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The nature and specificity of paired associate learning deficits in children with dyslexia

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ABSTRACT

We report three experiments investigating the specificity and nature of paired associate learning (PAL) deficits in children with dyslexia. Experiments 1 and 2 compared children with dyslexia and age-matched controls across the following stimulus–response mapping conditions, designed to dissociate crossmodal and verbal demands: visual–verbal, verbal–verbal, visual–visual, and verbal–visual. Children with dyslexia exhibited deficits in visual–verbal and verbal–verbal PAL only. Experiment 3 investigated the stage of learning in which PAL deficits arise by separating the verbal learning and associative learning components of a visual–verbal PAL task. Results revealed an item-specific relationship between phonological form learning and later associative learning success. Visual–verbal PAL deficits were fully accounted for by the preceding deficit in phonological form learning. Together, our results show that PAL deficits in dyslexia are not a consequence of difficulties with associative learning; instead, they are best characterized as deficits in phonological form learning. The implications of these findings for theories of reading development and dyslexia are discussed.

Introduction

Paired associate learning (PAL) is thought to tap basic associative learning mechanisms by requiring the pairing of a stimulus and response item in memory. Evidence suggests, however, that not all PAL tasks are created equal when it comes to the relationship with reading ability. Decades of research have documented visual–verbal PAL (i.e., pairing a visually-presented symbol with a verbal output, normally a nonword) deficits in children with dyslexia, despite age-appropriate performance in nonverbal tasks such as visual–visual PAL (i.e., pairing a visually-presented symbol with another visually presented symbol) (Liberman, Mann, Shankweiler, & Werfman, 1982; Messbauer & de Jong, 2003; Vellutino, Steger, Harding, & Phillips, 1975; Vellutino, Steger, & Pruzek, 1973). This reliable pattern of PAL deficits in dyslexia is observed across languages, despite variations in orthographic, phonological, and morphological complexity (Li, Shu, McBride-Chang, Liu, & Xue, 2009; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003). Indeed, across the range of abilities, visual–verbal PAL shares a robust and specific relationship with reading skill (Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Litt, de Jong, van Bergen, & Nation, 2013).

In the dyslexia literature, visual–verbal PAL deficits have typically been interpreted within the phonological deficit hypothesis of dyslexia (Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003, 2006; Vellutino, Scanlon, & Spearing, 1995; Vellutino et al., 1973, 1975). This prominent theory views difficulties in phonological processing as the primary cognitive-level cause of dyslexia (e.g., Fowler, 1991; Snowling, 1995; Snowling & Hulme, 1994). Difficulties with phonological processing can give rise to deficits on any task that places demands on the phonological system, including phonological awareness, verbal short term memory, speech perception and production, naming, and of course, reading and spelling. The finding

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of visual–verbal PAL deficits in children with dyslexia, in the absence of visual–visual PAL deficits fits comfortably within this framework (Messbauer & de Jong, 2003; Vellutino et al., 1973, 1975).

Evidence for the phonological nature of PAL deficits comes from the finding that the errors produced by children with dyslexia are more likely to be phonological, rather than associative in nature (Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003). Additionally, differences between dyslexic and control groups in visual–verbal PAL can largely be accounted for by differences in phonological processing skills (Messbauer & de Jong, 2003, 2006). The importance of phonological skills in determining visual–verbal PAL performance is also observed in typically developing readers. For example, individual differences in phonological skills predict visual–verbal PAL performance (de Jong, Seveke, & van Veen, 2000; Windfuhr & Snowling, 2001). Furthermore, de Jong and colleagues (2000) showed that training in phonological awareness significantly improved visual–verbal PAL performance in kindergartners.

A phonological locus of PAL deficits can also account for the graded pattern of PAL deficits observed in dyslexia. When the verbal response to be learned is a nonword, PAL deficits are both robust and reliable, but when the response to be learned is a word, deficits are more equivocal (Elbro & Jensen, 2005; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003, 2006; Vellutino, Bentley, & Phillips, 1978; Vellutino, Scanlon, & Bentley, 1983; Vellutino et al., 1975). Whether visual–verbal PAL deficits emerge for words seems to depend upon the nature of the verbal stimuli and the degree to which they tax the phonological system (e.g., de Jong et al., 2000; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003, 2006; Vellutino et al., 1995). For example, deficits are observed when stimuli comprise abstract or low frequency words, but are typically absent for concrete words, or words that are high in frequency or imageability (Elbro & Jensen, 2005; Messbauer & de Jong, 2006; Samuels & Anderson, 1973; Vellutino et al., 1995). Such findings suggest that both the phonological demands of the stimuli (e.g., frequency, complexity) and the availability of non-phonological information (e.g., visual, semantic) influence the likelihood of observing PAL deficits in dyslexia. Viewed in this manner, the pattern of deficits observed in visual–verbal PAL seems a natural consequence of the degree to which learning hinges on phonological processes.

Clearly, the verbal component of visual–verbal PAL is crucial to explaining PAL deficits in dyslexia. However, evidence also suggests that visual–verbal PAL may index broader abilities than phonological processing alone. For example, Wimmer, Mayringer, and Landerl (1998) reported PAL deficits in children with dyslexia even when they were matched to controls for phonological awareness. Additionally, visual–verbal PAL accounts for unique variance in reading ability in typically developing readers, above and beyond two of the best known cognitive predictors of reading ability: phonological awareness and rapid automatized naming (RAN) (Hulme et al., 2007; Litt et al., 2013; Warmington & Hulme, 2012; Windfuhr & Snowling, 2001). Thus, although it is tempting to conclude that deficits in visual–verbal PAL (in the absence of deficits in visual–visual PAL) arise as a consequence of the verbal demands that are inherent in visual–verbal PAL, this conclusion is premature. Additional differences between these tasks must not be overlooked. One important difference is that visual–verbal PAL requires crossmodal (between-modality) mappings, whereas visual–visual PAL requires unimodal (within-modality) mappings. Because the contrast between these PAL mapping conditions confounds verbal and crossmodal demands, it does not allow for firm conclusions regarding the locus of PAL deficits in dyslexia.

Some researchers have argued that the crossmodal nature of visual–verbal PAL is central to its association with reading, as both require the establishment of visual-phonology mappings (Hulme et al., 2007; Warmington & Hulme, 2012; Windfuhr & Snowling, 2001). According to their view, visual–verbal PAL taps a crossmodal mapping mechanism akin to that operating in connectionist models of reading, in which learning occurs via the alteration of connection weights between orthographic and phonological units (Hulme et al., 2007; Seidenberg & McClelland, 1989; Snowling, 2000; Windfuhr & Snowling, 2001). Crucially, it is the learning of the *associations* between visual and verbal stimuli, rather than the learning of the verbal stimuli itself, that is proposed to drive the relationship between visual–verbal PAL and reading. The primary evidence for the crossmodal hypothesis comes from a study by Hulme and colleagues (2007), in which the authors examined the specificity of the relationship between visual–verbal PAL and reading in typically developing children. The design included three mapping conditions: visual–verbal, visual–visual, and verbal–verbal. The verbal–verbal PAL task allowed Hulme et al. to evaluate whether crossmodal learning (e.g., visual–verbal), rather than unimodal verbal learning (e.g., verbal–verbal) drives the relationship with reading ability. Although both visual–verbal and verbal–verbal PAL correlated significantly with reading skill, visual–verbal PAL was the only PAL task to predict unique variance in reading ability, consistent with there being a specific role for crossmodal mechanisms in reading.

In contrast, an experiment by Litt and colleagues (2013) is at odds with a crossmodal account of the PAL–reading relationship. The authors included four mapping conditions: visual–verbal, verbal–verbal, visual–visual, and verbal–visual. The addition of verbal–visual PAL to the design allowed for a strong test of the crossmodal hypothesis: if crossmodal associative learning is the crucial component of the task, both visual–verbal and verbal–visual PAL should show robust relationships with reading ability, as both require crossmodal mappings. The results were not in accordance with this hypothesis. Both visual–verbal and verbal–verbal PAL predicted unique variance in reading above and beyond phonological awareness and RAN, whereas verbal–visual and visual–visual PAL were unrelated to reading ability. The lack of a relationship between verbal–visual PAL and reading is difficult to reconcile with the crossmodal hypothesis, as this task, like visual–verbal PAL, has a crossmodal mapping demand. Instead, the results strongly suggest that verbal output demands are responsible for the PAL–reading relationship: both