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Dyslexics are impaired on implicit higher-order sequence learning, but not on implicit spatial context learning

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Abstract

Developmental dyslexia is characterized by poor reading ability and impairments on a range of tasks including phonological processing and processing of sensory information. Some recent studies have found deficits in implicit sequence learning using the serial reaction time task, but others have not. Other skills, such as global visuo-spatial processing may even be enhanced in dyslexics, although deficits have also been noted. The present study compared dyslexic and non-dyslexic college students on two implicit learning tasks, an alternating serial response time task in which sequential dependencies exist across non-adjacent elements and a spatial context learning task in which the global configuration of a display cues the location of a search target. Previous evidence indicates that these implicit learning tasks are based on different underlying brain systems, fronto-striatal-cerebellar circuits for sequence learning and medial temporal lobe for spatial context learning. Results revealed a double dissociation: dyslexics showed impaired sequence learning, but superior spatial context learning. Consistent with this group difference, there was a significant positive correlation between reading ability (single real and non-word reading) and sequence learning, but a significant negative correlation between these measures and spatial context learning. Tests of explicit knowledge confirmed that learning was implicit for both groups on both tasks. These findings indicate that dyslexic college students are impaired on some kinds of implicit learning, but not on others. The specific nature of their learning deficit is consistent with reports of physiological and anatomical differences for individuals with dyslexia in frontal and cerebellar structures.

Keywords: Implicit learning; Developmental dyslexia; Serial reaction time task; Contextual cueing; Learning disorders; Learning disability

Fluent reading is achieved in a series of stages or phases over a protracted period in childhood via regular instruction and practice (for reviews, see Ehri, 1999) and is accompanied by brain-based changes (Simos et al., 2001; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). However, even with adequate educational opportunity, some children do not become fluent readers; 5–12% of school-aged children are identified with developmental dyslexia (Lyon, 1995; Vellutino, Fletcher, Snowling, & Scanlon, 2004). The most prominent weaknesses of developmental dyslexia are found in word identification, phonological (letter-sound) decoding and spelling. Although adults with developmental dyslexia may compensate in some areas of reading, the cardinal markers observed in childhood, such as poor phonological awareness skills (Bradley & Bryant, 1981), frequently persist into adulthood (Ransby & Swanson, 2003; Shaywitz et al., 1999).

Behavioral studies conducted in children and adults with dyslexia have focused on a diverse set of language and non-language skills. In addition to faulty phonological processing, developmental dyslexia has been described as a reading disorder attributable to other deficits, including impaired temporal processing, magnocellular processing or rapid naming, as well as a lack of automatization or a combination of the above (for reviews, see Eden & Zeffiro, 1998; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Stein & Walsh, 1997; Vellutino et al., 2004; Wolff & Lundberg, 2002). The result is an ongoing

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discussion on the contribution of these observed language and sensorimotor deficits and their potential role in the etiology of dyslexia. Anatomical (Eckert & Leonard, 2000; Eckert et al., 2003; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985) and functional studies in individuals with dyslexia have revealed differences in regions of occipital–temporal, temporo-parietal and frontal regions of the left hemisphere when compared to typical readers. These variations in brain function have been demonstrated while participants engage in cognitive linguistic (Brunswick, McCrory, Price, Frith, & Frith, 1999; Eden et al., 2004; Flowers, Wood, & Naylor, 1991; Rumsey et al., 1992; Shaywitz et al., 1998) as well as sensorimotor tasks (Demb, Boynton, & Heeger, 1998; Eden & Zeffiro, 1998). Taken together, both behavioral and brain-based research indicates that the manifestations observed in dyslexia are complex, making it difficult to provide a unitary account of the etiology of this common and heritable learning disability (Eden & Zeffiro, 1998).

Despite the apparent discrepancies in the field, it is widely accepted that children with dyslexia have impaired phonological awareness. Phonological awareness is the ability to isolate and manipulate the constituent sounds of oral language, and proficiency in phonological awareness is crucial in learning to map alphabetic symbols to sound, leading to successful phonological decoding of text (Vellutino et al., 2004). Further, there is strong evidence of beneficial effects of intervention using phonological awareness training, suggesting a direct causal relationship between phonological awareness skills and learning to read (Alexander & Slinger-Constant, 2004; Torgesen et al., 2001). Yet, little is known about why dyslexic children struggle to learn the code which links graphemes with phonemes, and whether their inability to learn the mapping of alphabetic symbols to sounds is evident in non-linguistic domains of learning. Dyslexia is rarely studied in the framework of the contemporary learning literature. The present research does so via a focus on implicit learning.

Unlike the deliberate and conscious processes that occur in explicit (declarative) learning, implicit learning occurs automatically without the intention to learn or the resulting explicit knowledge of what was learned (e.g., Reber, 1989). Learning to read involves both explicit and implicit processes; children initially learn grapheme–phoneme mappings explicitly after which they apply and continue to learn them implicitly (Gombert, 2003). They also learn the orthography–meaning correspondence explicitly through picture–word matching and implicitly through context.

One could contemplate several mechanisms by which a deficit in implicit learning contributes to difficulties associated with dyslexia, but the small literature on implicit learning and dyslexia has yielded mixed results. Five studies have used the serial reaction time task (SRTT) introduced by Nissen and Bullemer (1987) in which people respond to each of a series of stimuli by pressing a corresponding key. Sequence learning is revealed by a decline in performance when the predictable repeating pattern is replaced by a random sequence. Three of these studies reported an implicit learning deficit in poor readers (Stoodley, Harrison, & Stein, 2006; Vicari et al., 2005; Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003), whereas the other two did not (Kelly, Griffiths, & Frith, 2002; Waber et al., 2003). Two additional studies have used other implicit learning tasks, again with mixed results. Pothos and Kirk (2004) found no reading-related deficits in one version of an artificial-grammar learning task and a significant advantage for dyslexic people on the other version. Yet another study found a relationship between implicit categorical learning and reading ability such that poor readers were impaired in implicit learning, but not explicit learning (Sperling, Lu, & Manis, 2004). And finally, in contrast to most earlier studies that focused on only one kind of implicit learning, Vicari et al. (2005) examined two implicit learning tasks that engage different cognitive skills, serial reaction time and mirror drawing. They found that dyslexic children did more poorly than controls on both tasks, leading them to conclude that dyslexia is characterized by a general deficit in implicit learning.

These findings suggest that it is not enough to compare implicit versus explicit learning or to investigate a single implicit learning task. Thus, in the present study we used two implicit learning tasks that we expect to be differentially affected by dyslexia. The first is an alternating SRTT in which sequential dependences exist across non-adjacent elements (Howard & Howard, 1997; Howard, Howard, Japikse et al., 2004). The second is a spatial context learning task in which the global configuration of a display cues the location of a search target (Chun & Jiang, 1998). These two implicit learning tasks appear to rely on different cognitive skills and different brain regions (Howard, Howard, Dennis, Yankovich, & Vaidya, 2004). Learning of non-adjacent, higher-order, sequential regularities calls on fronto-striatal-cerebellar circuitry whereas spatial contextual learning depends on medial temporal lobe structures (Chun & Phelps, 1999; Prull, Gabrieli, & Bunge, 2000). Cerebellar (Nicolson, Fawcett, & Dean, 2001b) as well as striatal (Vicari et al., 2005) deficits have been associated with dyslexia, but there is no evidence to suggest medial temporal lobe dysfunction in developmental dyslexia. We therefore predicted that poor readers would be impaired on implicit sequence learning, but not implicit spatial context learning. Furthermore, a dissociation between the two types of implicit learning tasks would help to establish that the deficits shown on one implicit learning task are unlikely due to general attention deficits which would presumably influence both tasks.

Both of the implicit learning tasks used in the present study are structured so that predictable and unpredictable trials occur in every block, making it possible to measure pattern learning continuously throughout training. This approach is an improvement over the studies described above in which learning is not measured until a single random block occurs near the end of training. Hence, the present design should be more sensitive to any group differences in the rate of implicit learning. In addition, both tasks have been shown to result in relatively pure implicit learning: subjects are unable to consciously recognize or produce the regularities they have learned at above chance levels (Howard & Howard, 2001; Howard, Howard, Dennis et al., 2004; Howard, Howard, Japikse et al., 2004).

Another new aspect of the present study is that the sequence learning task used here requires that people learn higher-order structure. Unlike the simple repeating sequences in the previous