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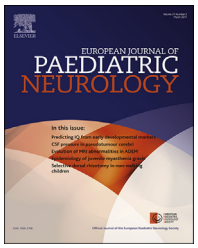

Original article

Neural changes associated to procedural learning and automatization process in Developmental Coordination Disorder and/or Developmental Dyslexia

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ABSTRACT

Objective: Recent theories hypothesize that procedural learning may support the frequent overlap between neurodevelopmental disorders. The neural circuitry supporting procedural learning includes, among others, cortico-cerebellar and cortico-striatal loops. Alteration of these loops may account for the frequent comorbidity between Developmental Coordination Disorder (DCD) and Developmental Dyslexia (DD). The aim of our study was to investigate cerebral changes due to the learning and automatization of a sequence learning task in children with DD, or DCD, or both disorders.

Method: fMRI on 48 children (aged 8-12) with DD, DCD or DD + DCD was used to explore their brain activity during procedural tasks, performed either after two weeks of training or in the early stage of learning.

Results: Firstly, our results indicate that all children were able to perform the task with the same level of automaticity, but recruit different brain processes to achieve the same performance. Secondly, our fMRI results do not appear to confirm Nicolson and Fawcett's model. The neural correlates recruited for procedural learning by the DD and the comorbid groups are very close, while the DCD group presents distinct characteristics. This provide a promising direction on the neural mechanisms associated with procedural learning in neurodevelopmental disorders and for understanding comorbidity.

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Abbreviations

Groups

DCD	Developmental Coordination Disorder
DD	Developmental Dyslexia
MI	comorbid group (for MIXED)

Tasks

OverTSeq	Overtrained Sequence
NovelSeq	Novel Sequence
DTS	Dual Task Sequence

Brain areas

CC	cortico-cerebellar
CS	cortico-striatal
ACC	anterior cingulate cortex
IPC	inferior parietal cortex
PCC	posterior cingulate cortex

1. Introduction

1.1. *DD and DCD*

Developmental Dyslexia (DD) and Developmental Coordination Disorder (DCD) are both persistent disorder in which children show learning deficits, respectively for reading and for motor skills, despite adequate intelligence, normal sensory abilities, and conventional instruction, sociocultural opportunity and school education.[2,66] In the recent version of the DSM-5, DD and DCD are classified as neurodevelopmental disorders, which include a group of conditions with onset in the early developmental period and are characterized by developmental deficits ranging from very specific limitations of learning or control of cognitive functions to global impairments of social skills or intelligence. An actually important source of interest for many researchers is that neurodevelopmental disorders frequently co-occur (DSM-5). Especially, up to 50% of children with DD also have DCD, and conversely.[8,22] Motor disorders can thus affect about 60% of subjects with dyslexia[8,51] and up to 70% of subjects with DCD have also reading problems.[40] A keen interest is therefore focused on this specific association, certainly participating to heterogeneity and complexity of those disorders.[52,63] If such comorbidity is well-established, very few studies have concerned this specific association. Is these disorders are the same or different in pure occurrence or in association? What impact might comorbidity have on behavioural, neuropsychological or cerebral level? Very little data are available as regard to the association between DD and DCD. Recent research,[3,4] comparing three groups: children with pure DCD, children with pure DD and children with dual-association, show that there are very few differences between groups at behavioural (procedural learning tasks) and neuropsychological level (efficiency, attention, psychosocial). Where differences exist, there were only between DCD and the two other groups, which raises questions about the nature of the DD and DCD comorbidity.

Works of Nicolson and Fawcett[37,38] sustain that procedural learning impairment, commonly encountered in neurodevelopmental disorder[10,35] provide a suitable explanation of the substantial overlap between DD and DCD. This kind of learning refers to motor and cognitive skills acquired progressively and finally automated (performed without effort and conscious control) thanks to repetitive practice. This process of gradual acquisition is known to involve a series of successive stages[12]: the fast learning stage where rapid improvement can be observed within a single session and next, the slow learning stage where further gains gradually appear across several training sessions until the attainment of automatization. For authors, specific developmental disorders should be secondary to an impairment of the procedural learning system (and especially in automatization), contrasting with general learning disabilities (i.e. intellectual developmental disorder) secondary to an impairment of the declarative learning system. A number of skills impaired in DD and DCD are indeed derived in large part from this system and impairment in procedural learning tasks are identified in both DD[34] and DCD.[10,21] However, DD as DCD does not imply a total incapacity to learn motor skills. Children are less efficient and probably need more time and practice to learn and reach a satisfactory level of performance, but they are still able to learn. They especially can achieve short term learning, long-term retention, automatization and transfer (see Refs. 14,41 for DD; and Ref. 5 for DCD).

Procedural learning and automatization are supported by cortico-striatal and cortico-cerebellar loops.[12] In this context, Nicolson and Fawcett[37,38] proposed 'the neural system typography for learning difficulties', in which DD is attributed to the language-related-component of the cortico-cerebellar circuit, as suggested by their difficulties in adaptation and supported by several neuroimaging studies revealing cerebellar abnormalities (for a review see Refs. 56,57), and in which DCD is associated with a deficit in the motor-related component of the cortico-striatal system. Naturally, their model proposes that comorbidity is characterized by impairments in more than one circuit. Even if this model offers explanations of common and distinct deficits presented by DD, DCD and their association, it is important to note that the hypotheses of neural-systems impairments are only deduced from behavioural symptoms, and not from neural studies. Effectively, in both case, neuroimaging studies have focused purely on the cornerstone of these disorders (the motor or reading aspects) and the questions of procedural learning and of comorbidity was not addressed. Briefly, neuroimaging studies conducted in DD report atypical activation of the left perisylvian fronto–temporo-parietal network, especially in the inferior frontal gyrus (Broca's area, BA 44/45), the inferior occipital–temporal area (Visual Word Form Area, BA 37) and the parietal/temporal regions (BA 22, 39, 40) (see Ref. 54 for a recent meta-analysis). But the role of subcortical structures such as the cerebellum or lenticular nuclei have also been highlighted by some authors.[47,56,57] Less neuroimaging studies have been conducted on DCD and dysfunctions of prefrontal, premotor and parietal cortices, basal ganglia and cerebellum are reported (for review see Refs. 6,48). Thus features in cortico-striatal as cortico-cerebellum networks could therefore be envisaged in both disorders.