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Later learning stages in procedural memory are impaired in children with Specific Language Impairment

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ABSTRACT

Background: According to the Procedural Deficit Hypothesis (PDH), difficulties in the procedural memory system may contribute to the language difficulties encountered by children with Specific Language Impairment (SLI). Most studies investigating the PDH have used the sequence learning paradigm; however these studies have principally focused on initial sequence learning in a single practice session.
Aims: The present study sought to extend these investigations by assessing the consolidation stage and longer-term retention of implicit sequence-specific knowledge in 42 children with or without SLI.
Methods and procedures: Both groups of children completed a serial reaction time task and were tested 24 h and one week after practice.
Outcomes and results: Results showed that children with SLI succeeded as well as children with typical development (TD) in the early acquisition stage of the sequence learning task. However, as training blocks progressed, only TD children improved their sequence knowledge while children with SLI did not appear to evolve any more. Moreover, children with SLI showed a lack of the consolidation gains in sequence knowledge displayed by the TD children.
Conclusions and implications: Overall, these results were in line with the predictions of the PDH and suggest that later learning stages in procedural memory are impaired in SLI.

What this paper adds

- The present study presents a further examination of the Procedural Deficit Hypothesis (PDH, Ullman & Pierpont, 2005) by investigating later procedural learning stages in children with Specific Language Impairment (SLI). The literature on consolidation of procedural memory in SLI was sparse and the present study was designed to fill this important gap by examining the consolidation and longer-term procedural sequence learning in children with and without SLI. Specifically, this study pursued the following objectives: (a) examining later learning stages in sequence-specific learning by using a serial reaction time task over an initial practice session and two follow-up sessions 24 h and one week later, (b) investigating the role of extended practice in training and (c) exploring the association between procedural learning and language abilities in both groups of children. The results indicated that the SLI group did not benefit from extended practice and did not show the expected consolidation gains in performance, indicating a need for further research in this area.

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Moreover, the amount of sequence learning gained at the end of training and during both follow-up sessions was associated with receptive grammatical ability only in children with normal language, in line with the predictions of the PDH.

1. Introduction

Specific Language Impairment (SLI) involves a significant difficulty in the acquisition of oral language in the absence of hearing deficits, severe environmental deprivation, mental retardation, emotional and social problems or frank neurological damage that could account for the children's language problems (American Psychiatric Association, 2000). Children with SLI present varied profiles of language deficits that may be more pronounced in some language components, especially phonology and morphosyntax (Leonard, 2014). Although the language domain is the core impairment in these children, deficits are not limited to language but generally include other non-linguistic difficulties (Ullman & Pierpont, 2005). Indeed, SLI is often associated with impairments of motor skills and working memory (Archibald & Gathercole, 2006; Flapper & Schoemaker, 2013), as well as with attention or inhibition difficulties (Gillam, Montgomery, & Gillam, 2009). The presence of these non-linguistic deficits has complicated the understanding of SLI (Leonard, 2014). In 2005, Ullman and Pierpont proposed that both linguistic and non-linguistic impairments in children with SLI might be explained by the Procedural Deficit Hypothesis (PDH).

1.1. The PDH of SLI

The PDH is based on the declarative-procedural model of language learning (Ullman, 2001a, 2001b, 2004). According to Ullman (2001a), language development is underpinned by two distinct but interdependent memory systems, namely declarative and procedural memory. *Declarative memory* is primarily supported by the medial temporal lobes and is responsible for encoding, storing and retrieving general knowledge about the world (semantic memory) or specific events (episodic memory). In many contexts, the learning and retrieval of information are (typically) accompanied by awareness. In language, declarative memory is crucial for all learned idiosyncratic knowledge such as simple content words (e.g., cat, devour), irregular morphological forms (e.g., solemn–solemnity), idioms and proverbs (e.g., jump the gun), and so on (Ullman, 2015). The *procedural memory* system comprises a network of brain structures that includes the basal ganglia (specifically, the striatum), the cerebellum and portions of the parietal and frontal cortices (Packard & Knowlton, 2002). Procedural memory is involved in the implicit acquisition, storage and use of knowledge (Gabrieli, 1998; Willingham, 1998). This system underlies a range of different cognitive skills including motor skills, cognitive routines, and in particular, sequencing. This procedural memory system is responsible for learning several aspects of grammar, including the learning and use of rule-governed aspects of syntax, morphology, and phonology (Ullman, 2004).

The PDH posits that children with SLI have a dysfunction affecting the basal ganglia leading to an impairment of the procedural memory system (Ullman & Pierpont, 2005). This PDH accounts for a common language profile observed in several children with SLI: grammatical and phonological skills are largely impaired while vocabulary is relatively spared. A dysfunction of the procedural memory system should lead to difficulties with treating and maintaining sequences as well as in detecting and learning regularities. These skills are fundamental to discover and learn the morphosyntactic and phonological rules of language. Furthermore, some non-linguistic functions depend at least in part on the frontal/basal ganglia circuitry, which might explain the heterogeneity of SLI. Indeed, because parts of this neural network can be impaired to varying degrees, and because they have neural connections to other areas, other functions (such as working memory) are also likely to be impaired.

Ullman and Pierpont (2005) predicted that people with SLI should perform worse than their Typically Developing (TD) peers on tasks assessing the procedural memory system. An experimental paradigm frequently used to investigate procedural learning, and specifically implicit sequence learning, is the serial reaction time task (SRT task; Nissen & Bullemer, 1987). In this task, a stimulus appears in one of several locations on a computer screen, and participants are instructed to respond as quickly and accurately as possible by pressing a button on the keyboard, which corresponds to the spatial location of the stimulus. Unknown to the participants, the stimuli appear in a repeated sequence, and sequence-specific learning is demonstrated by a difference between reaction time to sequence and random (or a different sequence) blocks. This task has been shown to particularly activate the basal ganglia (especially the striatum) and to be sensitive to neurological disorders affecting the basal ganglia, such as patients with Huntington's or Parkinson's disease (Knopman & Nissen, 1991; Siegert, Taylor, Weatherall, & Abernethy, 2006). In children, a dysfunction or lesions of the basal ganglia also leads to procedural learning deficits (Mayor-Dubois, Maeder, Zesiger, & Roulet-Perez, 2010).

1.2. Sequence learning abilities in SLI

According to the PDH, if children with SLI suffer from a dysfunction in the frontal/basal ganglia circuitry, leading to a procedural learning deficit, they should present difficulties learning a visuo-motor sequence contained in a SRT task. Such difficulties cannot be imputed to difficulties in speech perception or reduced phonological short-term memory because this visuo-motor task does not involve linguistic skills. There are now several studies that have investigated the procedural learning difficulties of individuals with SLI with the SRT paradigm. In an early report, Tomblin, Mainela-Arnold, and Zhang