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Research Paper

Visual artificial grammar learning in dyslexia: A meta-analysis

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ABSTRACT

Background: Literacy impairments in dyslexia have been hypothesized to be (partly) due to an implicit learning deficit. However, studies of implicit visual artificial grammar learning (AGL) have often yielded null results.
Aims: The aim of this study is to weigh the evidence collected thus far by performing a meta-analysis of studies on implicit visual AGL in dyslexia.
Methods and procedures: Thirteen studies were selected through a systematic literature search, representing data from 255 participants with dyslexia and 292 control participants (mean age range: 8.5–36.8 years old).
Results: If the 13 selected studies constitute a random sample, individuals with dyslexia perform worse on average than non-dyslexic individuals (average weighted effect size = 0.46, 95% CI [0.14 … 0.77], p = 0.008), with a larger effect in children than in adults (p = 0.041; average weighted effect sizes 0.71 [sig.] versus 0.16 [non-sig.]). However, the presence of a publication bias indicates the existence of missing studies that may well null the effect.
Conclusions and implications: While the studies under investigation demonstrate that implicit visual AGL is impaired in dyslexia (more so in children than in adults, if in adults at all), the detected publication bias suggests that the effect might in fact be zero.

1. Introduction

Individuals with dyslexia have severe and persistent difficulties with learning to read and spell. These difficulties occur despite normal intelligence, adequate educational and socio-economic opportunities, and in absence of sensory or neurological impairment[1] (DSM-IV; American Psychiatric Association, 2000). A generally accepted hypothesis is that the persistent difficulties with written language result from a core deficit in phonological processing and, specifically, phonological awareness (see Melby-Lervåg, Lyster, & Hulme, 2012 for a meta-analysis). Phonological awareness is the ability to detect and manipulate phonological segments of words (Shankweiler et al., 1995) and is related to the ability to map letters to sounds, which in turn affects the ability to learn to read and spell. Individuals with dyslexia also experience difficulties in other areas of language. Subtle problems have been reported in the area of inflectional morphology (e.g. pluralization and tense marking: Joanisse, Manis, Keating, & Seidenberg, 2000; subject-verb agreement: Rispens & Been, 2007; Rispens, Roeleven, & Koster, 2004) and syntax (relative clauses: Mann, Shankweiler, & Smith, 1984; Stein, Cairns, & Zurif, 1984, passive sentences: Stein et al., 1984; binding: Waltzman & Cairns, 2000). Additionally, dyslexia is associated with a range of non-linguistic cognitive dysfunctions, including impairments in visual and auditory processing

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[1] Note that in the DSM-V (American Psychiatric Association, 2013), dyslexia is included under the umbrella term 'Specific Learning Disorder'.

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(Stein & Walsh, 1997; Tallal, 2004), attention (Facoetti a Paganoni & Lorusso, 2000), motor functioning (Ramus, Pidgeon, & Frith, 2003), and verbal working memory (Gathercole & Alloway, 2006; Gathercole & Baddeley, 1990; Swanson & Jerman, 2007).

Several theories have attempted to define the underlying deficit that accounts for the range of problems experienced by individuals with dyslexia. One recent approach is explaining dyslexia as the result of a problem with implicit learning (see Nicolson & Fawcett, 2007; Ullman & Pierpont, 2005). The term implicit learning refers to the process through which humans extract rules and regularities from visual and auditory sequences available in the environment. Importantly, this happens in absence of awareness.

1.1. Implicit learning and literacy acquisition

Many studies have related implicit learning abilities to different aspects of language acquisition: the ability to segment words from continuous speech (Saffran, Aslin, & Newport, 1996), the acquisition of phonological categories and phonotactics (Nicolson & Fawcett, 2007; Wijnen, 2013), vocabulary acquisition (Evans, Saffran, & Robe-Torres, 2009; Yu, 2008), and more general language processing (e.g. passives: Kidd, 2012; relative clauses: Misyak, Christiansen, & Tomblin, 2010). Most important to the present discussion is the relationship between implicit learning and the acquisition of literacy skills, as these are the skills most affected in individuals with dyslexia. Learning to read and spell involves the mapping between letters and sounds (grapheme-to-phoneme mapping), which requires phonological awareness and knowledge of the orthographic system. This mapping, and the writing system in general, comprises many regularities. For example, a single letter (e.g. 'c') can map onto several phonemes (e.g./k/ ,/s/). Whether the letter 'c' is realized as a/k/or an/s/, depends on co-occurring letters (e.g. the letter 'c' followed by the letter 'a' generally results in the realization of the phoneme/k/as in *can't*, but in the phoneme/s/when followed by an 'e' as in *cent*). In other words, the writing system consists of a "set of correlations that determine the possible co-occurrences of letter sequences, which eventually result in establishing orthographic representations" (Frost, Siegelman, Narkiss, & Afek, 2013, p. 2). Although some of these regularities in written language are taught explicitly, it seems plausible that children's literacy acquisition is aided by implicit learning through exposure to written language.

Previous research has suggested a link between implicit learning and literacy skills in the typically developing population (e.g. Apfelbaum, Hazeltine, & McMurray, 2013; Arciuli & Cupples, 2006; Arciuli & Simpson, 2012; Frost et al., 2013; Pacton, Fayol, & Perruchet, 2005; Spencer, Kaschak, Jones, & Lonigan, 2014). For example, typically developing children apply orthographic regularities in pseudo-word spelling (e.g. in French, /ɛt/ is more often written as < ette > after $-v$ than after $-f$), which reflects their implicit knowledge of single letters and letter combinations (Pacton et al., 2005). Similarly, Pacton, Perruchet, Fayol, and Cleeremans (2001) show that French-speaking typically developing children are sensitive to the orthographic constraints of the positions of double consonants (e.g. *xevvu* is more acceptable than *xxevu*). Additionally, correlational studies have established a link between performance on implicit learning tasks and reading in English (Arciuli & Simpson, 2012), reading in Hebrew as a second language (Frost et al., 2013), and a variety of literacy-related skills including oral language, vocabulary and phonological processing (Spencer et al., 2014). Using a linear regression analysis, Ise, Arnoldi, Bartling, and Schulte-Körne (2012) showed that children's performance on a visual artificial grammar learning (AGL) task, a measure of implicit learning which will be explained in more detail below, predicts their performance on a spelling task. Together, the abovementioned studies suggest there is a relationship between implicit learning and (the acquisition of) literacy skills in typical populations.

1.2. Implicit learning in dyslexia

A number of studies have investigated the hypothesis that individuals with dyslexia have problems with implicit learning, which affect their literacy skills. Several tasks have been deployed to investigate implicit learning skills in dyslexia. Examples include the serial reaction time (SRT) task (e.g. Deroost et al., 2010; Menghini et al., 2010; Vicari et al., 2005), the alternating SRT task (Hedenius et al., 2013), as well as visual AGL tasks (e.g. Ise et al., 2012; Pothos & Kirk, 2004; Rüsseler, Gerth, & Münte, 2006). Although both the SRT and AGL paradigm are methods used to investigate implicit learning, the type of structure learned in each paradigm differs (greatly). Whereas the SRT measures a motoric response to visual sequences and is stimulus-bound (i.e. no generalization rule can be abstracted from the sequence), the visual AGL measures rule learning from visual input. While numerous studies report implicit learning difficulties in individuals with dyslexia (e.g. Du & Kelly, 2013; Ise et al., 2012; Jiménez-Fernández, Vaquero, Jiménez, & Defior, 2011; Vicari et al., 2005), others do not find evidence for such a deficit (e.g. Deroost et al., 2010; Menghini et al., 2010; Pothos & Kirk, 2004; Rüsseler et al., 2006). Because of these mixed results, Lum, Ullman, and Conti-Ramsden (2013) performed a meta-analysis on 14 studies that investigated implicit learning in individuals with dyslexia using the SRT paradigm. Their results show that implicit sequence learning, as measured by the SRT task, is significantly poorer in people with dyslexia than in non-dyslexic controls (average weighted effect size 0.45, $p < 0.001$). Thus, these results indicate a deficit in implicit visuo-motor learning in dyslexia. In the current study we investigate whether individuals with developmental dyslexia are also affected in visual artificial grammar learning. If individuals with dyslexia have difficulties with implicit learning across the board, group differences should be found using both the SRT and AGL paradigms. However, it could also be the case that poor performance by individuals with dyslexia on the SRT task is due to a specific *motor* learning deficiency, as dyslexia has previously been associated with motor problems (e.g. Fawcett & Nicolson, 1995; Ramus, 2003; Ramus et al., 2003). In that case, one would not necessarily also expect difficulties in the area of visual AGL learning.