



Linking memory and language: Evidence for a serial-order learning impairment in dyslexia



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ABSTRACT

The present study investigated long-term serial-order learning impairments, operationalized as reduced Hebb repetition learning (HRL), in people with dyslexia. In a first multi-session experiment, we investigated both the persistence of a serial-order learning impairment as well as the long-term retention of serial-order representations, both in a group of Dutch-speaking adults with developmental dyslexia and in a matched control group. In a second experiment, we relied on the assumption that HRL mimics naturalistic word-form acquisition and we investigated the lexicalization of novel word-forms acquired through HRL. First, our results demonstrate that adults with dyslexia are fundamentally impaired in the long-term acquisition of serial-order information. Second, dyslexic and control participants show comparable retention of the long-term serial-order representations in memory over a period of 1 month. Third, the data suggest weaker lexicalization of newly acquired word-forms in the dyslexic group. We discuss the integration of these findings into current theoretical views of dyslexia.

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1. Introduction

1.1. Dyslexia

Developmental dyslexia is commonly defined as a learning disorder characterized by persistent difficulties with reading and/or spelling despite adequate intelligence, education and sensory functions (Lyon, Shaywitz, & Shaywitz, 2003; World Health Organization, 2008). Although the above definition focuses on problems with reading and spelling, the literature on dyslexia reveals a strikingly broad scope of associated nonlinguistic dysfunctions. Examples include impaired short-term memory (e.g., Martinez Perez, Majerus, Mahot, & Poncelet, 2012), working memory (e.g., Gathercole, Alloway, Willis, & Adams, 2006; Smith-Spark & Fisk, 2007), implicit (sequence) learning (e.g., Lum, Ullman, & Conti-Ramsden, 2013; Pavlidou, Kelly, & Williams, 2010; Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003), motor functions (e.g., Nicolson, Fawcett, & Dean, 2001) and sensory functioning (e.g., Stein, 2001, but see also Goswami, 2015).

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The underpinnings of dyslexia remain a source of controversy. The influential phonological theory (Snowling, 2000; Stanovich, 1988) postulates that an impairment in the representation and processing of phonological information is the core underlying deficit in dyslexia. However, while phonological impairments are indeed found in a clear majority of the studies (Melby-Lervag, Lyster, & Hulme, 2012; Ramus & Ahissar, 2012; Ziegler & Goswami, 2005), the presumption of an etiological and causal role for these phonological problems in relation to reading is not without its critics (Blomert & Willems, 2010; Castles & Coltheart, 2004). Most importantly, there is evidence for a double dissociation between dyslexia and phonological deficits: some individuals with severe reading disability do not show a phonological impairment, while some children with an apparent phonological deficit nevertheless do achieve fluency in (word) reading (Paulesu et al., 2001; Wimmer, Mayringer, & Landerl, 2000). Moreover, it is unclear how some of the nonlinguistic impairments often associated with dyslexia (e.g., implicit learning or motor deficits) may be accounted for by phonological deficits. Perhaps as a result, diverse alternative theoretical accounts of dyslexia have been proposed (e.g., the automaticity/cerebellar deficit hypothesis, Nicolson & Fawcett, 1990; the anchoring-deficit hypothesis, Ahissar, 2007; the magnocellular theory, Stein, 2001) but a unifying framework that addresses the diversity of associated dysfunctions is still lacking (Pennington, 2006; Ramus, 2003). A recently introduced integrative hypothesis proposes that several of the associated dysfunctions observed in dyslexia arise from a deficit in memory for serial-order information (i.e., the order in which items are presented within a sequence; Szmalec, Loncke, Page, & Duyck, 2011). The present study builds on this novel hypothesis, which is explained in more detail later.

1.2. Serial-order memory and language learning

It is well known that both the immediate processing and the long-term learning of sequential information have relevance to language skills (Conway & Christiansen, 2001). First, there is the observation of a clear association between verbal immediate serial recall performance and the learning of novel phonological word-forms (Baddeley, Gathercole, & Papagno, 1998; Gathercole, Service, Hitch, Adams, & Martin, 1999; Gupta, 2003). At the theoretical level, models of short-term memory suggest that the encoding of item identity on the one hand, and serial order processing on the other hand, are distinct and dissociable functions (e.g., Burgess & Hitch, 1999, 2006; Gupta, 2003, 2008; Page & Norris, 2009). These models contend that verbal item-information is stored via temporary activation of long-term phonological and lexico-semantic representations, with a strength depending primarily on the quality of these long-term traces (see also Majerus & D'Argembeau, 2011). In contrast, the encoding of serial order occurs via a system that operates on items, over-and-above those processes used in their individual recognition. Several recent studies by Majerus and colleagues have highlighted the importance of the serial-order processing component of short-term memory (STM), in addition to memory for item identity, in relation to novel word-form learning (e.g., Leclercq & Majerus, 2010; Majerus & Boukebza, 2013; Majerus Poncelet, Greffe, & Van der Linden, 2006) and literacy acquisition (Martinez Perez, Majerus, & Poncelet, 2012).

Recently, Page and Norris (2008, 2009) explicitly related word learning to a memory framework by extending their computational model of verbal short-term memory (the primacy model, Page & Norris, 1998) to word-form learning. They proposed that the order-STM processes described above contribute to long-term learning of new phoneme sequences (and by extension novel lexical or orthographic representations) via a mechanism that is also seen operating in Hebb repetition learning (HRL). HRL refers to the observation that when a particular ordered sequence of stimuli is repeated several times over the course of an immediate serial recall task, people show gradually enhanced recall of that sequence—known as the *Hebb* sequence—relative to *filler* sequences in which stimuli appear in a random order (Hebb, 1961). In essence, HRL reflects how, through repeated presentation and recall, an ordered sequence of information in short-term memory gradually develops into a stable, long-term memory trace. In the framework of Page and Norris (2008) and Page and Norris (2009), a new word-form is conceived as a familiarized sequence of sublexical components, such as phonemes or syllables (see also Gupta, 2008, for a similar view). HRL of a syllable sequence like “*lo fo du*” is therefore assumed to be functionally equivalent to acquiring the novel word-form “*LOFODU*”, similar to the way in which children learn new words by picking up statistical regularities from the verbal input in their environment (e.g., Saffran, Aslin, & Newport, 1996). Experimental evidence for the hypothesis that HRL mimics naturalistic word-form acquisition was provided by Szmalec and colleagues (Szmalec, Duyck, Vandierendonck, Barberá Mata, & Page, 2009; Szmalec, Page, & Duyck, 2012). In these experiments, that included only normal readers, participants typically had to recall nonsense sequences of nine visually presented consonant-vowel syllables (CVs), with each sequence grouped by short pauses into three three-CV groups (e.g., “*fi ke da-sa mo pu-vo ti zu*”). A Hebb sequence, presented every third trial, always contained the same three three-CV groups, in a random group-ordering. Participants showed clear HRL (i.e., improved recall of sequences whose groups repeated relative to filler sequences). After learning, auditory lexicalization tests showed that the three-CV groups that had been repeatedly presented and recalled, exhibited the properties expected of novel word-form entries in the mental lexicon. In summary, these studies suggest that HRL draws on the same memory processes responsible for representing and learning serial-order information in the service of language acquisition (i.e., novel word-form learning).

1.3. Dyslexia as a disorder?

Drawing on the crucial role that serial order plays in language learning and processing, Szmalec et al. (2011) proposed a novel hypothesis relating to dyslexia, that we will call the “*SOLID*” (Serial-order Learning Impairment in Dyslexia)

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