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# Crossmodal synesthetic congruency improves visual timing in dyslexic children

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ABSTRACT

Consistent with the temporal ventriloquism effect, synesthetic correspondence between the features of visual size and auditory pitch has been shown to modulate the performance of visual temporal order judgment (TOJ) in typical adults. Here in the two main experiments we recruited seventeen dyslexic children and twenty typically developing children to perform a visual TOJ task and measured their ability of synesthetic correspondence between visual size and auditory pitch. In Experiment 1, participants were shown two consecutively presented visual discs that were temporally flanked by two synesthetic congruent or incongruent auditory beeps. In Experiment 2, participants received a crossmodal matching test (visual-size vs. auditory pitch). The results showed that compared to the typically developing group, dyslexic children benefited more from cross-modal synesthetic correspondence to partially compensate for their deficiency in visual TOJ task. The multisensory facilitation for timing performance was correlated with reading ability (Exp.1). Moreover, dyslexic children formed intact "congruent" matching of visually larger shapes to lower auditory pitch, and visually smaller shapes to higher auditory pitch, as did their typically developing peers (Exp 2). The results of our present study suggested general deficits of temporal processing in dyslexic children, However, with relatively intact ability of auditory pitch-visual size matching, dyslexic children could separate visual events using auditory cues. The current study also indicates a feasible way to improve the reading ability by exploiting temporal ventriloquism effect, modulated by appropriate crossmodal synesthetic associations.


## 1. Introduction

Developmental dyslexia is a specific learning disability of reading and spelling which cannot be attributed to low intellectual ability or inadequate schooling, and affects roughly five to ten percent of school children (Demonet, Taylor, & Chaix, 2004; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). Many reading disabilities, especially that of developmental dyslexia, are characterized by audiovisual deficits especially in a context of naturalistic speech and word-like stimulation (Shaywitz et al., 1990) and processing deficits in temporally related tasks, such as temporal order judgments (TOJs), sensory-motor synchro-

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nization, and rhythm coordination (Jaskowski & Rusiak, 2005, 2008; Laasonen, Service, & Virsu, 2002; Virsu, Lahti-Nuuttila, & Laasonen, 2003).

In the last decade, studies of temporal processing in dyslexics have changed focus from the unisensory (visual) domain to a multisensory context, mostly by applying the *temporal ventriloquism effect* to the task of TOJ (Hairston, Burdette, Flowers, Wood, & Wallace, 2005; Harrar et al., 2014; Virsu et al., 2003). In temporal ventriloquism, temporal aspects of a visual stimulus such as its onset, interval, or duration, can be shifted by concurrent task-irrelevant but slightly asynchronous auditory stimuli (Bertelson, 1999; Burr, Banks, & Morrone, 2009; Chen & Vroomen, 2013; Fendrich & Corballis, 2001; Freeman & Driver, 2008; Morein-Zamir, Soto-Faraco, & Kingstone, 2003; Scheier, Nijhawan, & Shimojo, 1999; Shi, Chen, & Müller, 2010; Vroomen and de Gelder, 2004). For example, the perceived onset time of a visual stimulus can be biased by the presentation of a task-irrelevant and slightly asynchronous auditory stimulus (Fendrich & Corballis, 2001; Scheier et al., 1999). Hairston et al. (2005) investigated the role of the temporal ventriloquism effect in studying the effects of task-irrelevant auditory information on the performance of a visual TOJ task. They found that dyslexic subjects' performance differed significantly from that of control subjects. This difference occurred because dyslexics integrated auditory and visual information over longer time intervals (i.e., with expanded temporal windows), and showed low sensitivities for discriminating visual temporal order (Hairston et al., 2005). In a similar vein, Laasonen et al. (2002) examined temporal window of integration (TWIN) in dyslexic adults and age and IQ matched controls using audio-tactile temporal order judgment, and found a relative longer stimulus-onset asynchrony (SOA) for the dyslexic group, indicating the multisensory TWIN is generally larger than the one in unisensory conditions.

Stimuli presented in different sensory modalities can share a number of phenomenological attributes. The discrimination of (visual) temporal order, however, is modulated by the processing of concurrent task-irrelevant (and non-temporal) features of the stimuli presented (Droit-Volet & Gil, 2009; Eagleman, 2008; Kanai, Paffen, Hogendoorn, & Verstraten, 2006; Xuan, Zhang, He, & Chen, 2007). For example, people usually associate higher-pitched sounds with smaller/higher/brighter/sharper objects, and lower-pitched sounds with larger/lower/dimmer/rounder objects (Hubbard, 1996). These associations show the synesthetic correspondence between the physical features in different sensory events. Factors such as pitch/loudness in the auditory dimension with size/brightness in the visual dimension could modulate the strength of the crossmodal temporal capture effect including the temporal ventriloquism effect (Evans & Treisman, 2010; Gallace & Spence, 2006; Guzman-Martinez, Ortega, Grabowecky, Mossbridge, & Suzuki, 2012; Makovac & Gerbino, 2010; Parise & Spence, 2008; Parise & Spence, 2009; Parise & Spence, 2012; Spence, 2011; Sweeny, Guzman-Martinez, Ortega, Grabowecky, & Suzuki, 2012). By testing the normal developing adult subjects, Parise and Spence (2008) used the documented synesthetic association between auditory pitch and visual size to show that synesthetic congruency could modulate TOJ performance. They asked adult participants to execute a visual TOJ task, in which two synchronous/consecutively presented visual flashes (one small, one large) were flanked by two auditory beeps (one of low pitch, the other of high pitch), with 150 ms onset asynchronies in each sound/visual pair. In accordance with the typical ventriloquism effect, they found that participants showed enhanced sensitivities for visual TOJ performance in the presence of the flanked beeps. Moreover, participants were better able to discriminate the temporal order of visual stimuli when the visual size was synesthetically congruent with the auditory pitch, due to increased sensitivity.

The correspondence between orthographic tokens and phonemic utterances is quite basic for a beginning reader. However, individuals with developmental dyslexia show impaired ability as well as weak and less automatic integration of letters and speech sounds (Blau, van Atteveldt, Ekkebus, Goebel, & Blomert, 2009; Goswami, 2002; Hahn, Foxe, & Molholm, 2014; Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Jones, Branigan, Parra, & Logie, 2013; Litt & Nation, 2014). Despite of this, dyslexics can achieve typical levels of accuracy in the associations between letters and sounds (Blomert, 2011). To our knowledge, whether synesthetic correspondence, as a form of cross-modal association is preserved in dyslexics remains largely unknown. Moreover, for dyslexic group, the ability of exploiting crossmodal association to modulate visual temporal processing has received relatively little attention in the literature. Therefore, the empirical question for current study is to ask whether/how young dyslexics lean on crossmodal synesthetic correspondence in visual TOJ and if this timing ability has relevance to the reading ability.

We conducted two experiments to address the above question. We recruited two groups of participants for the study: developing dyslexic children (DD) and their typically developing (TD) peers. In Experiment 1, all participants took part in the task of visual TOJ, in the presence of synesthetically congruent or incongruent auditory-visual associations. Experiment 2 was a control test. We presented auditory and visual stimuli from Experiment 1 to participants and instructed them to choose appropriate visual sizes to match given auditory pitches. For experiment 2, we aimed to determine whether the performance of TOJs in Experiment 1 is dependent on the potential differential ability for forming auditory-visual synesthetic associations.

## 2. Method

### 2.1. Participants

Fourth and fifth grade students were recruited from two local primary schools in Beijing, China to participate in the current study. Seventeen dyslexic children (11 females), with a mean age of 9.96 years old (SE = 0.19) comprised the experimental group. Twenty typically developing children (12 female), with a mean age of 10.16 years old (SE = 0.20) comprised the control group. All participants were native Chinese speakers from families of middle to high socioeconomic status. None of the