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Review

Procedural learning deficits in specific language impairment (SLI): A meta-analysis of serial reaction time task performance☆

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ABSTRACT

Meta-analysis and meta-regression were used to evaluate whether evidence to date demonstrates deficits in procedural memory in individuals with specific language impairment (SLI), and to examine reasons for inconsistencies of findings across studies. The Procedural Deficit Hypothesis (PDH) proposes that SLI is largely explained by abnormal functioning of the frontal-basal ganglia circuits that support procedural memory. It has also been suggested that declarative memory can compensate for at least some of the problems observed in individuals with SLI. A number of studies have used Serial Reaction Time (SRT) tasks to investigate procedural learning in SLI. In this report, results from eight studies that collectively examined 186 participants with SLI and 203 typically-developing peers were submitted to a meta-analysis. The average mean effect size was .328 (CI_{95}: .071, .584) and was significant. This suggests SLI is associated with impairments of procedural learning as measured by the SRT task. Differences among individual study effect sizes, examined with meta-regression, indicated that smaller effect sizes were found in studies with older participants, and in studies that had a larger number of trials on the SRT task. The contributions of age and SRT task characteristics to learning are discussed with respect to impaired and compensatory neural mechanisms in SLI.

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1. Introduction

Specific language impairment (SLI) is a neurodevelopmental disorder characterized by impaired or delayed language skills that occur in the absence of intellectual, sensory or medical problems (American Psychiatric Association, 2000; World Health Organization, 1996). Substantial research suggests an association between SLI and a range of cognitive and motor impairments (for reviews see Hill, 2001; Leonard, 2000; Ullman & Pierpont, 2005). In some cases, such non-language problems are thought to either cause or exacerbate the difficulties that affected individuals have in understanding and using language (e.g., Gathercole & Baddeley, 1990; Montgomery, Magimairaj, & Finney, 2010; Tallal, 2004).

The Procedural Deficit Hypothesis (PDH), proposed by Ullman and Pierpont (2005), holds that a number of the language difficulties in SLI, in particular the grammatical deficits, may be largely explained by procedural memory impairments. The procedural memory system underlies the implicit learning and representation of skills and knowledge, as well as their automatic and rapid execution (Gabrieli, 1998; Ullman, 2004). The learning and memory functions of the system are said to be implicit because they do not require awareness. Learning via the procedural memory system is often slow, with substantial repetition or practice required in order for skills or knowledge to be processed rapidly and automatically. According to Ullman and Pierpont (2005), the procedural memory impairments in SLI are likely to be caused by neural abnormalities of one or more structures that underlie the procedural memory system, in particular the basal ganglia and frontal cortex, especially the caudate nucleus and Broca's region.

Ullman and colleagues (Ullman & Pierpont, 2005; Ullman and Pullman, submitted for publication) further suggest that the presence or severity of cognitive and language impairments in SLI will depend not only on procedural memory deficits but also on the extent to which declarative memory, which is proposed to remain largely intact in SLI, can compensate for the procedural deficits. Thus, in principle, if declarative memory could fully compensate for such underlying problems, impairments in procedural memory might not be evident.

Despite the possibility of such compensation, the PDH predicts that individuals with SLI should generally perform worse than typically-developing individuals on tasks assessing the learning and memory functions of the procedural memory system. To date, procedural memory in SLI has been explored using a range of different paradigms, including artificial grammar learning (Plante, Gomez, & Gerken, 2002), probabilistic classification (Kemény & Lukács, 2010; Mayor-Dubois, Zesiger, van der Linden, & Roulet-Perez, 2013), implicit statistical auditory learning (Evans, Saffran, & Robe-Torres, 2009; Mayor-Dubois et al., 2013), and Serial Reaction Time (SRT) tasks (Gabriel et al., 2013a; Hedenius et al., 2011; Lum, Conti-Ramsden, Page, & Ullman, 2012; Mayor-Dubois et al., 2013; Tomblin, Mainela-Arnold, & Zhang, 2007). A number of studies have reported procedural learning impairments in SLI (Adi-Japha, Strulovich-Schwartz, & Julius, 2011; Evans et al., 2009; Kemény & Lukács, 2010; Lum et al., 2012; Lum, Gelgec, Conti-Ramsden, 2010; for phonotactic information only Mayor-Dubois et al., 2013; Tomblin et al., 2007). However, these results have not always been replicated (Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011, Gabriel et al., 2013b, Gabriel, Stefaniak, Maillart, Schmitz, & Meulemans, 2012; Lum & Bleses, 2012; Mayor-Dubois et al., 2013). Thus, it is not yet clear whether procedural memory impairments constitute a core deficit of SLI.

The heterogeneity of study findings calls for a systematic assessment of the evidence in order to test whether or not SLI is indeed associated with overall procedural memory impairments, and to identify potential sources of variability between studies. To achieve this aim, we performed a systematic search of the literature and then used meta-analysis to pool results from studies and compute an overall result. Meta-analysis enables results from studies using similar methodologies to be combined, allowing population parameters to be estimated with greater precision (Borenstein, 2009; Hunter & Schmidt, 1990). Given inconsistent findings in past research, we also used meta-regression to investigate whether participant and study level variables predicted differences between study findings. Importantly, these quantitative approaches to reviewing past research overcome limitations with traditional qualitative narrative reviews in which it is difficult to pool results from studies, whilst simultaneously taking into account study-specific features such as effect size, sample size, and task-related methodological differences.

1.1. *The SRT task*

In our analyses we focused on the SRT task, because it has been widely used to investigate procedural memory in SLI. In the SRT task a visual stimulus repeatedly appears in one of four predefined spatial locations on a computer display. Participants are provided with a four-button response box. The topographic positioning of the four buttons matches the spatial locations where the stimulus appears on the display. Participants are instructed to press the button that matches the location of the visual stimulus. Reaction times (RTs) that measure how fast participants press the button following the appearance of the visual stimulus constitute the main dependent variable of interest. Presentation of the visual stimulus is divided into blocks. In the implicit version of the task, unknown to participants, stimulus presentations in most blocks follows a predefined sequence. This sequence repeats multiples times within these 'Sequenced Blocks'. Following one or more 'Sequenced Blocks', a 'Random Block' is then presented, in which the visual stimulus appears randomly, or in some studies a new sequence is introduced (e.g., Gabriel et al., 2011).

In participant groups that do not have procedural memory impairments, RTs become faster across the Sequenced Blocks, but then slow down in the Random Block (e.g., Lum, Kidd, Davis, & Conti-Ramsden, 2010; Thomas et al., 2004). This increase in RTs in the Random Block is taken to indicate that information about the sequence has been learnt (Robertson, 2007). However, in participant groups with neurodegenerative diseases or lesions affecting parts of the brain supporting the procedural memory system, the change in RTs between