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# Implicit learning and reading: Insights from typical children and children with developmental dyslexia using the artificial grammar learning (AGL) paradigm

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ABSTRACT

We examined implicit learning in school-aged children with and without developmental dyslexia based on the proposal that implicit learning plays a significant role in mastering fluent reading. We ran two experiments with 16 typically developing children (9 to 11-years-old) and 16 age-matched children with developmental dyslexia using the artificial grammar learning (AGL) paradigm. In Experiment 1 (non-transfer task), children were trained on stimuli that followed patterns (rules) unknown to them. Subsequently, they were asked to decide from a novel set which stimuli follow the same rules (grammaticality judgments). In Experiment 2 (transfer task), training and testing stimuli differed in their superficial characteristics but followed the same rules. Again, children were asked to make grammaticality judgments. Our findings expand upon previous research by showing that children with developmental dyslexia show difficulties in implicit learning that are most likely specific to higher-order rule-like learning. These findings are discussed in relation to current theories of developmental dyslexia and of implicit learning.


## 1. Introduction

People have innate learning mechanisms that allow them to acquire structural regularities in their environment (e.g. Folia et al., 2008; Gomez, 1997; Perruchet and Pacteau, 2006; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997) incidentally (and largely non-consciously), whether this environment calls on perceptual, motor, social or linguistic skills (Frost, Siegelman, Narkiss, & Afek, 2013; Perruchet and Pacteau, 2006). The view that general non-linguistic learning abilities could mediate fundamental reading mechanisms (e.g. Nicolson & Fawcett, 1999) has led many authors to claim that reading involves a blend of explicit and implicit learning abilities (e.g. Sperling, Lu, & Manis, 2004). Implicit learning in the context of the present work is understood as the learning process by which we acquire knowledge of the regularities of the learning environment in a passive way and possibly without conscious awareness (Pothos, 2007).

The central task in learning to read is the establishment of relationships between letters (graphemes) of printed words (orthography) and speech sounds (phonemes) of spoken words (phonology) for the successful decoding of the words (Tulving, 2000). To establish such relationships children require to have (1) phonological awareness (i.e. the conscious knowledge that words can be taken apart into phoneme segments such as consonants and vowels and that these can be

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manipulated) and (2) letter knowledge (i.e. knowing that letters represent phonemes). Each writing system is "characterized by a set of correlations that determine the possible co-occurrences of letter sequences, which eventually result in establishing orthographic representations" (Frost et al., 2013, p. 2): words in a given language are characterized by patterns of transitional probabilities that constrain their possible phonological structure and the co-occurrences of letter sequences. Implicit learning mechanisms are thought to aid the abstraction of such patterns in print by reducing the cognitive demands of word recognition (Stanovich, 1980).

Support for implicit learning contributions to competent reading skills comes from both behavioral and computational research. For example, a number of behavioral studies (Cassar & Treiman, 1997; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Pollo, Kessler, & Treiman, 2009) have shown that children acquire implicit knowledge of both single letters and letter combinations (bigrams and trigrams): children are found to be sensitive toward orthographic regularities much earlier than most developmental theories of spelling have predicted (e.g. Cassar & Treiman, 1997). Other studies (Folia et al., 2008; Gombert, 2003; Petersson & Reis, 2006; Ziegler & Goswami, 2005) have shown that children explicitly acquire the initial grapheme–phoneme correspondences but continue to learn how phonemic representations map onto their graphemic representation in an implicit manner. In a recent study with English-Hebrew bilingual young adults, Frost et al. (2013) demonstrated that individual differences in visual implicit learning performance for non-language materials predict reading efficiency in Hebrew as a second language. They argue that when the statistical properties of the L2 differ from those of L1, then it is very likely that general non-linguistic mechanisms mediate language learning. Connectionist models of reading provide supporting evidence for implicit learning processes during fluent reading. According to Harm and Seidenberg (1999, 2004) while initial orthography-phonology connections are 'taught' explicitly, the rest of mappings result from coincidence detection of probabilistic properties in the input.

Additional evidence for implicit learning in reading comes from studies in reading impaired populations; both adults (Benett, Romano, Howard, & Howard, 2008; Howard, Howard, Japikse, & Eden, 2006; Sperling et al., 2004; Stoodley, Harrison, & Stein, 2006 but see also Kelly, Griffiths, & Frith, 2002) and children (Pavlidou, Kelly, & Williams, 2010; Pavlidou, Williams, & Kelly, 2009; Vicari, Marrota, Menghini, Molinari, & Petrosini, 2003; Vicari et al., 2005 but see also Roodenrys & Dunn, 2007). Developmental dyslexia is a very interesting platform through which we can study implicit learning mechanisms and their interaction with reading and other explicit cognitive abilities.

Impaired reading in populations with developmental dyslexia has been repeatedly found to be associated with poor implicit learning performance of sequential stimuli (e.g. Benett et al., 2008; Howard et al., 2006; Szmalec, Loncke, Page, & Duyck, 2011) even in the presence of intact explicit learning abilities (Vicari et al., 2003). Similarly, poor performance of reading impaired cohorts in artificial grammar learning (AGL) tasks with simultaneously presented stimuli (Pavlidou et al., 2009, 2010) suggests that implicit learning deficits are not limited to serial order learning but could also extend to learning mechanisms that abstract rules.

Benett et al. (2008) report a positive correlation between non-motor implicit sequence learning and pseudoword reading in adults with developmental dyslexia: poor pseudoword accuracy scores were positively correlated with lower implicit learning performance. Based on our work with the artificial grammar learning (AGL) paradigm (Pavlidou et al., 2009, 2010) in primary school children, we suggest that there is a close relationship between implicit learning deficits and poor phonological skills. Whereas typical readers abstract the statistical properties of print to achieve fluency (e.g. Harm & Seidenberg, 2004) poor readers fail to do so: implicit learning deficits could inhibit the development of stable integrated representations for printed words and in turn, compromise the automatization of phonological structures: in other words, failure does not seem to be in implicit learning per se but rather in consolidating or abstracting this learning into rule-like behavior.

Recent work by Blomert (2011) reveals that the development of automated letter-speech sound associations boosts phonological skills (instead of the reverse) adding significant weight to our suggestion. Our previous findings (Pavlidou et al., 2009, 2010) suggest that children acquire higher-order visual features, for example, they can recognize as grammatical not only items that have adjacent dependencies (bigrams or trigrams) but also items that have long distance non-adjacent dependencies. The learning of such regularities allows the development of efficient representations for further associative learning (for familiar elements) and also structure (rule) learning (that will aid the acquisition of novel elements). In the case of reading, such associative and rule-based mechanisms help children to cope with the similarities in the phonological structure of alphabetic languages (e.g. homophones) and to compute their mappings to achieve fluency (Harm & Seidenberg, 2004).

Overall, taken together, the findings suggest that the learning difficulties are not limited to linguistic materials and thus, are not likely to be simply a consequence of poor phonological decoding, although they could relate to noisy representations and could account for some of the reading problems encountered in developmental dyslexia.

### *1.1. The artificial grammar learning paradigm*

The AGL framework provides the theoretical and empirical grounds for exploring various hypotheses pertinent to how implicit learning mechanisms operate in the presence of developmental dyslexia and contribute to reading. AGL has been effectively used to explore implicit learning (and its resulting knowledge) in typical populations, as it is thought to tap the mechanisms that recognize complex statistical regularities in simultaneously presented serial materials (e.g. Petersson, Forkstam, & Ingvar, 2004).