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Procedural memory and speed of grammatical processing: Comparison between typically developing children and language impaired children



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ABSTRACT

Background: Procedural memory has been proposed to underlie the acquisition of a range of skills including grammar, reading, and motor skills. In developmental language disorder (DLD) it has been suggested that procedural memory problems lead to the difficulties with grammar in this group.

Aims: This study aimed to extend previous research by exploring associations between procedural memory and a range of cognitive skills, in children with and without language impairments.

Methods and procedures: Twenty children with DLD and 20 age-matched non-language impaired children undertook tasks assessing procedural memory, grammatical processing speed, single word and nonword reading, and motor skills (as indexed by a pegboard task).

Outcomes and results: For the DLD group, no significant correlations between procedural memory and any of the variables were observed. The typically developing group showed a significant correlation ($r = .482, p < 0.05$) between the measure of procedural memory and grammatical processing speed. Correlations between procedural memory and the remaining variables were all non-significant for this group.

Conclusions and implications: This study provides new evidence showing that grammatical processing speed is correlated with procedural memory in typically developing children. Furthermore, results suggest that the relationship with procedural memory does not extend to reading or the types of motor skills used on a pegboard task. For the DLD group the pattern of result indicate grammatical processing, reading, and motor sequencing are not supported by procedural memory or a common memory system.

What this paper adds

An influential theory suggests that procedural memory underlies the ability to process grammar, and that procedural memory problems lead to the grammatical problems found in children with DLD. However, procedural memory is also proposed to underlie reading and motor skills. This is the first study to directly investigate associations between each of these variables in groups of children with and without DLD. We suggest that grammatical processing speed may be a better measure than the often-used measure of accuracy in tapping into procedural system functioning. Results show that relationships between skills are different in DLD and TD groups. It appears that procedural memory, grammar, reading, and motor skills each rely on different processes or networks in DLD.

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1. Introduction

Developmental language disorder (DLD) is a neurodevelopmental disorder characterised by varying levels of expressive and receptive language problems (American Psychiatric Association, 2013; World Health Organization, 1992). A key characteristic of DLD is the language impairments found in this group do not appear to be attributable to any medical condition or deficiencies with linguistic input (Leonard, 2014). While the diagnostic criteria for DLD suggests a potential dissociation between language and non-language skills, research indicates this is not the case. Children with DLD typically present with a range of co-occurring problems (e.g., Bishop & Snowling, 2004; Hill, 2001; Vugs, Cuperus, Hendriks, & Verhoeven, 2013). Chief amongst these include motor (Hill, 2001) and reading (McArthur, Hogben, Edwards, Heath, & Mengler, 2000) skill deficits. A growing body of literature suggests that skills and abilities supported by the procedural memory system may underlie the language problems in DLD (Nicolson & Fawcett, 2007; Ullman & Pierpont, 2005). However, poor procedural memory has also been linked to motor and reading deficits (Nicolson & Fawcett, 2007), both of which are often present in DLD (Hill, 2001; McArthur et al., 2000). The extent to which procedural memory problems in DLD relate to the language problems in this group has yet to be tested and is the focus of the current study.

1.1. Procedural memory in developmental language disorder

The initial claim implicating procedural memory in DLD was forwarded by Ullman and Pierpont (2005). According to the Procedural Deficit Hypothesis (PDH), dysfunction of the caudate and/or prefrontal regions gives rise to a procedural memory impairment in DLD. The procedural memory system is supported by a network of subcortical structures including the basal ganglia and cerebellum, and cortical structures including motor and prefrontal areas (Eichenbaum & Cohen, 2004; Graybiel, 1995; Knowlton, Mangels, & Squire, 1996). This memory system is responsible for the implicit acquisition, storage, and retrieval of a range of information that is sequential, statistical, or rule-like in structure. Ullman (2001, 2004) and Ullman et al. (1997) argues that the acquisition and use of grammar is also supported by the procedural memory system. Grammar follows statistical regularities, and like other information learnt via procedural memory, general rules relating to phonology, grammatical morphology, and syntax are acquired gradually and incidentally, after repeated exposure to the input.

One prediction of the PDH is that individuals with DLD should have poorer procedural memory than their non-language impaired peers (Ullman & Pierpont, 2005). Procedural memory functioning in DLD has commonly been investigated using the serial reaction time task (SRTT; e.g., Desmottes, Meulemans, & Maillart, 2015; Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011; Hsu & Bishop, 2014; Lum, Conti-Ramsden, Page, & Ullman, 2012; Tomblin, Mainela-Arnold, & Zhang, 2007). The SRTT involves implicitly learning a visuo-motor sequence (Nissen & Bullemer, 1987). Participants are required to press a button that corresponds to the location of a visual stimulus on a computer screen. Unknown to participants, the location of the stimulus follows a predetermined sequence. Learning is considered to have taken place if participants respond faster to trials in which the stimulus follows a sequence compared to trials in which the stimulus appears in random locations. There is evidence for procedural memory problems in DLD, as indexed by SRTT performance. Lum, Conti-Ramsden, Morgan, and Ullman (2014) conducted a meta-analysis that synthesised results of DLD-SRTT studies. It was found that overall, individuals with DLD performed significantly more poorly on the SRTT than their typically developing (TD) peers.

1.2. Associations between procedural memory and grammar

A second prediction of the PDH is that procedural memory should be related to grammatical proficiency. A number of studies (Desmottes et al., 2015; Gabriel et al., 2011; Gabriel et al., 2013; Gabriel, Meulemans, Parisse, & Maillart, 2014; Gabriel, Stefaniak, Maillart, Schmitz, & Meulemans, 2012; Lum et al., 2012; Lum & Kidd, 2012; Mimeau, Coleman, & Donlan, 2016) have investigated this relationship by examining correlations between the ability to learn the sequence in the SRTT, and performance on tasks that assess expressive and/or receptive grammatical skills. In these studies ‘performance’ has been operationalised as the ability to correctly comprehend (e.g., Gabriel et al., 2014; Gabriel et al., 2012; Lum et al., 2012) or produce (e.g., Gabriel et al., 2011; Lum & Kidd, 2012; Mimeau et al., 2016) one or more sentences. One finding to emerge from this literature is that the association between SRTT performance and grammatical skills are typically low. In DLD groups, most studies have reported positive non-significant correlations between 0.1 and 0.3 (Gabriel et al., 2011; Gabriel et al., 2012; Lum et al., 2012), although Gabriel et al. (2013) did find a significant association of 0.48. The positive values in these studies indicate that children who were better able to learn the sequence on the SRTT obtained higher scores on tasks assessing grammatical skills. Non-significant, but negative correlations have also been reported in DLD (Desmottes et al., 2015; Gabriel et al., 2014; Gheysen, Van Waelvelde, & Fias, 2011). These range from -0.31 (Desmottes et al., 2015) to -0.46 (Gabriel et al., 2014). The negative correlations indicate that in those studies, children with DLD who performed more poorly on the procedural memory task performed better on the test of grammar.

One explanation for the weak associations between procedural memory and grammar in DLD is that in this group, grammar is learnt and processed by a different memory system. Ullman and Pierpont (2005) proposed that the declarative memory system might compensate for poor procedural system functioning in DLD. Thus, in this group grammar is processed by the declarative memory system. However, this explanation does not account for the weak associations observed between procedural memory and grammar in TD children. In TD groups, correlations between procedural memory and grammar are also small and often non-significant. The magnitude of association has commonly been found to be between 0.1 and 0.3 (Gabriel et al., 2011; Gabriel et al., 2013; Gabriel et al., 2012; Lum & Kidd, 2012; Mimeau et al., 2016), though this varies from -0.28 (Gabriel et al., 2014) to 0.47 (Desmottes et al., 2015).

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