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Auditory temporal perceptual learning and transfer in Chinese-speaking children with developmental dyslexia

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ABSTRACT

Perceptual learning refers to the improvement of perceptual performance as a function of training. Recent studies found that auditory perceptual learning may improve phonological skills in individuals with developmental dyslexia in alphabetic writing system. However, whether auditory perceptual learning could also benefit the reading skills of those learning the Chinese logographic writing system is, as yet, unknown. The current study aimed to investigate the remediation effect of auditory temporal perceptual learning on Mandarin-speaking school children with developmental dyslexia. Thirty children with dyslexia were screened from a large pool of students in 3th-5th grades. They completed a series of pretests and then were assigned to either a non-training control group or a training group. The training group worked on a pure tone duration discrimination task for 7 sessions over 2 weeks with thirty minutes per session. Post-tests immediately after training and a follow-up test 2 months later were conducted. Analyses revealed a significant training effect in the training group relative to non-training group, as well as near transfer to the temporal interval discrimination task and far transfer to phonological awareness, character recognition and reading fluency. Importantly, the training effect and all the transfer effects were stable at the 2-month follow-up session. Further analyses found that a significant correlation between character recognition performance and learning rate mainly existed in the slow learning phase, the consolidation stage of perceptual learning, and this effect was modulated by an individuals' executive function. These findings indicate that adaptive auditory temporal perceptual learning can lead to learning and transfer effects on reading performance, and shed further light on the potential role of basic perceptual learning in the remediation and prevention of developmental dyslexia.

What this paper adds?

The current research suggested that basic perceptual learning was an efficient tool to empower reading acquisition in children with developmental dyslexia. Executive function is thought to have modulated the transfer, somehow, from perceptual learning to reading development.

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1. Introduction

Developmental dyslexia, affecting about 5%–10% of the population, is a learning disorder characterized by specific difficulty in reading, despite adequate intelligence and extensive practice (Shaywitz & Shaywitz, 2005). In the past decades, longitudinal and training studies have established the core deficit status of phonological processing and showed the remedial effect of phonological intervention in developmental dyslexia (Bradley & Bryant, 1978; Eden et al., 2004; Shaywitz et al., 2004). However, given that reading and phonological processing involve multiple sensory processes (Talcott et al., 2002), the deficits in reading and phonological processing in people with dyslexia may stem from more fundamental deficits in basic sensory processing. A large body of research has indeed demonstrated deficits in auditory temporal processing (Tallal, 1980; Merzenich et al., 1996; Nagarajan et al., 1999), and/or visual processing (Stein & Walsh, 1997) in reading-impaired individuals. Also, the substantial remediation effect of nonlinguistic intervention programs, like auditory temporal training (Fostick, Eshcoly, Shtibelman, Nehemia, & Levi, 2014; Kujala et al., 2001; Murphy & Schochat, 2011; Temple et al., 2003), visual perceptual learning (Chouake, Levy, Javitt, & Lavidor, 2012; Meng, Lin, Wang, Jiang, & Song, 2014; Zorzi et al., 2012), and even action video games (Franceschini et al., 2013), on improving reading performance has been observed in individuals with dyslexia. Among these nonlinguistic intervention protocols, perceptual learning was recently regarded as a possible new prevention and remediation approach for dyslexia, due to its relatively high efficiency and long-lasting effectiveness in improving reading/phonological performance (Gori & Facoetti, 2014).

Perceptual learning is evidenced by a sustainable improvement of perceptual performance as a function of practice (Gibson, 1969), which has been found in various visual tasks involving basic visual features, such as motion direction (Ball & Sekuler, 1987), orientation discrimination (Vogels & Orban, 1985), and texture discrimination (Karni & Sagi, 1991), and auditory tasks mainly incorporating temporal processing/learning, such as temporal order judgment (Bernasconi, Grivel, Murray, & Spierer, 2010; De Martino, Espesser, Rey, & Habib, 2001), and temporal interval discrimination (Huyck & Wright, 2013; Karmarkar & Buonomano, 2003). As a progressive enhancement in perceptual acuity and processing efficiency formed by both explicit instruction and implicit consolidation, the time course of perceptual learning has drawn a great deal of attention (Alain, Snyder, He, & Reinke, 2007; Karni & Sagi, 1993; Molloy, Moore, Sohoglu, & Amitay, 2012; Qu, Song, & Ding, 2010; Yotsumoto, Watanabe, & Sasaki, 2008). Significant improvement in stimulus discrimination has been reported after a short period of exposure (e.g. Poggio, Fahle, & Edelman, 1992). Subsequently, this rapid acquisition process, referred to as fast learning, is followed by a relatively slow phase of accumulation achieved over many more sessions (e.g. Karni & Sagi, 1993; Schoups & Orban, 1996). More importantly, the latter effect proves to last longer after training (Karni & Sagi, 1993; Meng et al., 2014; Polat, Ma-Naim, Belkint, & Sagi, 2004). Fast learning, which is also known as a rapid process of adaptation or habituation, involves a quick establishment of response routine and a dynamic modification of perceptual fields for particular stimuli, while the slow learning process mainly reflects plastic changes in synaptic connectivity that underpins perceptual refinement (Qu et al., 2010). Scores of researchers have pointed out the possible contribution of post-training sleep (behaviorally) (Aeschbach, Cutler, & Ronda, 2008; Deliens, Schmitz, & Peigneux, 2014; Matarazzo, Franko, Maquet, & Vogels, 2008; McDevitt, Rowe, Brady, Duggan, & Mednick, 2014) and neural reorganization in sensory cortices (neurologically) (for visual perceptual learning, see Gu et al., 2011; Shibata et al., 2012; Zohary, Celebrini, Britten, & Newsome, 1994; for auditory perceptual learning, see Fritz, Shamma, Elhilali, & Klein, 2003; Kilgard & Merzenich, 1998; Recanzone, Schreiner, & Merzenich, 1993) during slow learning phase, to the long-term retention of proficiency in specific tasks.

The transfer effect of perceptual learning with nonlinguistic visual or auditory stimuli in ameliorating phonological/reading deficits of dyslexia might be, in a way, supportive of nonlinguistic perspective, which considered the origin of developmental dyslexia as fundamental deficits in sensory information processing (Lin, Wang, & Meng, 2013). Studies gradually established a link between perceptual learning and reading through the observations of visual perceptual learning enlarging visual span size and producing subsequent improvement in reading speed in young children (Chung, Legge, & Cheung, 2004) and older adults (Yu, Cheung, Legge, & Chung, 2010). Other studies revealed similar effects in terms of reading fluency in children with dyslexia (Meng et al., 2014; Wang et al., 2014). Neuroimaging studies have revealed some top-down influences exerted on V1 from later visual processing stages (Chen et al., 2015; Hupé et al., 1998) or fronto-parietal attention networks (Chen et al., 2015; Li, Piech, & Gilbert, 2004; Mehta, Ulbert, & Schroeder, 2000; Mukai et al., 2007). This perceptual learning transfer effect was also reported in auditory temporal training earlier by Tallal and her colleagues (Merzenich et al., 1996; Tallal et al., 1996; Tallal, Miller, Jenkins, & Merzenich, 1997; Temple et al., 2003) and recently by Fostick et al. (2014) and Szelag et al. (2015). Tallal and her colleagues postulated that individuals with dyslexia had a deficit in auditory temporal processing, which can be ameliorated by individually-adaptive stretching auditory stimuli (Gaab, Gabrieli, Deutsch, Tallal, & Temple, 2007; Merzenich et al., 1996; Temple et al., 2003). In Tallal and her colleagues' studies, they utilized comprehensive training protocol involving both pure tone and linguistic materials. In contrast, Fostick et al. (2014) trained adults with dyslexia to discriminate either the temporal order or intensity of two rapidly presented pure tones. They found that only the temporal order training group achieved significant improvement in phonological awareness, while the intensity discrimination group did not show such a transfer, suggesting the effectiveness of pure tone temporal training in ameliorating phonological deficit. Szelag et al. (2015) further found that auditory temporal training significantly improved not only the performances of temporal information processing and auditory comprehension, but also the performance of working memory in both aphasic patients and children with specific language impairment.

Notably, the above-mentioned auditory temporal training studies have mostly been conducted in alphabetic writing systems. Due to the phonological nature of alphabetic language/writing system, researchers postulated that the observed transfer effect of auditory temporal training might result from the enhanced perception of rapid phonological information (Fostick et al., 2014; Tallal et al., 1996). However, whether such training and transfer effect also exist in children with dyslexia who learn logographic writing system, like Chinese, is still unknown.