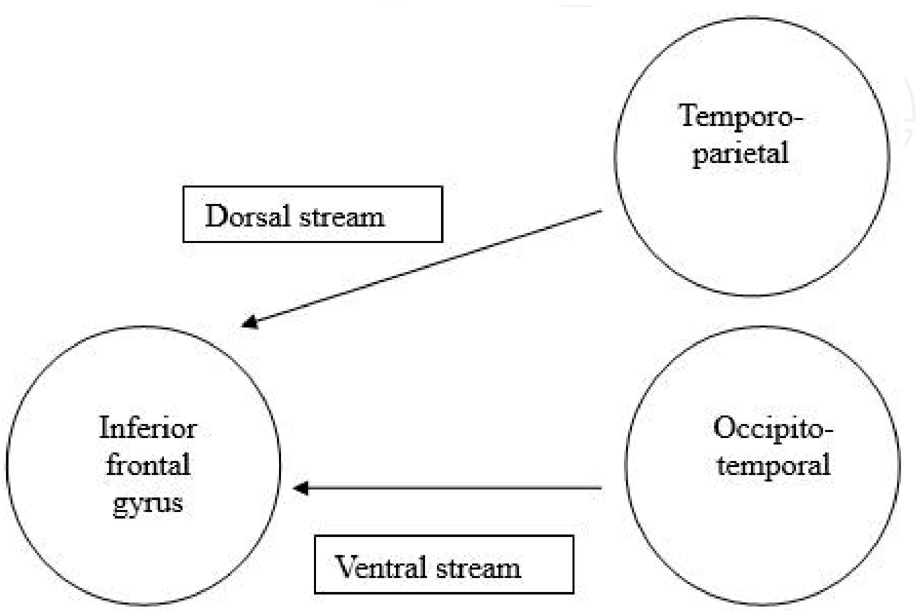

Figure 2.
Cerebral network that influences word reading.

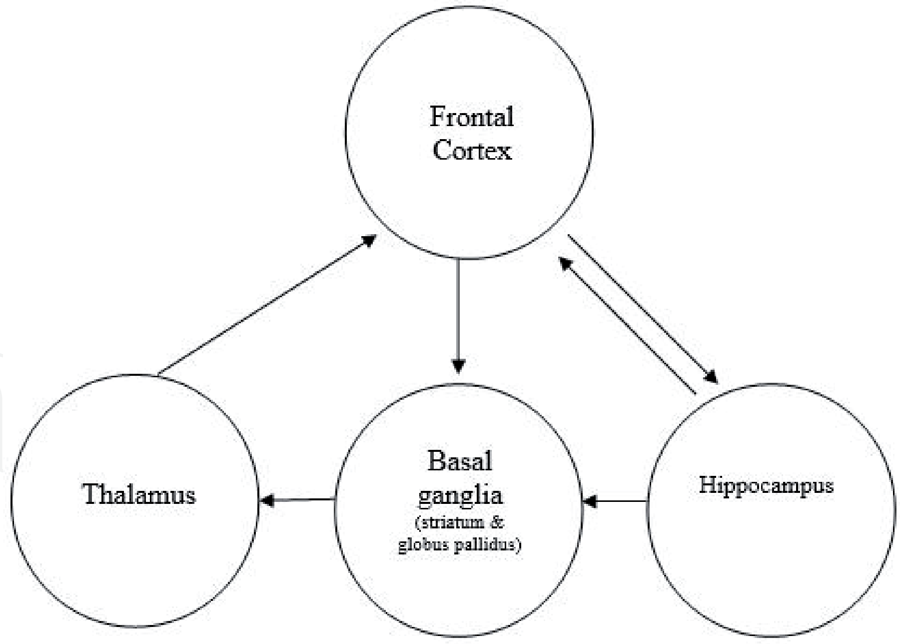

Figure 3.
Corticostriatal and hippocampal learning networks that influence language learning.

Functional interactions between these regions have been described during learning processes [40]. Consequently, changes in functional neural activity in one of these regions during language learning might reflect a local change of a complex learning network. The frontal cortex and basal ganglia appear to be relevant in learning the phonology and grammar of a language [41]. The hippocampus is also necessary in word learning; in fact, in fMRI studies, the hippocampus results to be activated during the process of learning new vocabularies [42] and during encoding processes related to words [43].

The ventral striatum (nucleus accumbens) is activated in learning novel words [44], while the dorsal striatum responds to feedback in verbal paired-associated tasks [45]. Abnormalities in the striatum have been seen also in children with language disorders [46]. Some studies suggest a reduction of volume of the caudate nucleus in children with specific language and learning impairment [47], while others have reported increases in caudate nucleus volume [48]. Functional studies conducted on adults with dyslexia show hyperactivation of the striatum, not seen in children with dyslexia, suggesting to be a compensatory mechanism in adulthood. Structural network analysis in children with a higher risk for dyslexia and other reading difficulties have showed that the hippocampus, temporal lobe, and putamen are less strongly connected in these individuals [49].

Studies conducted on children with math disabilities have found disorders of connectivity in temporoparietal and inferior parietal white matter [50].

Researchers have not found consistent structural differences across all studies in dyslexic patients, probably since this disorder is the result of a combination of multiple risk factors including motor, oral language, phonological disorders, and executive deficits [51].

Functional neuroimaging studies on numerical processing and mental arithmetic have also demonstrated the existence of a neural network [52], connecting frontotemporal regions with three left parietal circuits: superior parietal, intraparietal, and inferior parietal (**Figure 4**). This network is characterized by increased activity in children with math learning disabilities [53].

Other reports have demonstrated that specific cerebellar regions contribute to cognitive functions in children with learning disorders in particular with verbal short-term memory deficits [54], reading development [55], or in general to cognitive, emotional, and behavioral functions [56].

According to the cerebellar deficit hypothesis, specific regions of the cerebellum are functionally connected with cerebral reading network [57].

The reading-related cerebral regions that result to have functional connectivity with the cerebellum are supposed to be three: the inferior frontal junction (IFJ), the inferior parietal lobule (IPL), and the middle temporal gyrus (MTG) (**Figure 5**).

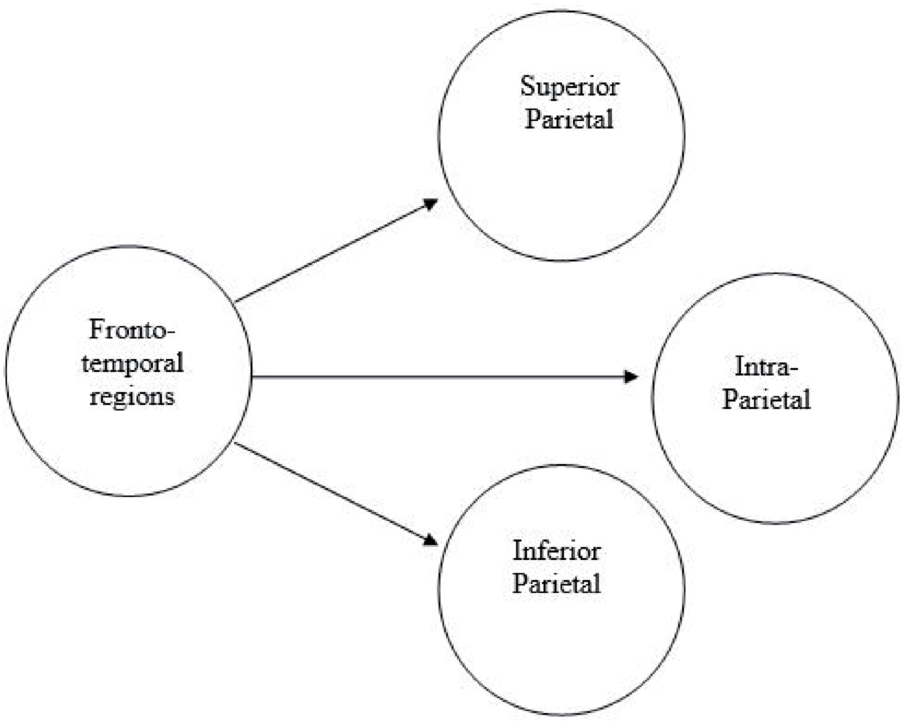

Figure 4.
Cerebral network that influences numerical processing.

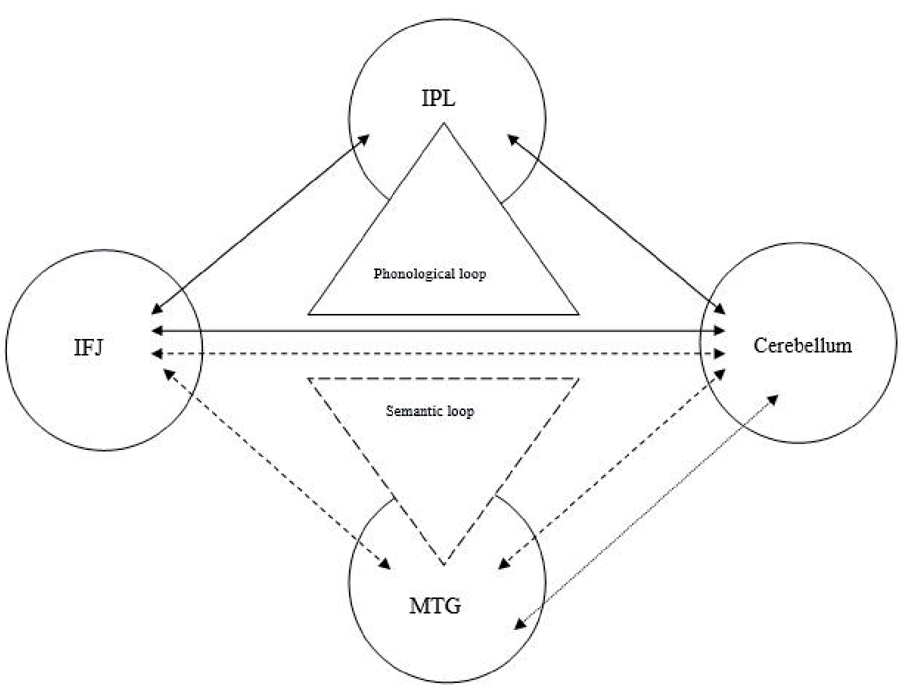

Figure 5.
Cerebro-cerebellar network that influences reading processing.

An analysis on connectivity has demonstrated three distinct sets of connections between cerebral and cerebellar regions. The first set of connections consist of a connection between IFJ and IPL that converges to a region in the right lateral posterior inferior cerebellum and is supposed to have a phonological role. The second set of connections consist of a connection between IFJ and MTG, which converges to a region in the right posterior superior cerebellum and is supposed to have a semantic role. The third set consist of a functional connectivity between MTG region and lateral anterior region of the cerebellum. There is not a common functional terminology for the third set of connections [55].

3. Conclusions

Studies conducted on children with learning disabilities, in particular with dyslexia, have shown an involvement in the function of cerebral areas and systems relevant in cognitive process about speech and learning (summarized in **Table 1**).

As evidenced in **Table 1**, structural or functional abnormalities of cerebral systems, localized in particular in the left hemisphere, in corticostriatal systems, and in cerebro-cerebellar connections, support the hypothesis of the existence of cerebral networks that can explain learning disorders.

These cerebral areas have an important impact on the development of learning and different aspects of language such as phonological and morpho-syntactic aspects.

Cognitive function	Cerebral areas	Hemisphere
Word reading	Dorsal stream: temporoparietal	Left
Visual processing of orthographic patterns	Ventral stream: occipitotemporal	Left
Lexical functions	Occipitotemporal	Left
Orthographic function	Inferior frontal gyrus	Left
Word recognition	Fusiform gyrus	Left
Semantic functions	Inferior temporal regions	Left
Reading comprehension	Both dorsal and ventral streams	Left
Executive functions	Frontal regions	Left and right
General language learning	Corticostriatal and hippocampal systems	Left
Learning of phonology and grammar	Frontal cortex and basal ganglia	Left
Word learning	Hippocampus	Left
Learning of new words	Ventral striatum (nucleus accumbens)	Left
Feedback in verbal paired-associated tasks	Dorsal striatum	Left
Numerical processing and mental arithmetic	Fronto-temporoparietal regions	Left
Math learning	Fronto-temporoparietal regions	Left
Verbal short-term memory	Cerebellum	Right?
Reading development	Cerebellum	Right?

Table 1.
Cerebral areas that influence cognitive learning processes.

However, there is a need to develop further longitudinal studies, conducted on children with learning disabilities, to explore cerebral anatomical and functional alterations during development and their correlation with specific pattern of learning disabilities.

Further progress in understanding the nature and specific components of learning difficulties in children will allow us to develop future specific targets and rehabilitative strategies of intervention.

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