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The sensitivity of children with SLI to phonotactic probabilities during lexical access

Pauline Quémart*, Christelle Maillart

University of Liège, Department of Psychology: Cognition and Behaviour, Unité de Logopédie clinique, 30, rue de l'Aunaie, B.38, 4000 Liège, Belgium

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ABSTRACT

The procedural deficit hypothesis (Ullman & Pierpont, 2005) has been proposed to account for the combination of linguistic and nonlinguistic deficits observed in specific language impairment (SLI). According to this proposal, SLI results from a deficit in procedural memory that prevents children from developing sensitivity to probabilistic sequences, amongst other deficits. We tested the ability of children with SLI to rely on a specific type of probabilities characterizing sequences that occur in a given language: phonotactic probabilities. Twenty French-speaking children with SLI (M = 10;1), 20 typically developing children matched for chronological age (M = 10;0) and 20 typically developing children matched for receptive vocabulary (M = 7;4) performed an auditory lexical decision task. Pseudoword stimuli were built with combinations of either frequently associated phonemes (high phonotactic probability) or infrequently associated phonemes (low phonotactic probability). Phonotactic probabilities had a significant impact on the accuracy and speed of pseudoword rejection in children with SLI, but not in the two control groups. SLI children's greater reliance on phonotactic probabilities relative to typically developing children appears to contradict the PD hypothesis. Phonotactic probabilities may help them to partially overcome their difficulties in developing and accessing the phonological lexicon during spoken word recognition.

Learning outcomes: After reading this article, readers will understand the importance of sensitivity to phonotactic probabilities in language processing. They will also learn that such sensitivity is preserved in children with SLI. Finally, readers will understand that children with SLI are more prone to use phonotactic information when accessing their lexicon than typically-developing children.

1. Introduction

Specific language impairment (SLI) is characterized by extreme difficulty with language acquisition in the absence of mental retardation, frank neurological damage, hearing deficits, or severe environmental deprivation (Bishop, 1992; Leonard, 2014; Tomblin et al., 1997). Children with SLI have deficits in a range of language domains including phonology (Joanisse & Seidenberg, 1998, 2003; Maillart & Parisse, 2006; Ramus, Marshall, Rosen, & van der Lely, 2013), word learning (Gray, 2003, 2004, 2005; Li & McGregor, 2010), and morpho-syntactic skills (Maillart & Schelstraete, 2005; Redmond & Rice,

* Corresponding author. Present address: Centre de Recherches sur la cognition et l'apprentissage (CeRCA), UMR CNRS 7295, Maison des Sciences de l'Homme et de la Société (MSHS), 5, rue Théodore Lefebvre, TSA 21103, F-86073 Poitiers, Cedex 9, France.
E-mail addresses: Pauline.quemart@univ-poitiers.fr (P. Quémart), christelle.maillart@ulg.ac.be (C. Maillart).

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2001; Rice, Wexler, & Cleave, 1995). Even though the exclusion criteria mentioned above are determinant in SLI diagnosis, there is increasing evidence that children with SLI also exhibit subtle non-linguistic deficits, such as impairments of working memory (Archibald & Gathercole, 2006; Gathercole & Baddeley, 1990), attention (Oram Cardy, Tannock, Johnson, & Johnson, 2010), or motor skills (Hill, 2001; Zelaznik & Goffman, 2010).

In order to account for the combination of linguistic and non-linguistic deficits observed in SLI, some authors have theorized that this neurodevelopmental disorder results from a non-linguistic processing deficit (e.g., Bishop, 1992; Gathercole & Baddeley, 1990; Joanisse & Seidenberg, 1998, 2003; Leonard, 2014; Tallal & Piercy, 1974), but most have failed to explain the heterogeneity of the co-occurring disorders. A possible exception is the hypothesis proposed by Ullman and Pierpont (2005) to account for the full range of linguistic and non-linguistic deficits observed in SLI: the procedural deficit (PD) hypothesis. The central claim of the PD account is that SLI results from a selective deficit of the procedural memory system, which is involved in the acquisition and retention of procedural knowledge. This hypothesis has received increasing attention in the past decade (e.g., Hsu & Bishop, 2014; Lum, Conti-Ramsden, Morgan, & Ullman, 2014), but few studies have sought to characterize the specific markers of this hypothetical deficit in the context of language acquisition itself. In the present study, we examined whether children with SLI develop sensitivity to a hallmark of the adequate functioning of the procedural memory system when processing oral language: phonotactic probability.

1.1. The procedural deficit (PD) hypothesis

The PD hypothesis (Ullman & Pierpont, 2005) is based on the assumption that long-term memory can be divided into two distinct memory systems: declarative and procedural (Squire & Zola, 1996). This distinction is supported by research indicating that the two systems are responsible for different types of learning and have a distinct neurobiological basis. Declarative memory is involved in the explicit learning and storage of past events and facts, and relies on the hippocampus. In contrast, procedural memory is involved in the acquisition and use of implicit motor and cognitive skills, and relies on the striatum of the basal ganglia. The two systems are also differentially involved in language development and processing. The declarative system is thought to be responsible for the development of the mental lexicon, which stores word-specific knowledge. The procedural system, on the other hand, is thought to be involved in the acquisition of various aspects of grammar, including morphology and syntax, but also phonology.

According to the PD hypothesis, SLI is the consequence of structural and functional abnormalities of the brain structures that control the procedural memory system. Support for this hypothesis comes from neuroimaging studies which have found functional abnormalities of the basal ganglia, inferior frontal cortex, and superior temporal cortex in children with SLI compared to normal controls when performing a linguistic task (Liegeois et al., 2003; Neville, Coffey, Holcomb, & Tallal, 1993; Vargha-Khadem et al., 1998).

A number of behavioral studies have given evidence of a deficit in procedural learning in children with SLI, but Ullman and Pierpont (2005)'s PD hypothesis has mainly been tested using non-verbal designs. In serial reaction time tasks – where reduced reaction times to stimuli are taken to indicate learning of sequences – children with SLI generally perform less well than typically developing children (Hsu & Bishop, 2014; Lum, Gelgic, & Conti-Ramsden, 2010; Tomblin, Mainela-Arnold, & Zhang, 2007), but such deficits have not been observed systematically (Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011; Gabriel, Stefaniak, Maillart, Schmitz, & Meulemans, 2012; Gabriel, Meulemans, Parisse, & Maillart, 2015; Lum & Bleses, 2012). In a recent meta-analysis that focused on SRT tasks only, Lum et al. (2014) showed that the likelihood that children with SLI will learn probabilistic sequences depends on a number of factors, such as the number of exposures to the sequence and the children's age.

Procedural learning in children with SLI has also been tested using non-sequential tasks. Preserved non-verbal procedural learning was found in a pursuit rotor task (Hsu & Bishop, 2014), in a spatial contextual cueing task (Gabriel, Schmitz, Maillart, & Meulemans, 2009), and in a mirror-tracing task (Desmottes, Maillart, & Meulemans, 2015). These results were taken to suggest that poor procedural learning in children with SLI might result from a specific difficulty learning sequence-specific information.

1.2. The importance of sensitivity to phonotactics in language development

Only a few studies have investigated the possible interference of an implicit sequence learning deficit with the processing of verbal materials in SLI. Language acquisition partly relies on statistical learning of phonological, lexical, and morphosyntactic regularities (see for example Shukla, Gervain, Mehler, & Nespor, 2012), an ability that is thought to be supported by the procedural system (Ullman et al., 1997). Regarding phonology in particular, languages are characterized by regularities in associations between their phonological constituents. In a given language, the rules that determine the sound combinations that may or may not occur in a language are referred to as 'phonotactic constraints', and the likelihood that a given phonological sequence will occur in syllables and words has been termed 'phonotactic probability'.

Sensitivity to phonotactic constraints and probabilities develops during infancy. Nine-month-olds are sensitive to the phonotactic patterns of their native language (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993), and prefer to listen to pseudowords containing legal or high-probability phonotactic sequences over those containing illegal or low-probability sequences (Friederici & Wessels, 1993; Jusczyk, Luce, & Charles-Luce, 1994).