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Dissociation between the procedural learning of letter names and motor sequences in developmental dyslexia ☆

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ABSTRACT

Motor sequence learning has been studied extensively in Developmental dyslexia (DD). The purpose of the present research was to examine procedural learning of letter names and motor sequences in individuals with DD and control groups. Both groups completed the Serial Search Task which enabled the assessment of learning of letter names and motor sequences independently of each other. Control participants learned both the letter names as well as the motor sequence. In contrast, individuals with DD were impaired in learning of the letter names sequence and showed a reliable transfer of the motor sequence. Previous studies proved that motor sequence learning is impaired in DD. The present study demonstrated that this deficit is more pronounced when the task to be learned involves linguistic units. This result implies that the procedural learning system of language is more deficient than the motor procedural learning system in individuals with DD. The dissociation between motor and letter names sequence learning in those with DD also implies that the systems underlying these two tasks are separable.

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1. Introduction

Developmental dyslexia (DD) is defined as unexpected, specific, and persistent failure to acquire efficient reading skills despite conventional instruction, adequate intelligence, and socio-cultural opportunity (American Psychiatric Association, 1994). Individuals with DD may have difficulties in acquiring a variety of language skills such as reading, writing and spelling as well as reading sub-skills such as word identification and phonological decoding (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Several theories which attempt to unravel the main deficits underlying DD have been reported in the literature. Despite decades of intensive research the underlying biological and cognitive causes of this reading impairment are still under extensive debate (for a review, see Démonet, Taylor, & Chaix, 2004). The mainstream hypothesis, i.e., *The Phonological Deficit Hypothesis* (Snowling, 2000), implicates a deficit of direct access to, and manipulation of, phonemic language units retrieved from the long-term declarative memory. This theory has been supported by numerous studies which indicated a phonological deficit in DD (for a review, see Vellutino et al., 2004). However, individuals with DD exhibit difficulties in auditory and visual processing (Farmer & Klein, 1995), as well as attention (Facoetti & Molteni, 2001), and sensori–motor deficits (Nicolson & Fawcett, 1994). *The Phonological Deficit Hypothesis* cannot account for these additional deficits which have been reported in many individuals with DD, and has been facing growing criticism. Nevertheless, the wide range of DD difficulties has led researchers to search for other more basic deficits than reading which may underlie DD (Hari & Renvall, 2001; Nicolson & Fawcett, 1990; Stein & Walsh, 1997).

One of the theories which conceptualize DD as a learning disorder is the *Cerebellum Deficit Hypothesis* (Nicolson, Fawcett, & Dean, 2001). According to this view, dyslexics fail to automate new cognitive and motor procedures. This deficit arises from dysfunction of the cerebellum, which is involved in the automatization of new skills. This theoretical framework has been recently modified to its current form, *Specific Procedural Learning Difficulties* (Nicolson & Fawcett, 2008, 2011) according to which DD arises specifically from impaired performance of the procedural learning system for language. This defect stems from damage to one of the brain areas related to this system (such as the prefrontal cortex around Broca's area, the parietal cortex and sub-cortical structures including the basal ganglia and the cerebellum). Nicolson and Fawcett (2011) indicate that a subgroup of DD may also have a deficit in the motor procedural learning system, yet in their opinion it is not a requirement for the

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diagnosis of DD. Empirical work supporting this account attempts to examine individuals with DD on a variety of procedural skills (for a review see Folia et al., 2008).

1.1. Procedural learning

One of the tasks used for studying procedural learning is the serial reaction time (SRT) task (Nissen & Bullemer, 1987). In this task, participants are presented with a visual stimulus in one of several discrete locations and are requested to make a rapid key press corresponding to the stimulus location. Unknown to the participants the stimuli appear in a repeated sequence, and learning of the sequence is indicated by a decrease in reaction time across blocks or as a difference between reaction time to sequence and random (or a different sequence) blocks (Seger, 1994). There is clear evidence of learning, irrespective of the participants' conscious awareness of the repeated sequence. This kind of sequential learning has therefore been referred to as implicit learning. (for reviews, see Berry & Dienes, 1993; Seger, 1994; Shanks & St John, 1994).

One of the main questions in the research literature on the SRT task is what exactly is being learned in this task? When a participant performs the task, it is not clear whether he learns the sequence of manual responses or the sequence of the stimulus positions or both. The motor view of implicit sequence learning suggests that implicit learning is based on motor learning. Research supporting this account demonstrates that implicit learning cannot occur without motor learning (Willingham, Nissen, & Bullemer, 1989; Ziessler, 1994). On the other hand, the perceptual account of sequence learning suggests that learning involves the acquisition of contingencies amongst perceptual stimuli (Dennis, Howard, & Howard, 2006; Vakil, Kahan, Huberman, & Osimani, 2000). Evidence supporting this view comes from observational studies which demonstrate that learning can occur by observing a pattern of finger movements (Heyes & Foster, 2002). Another similar question regarding the SRT task is whether implicit sequence learning consists of a single learning mechanism or multiple mechanisms for different kinds of input or tasks that involve partially different brain structures. Several studies point to the possible existence of multiple learning mechanisms, each one for a specific kind of input such as tones, speech like material, shapes etc. (Conway & Christiansen, 2006; Goschke, Friederici, Kotz, & Van Kampen, 2001).

1.2. Motor versus language procedural learning in DD

The SRT task has been studied extensively in DD in order to examine motor procedural learning (for review see Folia et al., 2008). Several studies have revealed impairment in sequence learning among adults with DD as measured by the SRT task (Howard, Howard, Japikse, & Eden, 2006; Menghini, Hagberg, Caltagirone, Petrosini, & Vicari, 2006). Other studies have reported intact sequence learning among individuals with DD (Kelly, Griffiths, & Frith, 2002; Rüsseler, Gerth, & Münte, 2006). A recent study explored both the acquisition and consolidation stages believed to be involved in skill learning in DD. This study revealed that individuals with DD have a deficit in general skill learning of the SRT task, while the transfer measure and consolidation processes remained intact (Gabay, Schiff, & Vakil, 2012). This inconsistency between studies can be attributed to differences in the experimental design, sampling, procedures being used, etc. Indeed, previous research on the SRT task indicated several parameters which can affect implicit learning, including the length of the sequence being used (Howard & Howard, 1992; Pascual-Leone et al., 1993), the length of response–stimulus interval (Destrebecqz & Cleeremans, 2001), the structure of the sequence (Stadler & Neely, 1997), the use of random/different blocks (Vaquero, Jiménez, & Lupiáñez, 2006) as well as the amount of training. The studies cited above differ greatly in these parameters. This makes it difficult to compare their results directly and to reach a clear conclusion on the SRT in DD. Moreover, Nicolson and Fawcett (2011) suggest DD stems mainly from a deficit in the procedural learning system of language, while some DD individuals may also be impaired in the motor procedural learning system. This suggestion might help clarify why some studies have demonstrated deficit in motor sequence learning in DD, while other studies have not.

Contrary to the extensive research on motor procedural learning in DD, only a few studies have examined language procedural learning in this population. Several studies employed the Artificial Grammar Learning (AGL) task (Reber, 1967). In this task, participants are shown a set of letter strings that conform to an underlying rule. In the training phase the participants memorize the letter strings. In a subsequent test phase the participants are shown new letter strings and are asked to judge whether they are constructed according to the artificial grammar or whether they contain violations of the grammatical structure. Classification of the novel strings significantly above chance level is taken as an indication for learning the structure of the grammar. Research on AGL in DD revealed mixed results. Rüsseler et al. (2006) demonstrated that AGL is intact in adults with DD. Yet, Pavildou, Kelly and Williams (2010) found that children with DD failed to learn the underlying rule.

Although the studies cited above examined procedural learning of motor and language deficits in DD, only one study has tested these different deficits simultaneously in a single study (Rüsseler et al., 2006). In this study the same participants performed SRT and AGL tasks. However, direct comparison is difficult due to the differences between these two experimental paradigms. Furthermore, it is also possible that these tasks tap different processes. A direct comparison of motor and language procedural learning (using the same experimental paradigm) is therefore necessary in order to understand the nature of procedural learning difficulties in DD.

The current study aimed to examine language and motor procedural learning in DD. Using an identical experimental paradigm enabled examination of whether motor versus language procedural learning difficulties may occur in individuals with DD. To the best of our knowledge, so far no research has examined letter names sequence learning in individuals with DD. These objectives were achieved by examining the Serial Search Task (SST; Goschke et al., 2001) in DD and control groups. In this task, four letters are presented visually in each trial, followed by a single letter presented auditorily. Participants are asked to press one of four response keys to indicate the location of the auditory letter in the visual display. The arrangement of the visual letters is changed from trial to trial so that either the key-presses (response sequence condition) or the auditory letters (letter names sequence condition) follow a repeating pattern, while the other sequence is random. The task allows examining whether participants acquired knowledge about a sequence of events in the absence of a regular response sequence, and vice versa. For example, participants in the letter names sequence condition can learn to anticipate the next letter name (for instance, they may learn that A–C–B is followed by D), but they cannot predict the next response before the mapping display appears, because there is no regular response sequence. Previous experiments have shown that normal readers learn both letter names and response sequences (Goschke, 1998b). The present study aimed to elucidate whether individuals with DD can learn both kinds of sequences as compared to normal readers.

Nicolson and Fawcett's (2011) model characterizes the deficits normally found among the DD population as arising to a great

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