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Phonological, temporal and spectral processing in vowel length discrimination is impaired in German primary school children with developmental dyslexia

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ABSTRACT

It is still unclear whether phonological processing deficits are the underlying cause of developmental dyslexia, or rather a consequence of basic auditory processing impairments. To avoid methodological confounds, in the current study the same task and stimuli of comparable complexity were used to investigate both phonological and basic auditory (temporal and spectral) processing in dyslexia. German dyslexic children (Grades 3 and 4) were compared to age- and grade-matched controls in a vowel length discrimination task with three experimental conditions: In a phonological condition, natural vowels were used, differing both with respect to temporal and spectral information (in German, vowel length is phonemic, and vowel length differences are characterized by both temporal and spectral information). In a temporal condition, spectral information differentiating between the two vowels of a pair was eliminated, whereas in a spectral condition, temporal differences were removed. As performance measure, the sensitivity index d' was computed. At the group level, dyslexic children's performance was inferior to that of controls for phonological as well as temporal and spectral vowel length discrimination. At an individual level, nearly half of the dyslexic sample was characterized by deficits in all three conditions, but there were also some children showing no deficits at all. These results reveal on the one hand that phonological processing deficits in dyslexia may stem from impairments in processing temporal and spectral information in the speech signal. On the other hand they indicate, however, that not all dyslexic children might be characterized by phonological or auditory processing deficits.

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1. Introduction

Developmental dyslexia is a specific impairment in learning to read, which does not reflect a general cognitive impairment, and does not result from sensory deficits and/or inadequate schooling (American Psychiatric Association, 1994; Shaywitz, 1998). Longitudinal studies indicate that dyslexia is a persistent condition rather than representing a "transient developmental lag" (Shaywitz & Shaywitz, 2005; Svensson & Jacobson, 2006). Current models of literacy development

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postulate that reading and spelling develop jointly; in different phases of literacy development, reading acts as a pacemaker for spelling, and vice versa (Frith, 1986). Therefore, dyslexia is often accompanied by poor spelling abilities (Shaywitz & Shaywitz, 2005).

Even though there is largely agreement that dyslexia has a neurobiological basis (see Démonet, Taylor, & Chaix, 2004; Habib, 2000, for review), consensus about its exact etiological basis is still lacking. On the behavioural level, dyslexia is mainly characterized by phonological processing deficits (Ramus et al., 2003; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wagner & Torgesen, 1987). These deficits have been found for *phonological recoding in lexical access* in rapid picture naming (e.g. Denckla & Rudel, 1976), in *phonological awareness*, i.e. the ability to consciously access and manipulate the sound units of language (e.g. Bradley & Bryant, 1983), and in *phonological short-term memory*, as assessed by immediate serial recall of unrelated verbal items such as words or digits, or by nonword repetition (e.g. Steinbrink & Klatte, 2008). Dyslexia is also associated with deficits in the *perception of phonemes* (e.g. Godfrey, Syrdal-Lasky, Millay, & Knox, 1981). All these abilities are accomplished on the basis of *phonological representations*. Thus, it can be concluded that the phonological deficit in dyslexia results either from an underspecification of (Adlard & Hazan, 1998; Boada & Pennington, 2006; Elbro & Jensen, 2005; Manis et al., 1997; Mody, Studdert-Kennedy, & Brady, 1997; Swan & Goswami, 1997a, 1997b) or a suboptimal access to these representations (Ramus & Szenkovits, 2008).

It is still debated, however, whether the phonological deficit constitutes the core problem of developmental dyslexia (Snowling, 2000; Stanovich, 1988) or whether it is secondary to more general auditory processing deficits (Ahissar, Protopapas, Reid, & Merzenich, 2000; Lachmann, Berti, Kujala, & Schröger, 2005; Richardson, Thomson, Scott, & Goswami, 2004). The rapid auditory processing theory of dyslexia (Tallal, 1980), for instance, argues that phonological deficits in dyslexia are secondary to low level auditory temporal processing impairments which affect the perception of acoustic elements characterized by rapid transitions or short durations (as in the speech signal). According to this view, a basic temporal processing impairment leads to an inability to integrate sensory information entering the central nervous system in rapid succession. This causes a cascade of effects, starting with disruption of the normal development of the phonological system and subsequent failure to read normally (Tallal, Miller, & Fitch, 1993).

Using non-speech stimuli, a number of psychophysical studies revealed evidence for rapid temporal auditory processing deficits in dyslexic adults (Ben-Artzi, Fostick, & Babkoff, 2005; Laasonen, Service, & Virsu, 2001; see Farmer & Klein, 1995 for review) and children (Cohen-Mimran & Sapir, 2007; Heiervang, Stevenson, & Hugdahl, 2002; van Ingelghem et al., 2001; see Farmer & Klein, 1995, for review). There are, however, also studies in which no such evidence was found (Breier, Fletcher, Foorman, Klaas, & Gray, 2003; Bretherton & Holmes, 2003; Schulte-Körne, Deimel, Bartling, & Remschmidt, 1998).

There are studies in which in one and the same sample non-linguistic material was applied in order to investigate temporal processing, and linguistic material in order to investigate phonological processing. Typically, for both conditions different task demands were applied, e.g. temporal order judgement or gap detection in the auditory condition and tasks such as phoneme deletion, non-word repetition or rapid automatized naming (RAN) in order to measure phonological awareness, phonological short-term memory or phonological recoding in lexical access, respectively. These studies revealed that temporal processing deficits are not related to phonological processing impairments in dyslexia (Bretherton & Holmes, 2003; Nittrouer, 1999) or that phonological deficits can appear in the absence of temporal processing deficits (Boets, Wouters, van Wieringen, & Ghesquière, 2007; Ramus et al., 2003; White et al., 2006).

The interpretation of this pattern of results, however, is difficult, since the phonological vs. temporal processing conditions in these studies do not only differ in the linguistic nature (linguistic vs. non-linguistic), but also in task and stimulus complexity. Both are usually much higher in the phonological condition as compared to the auditory one. This alone might explain why dyslexics showed deficits only in the phonological conditions.

With the aim to overcome these potential methodological confounds, we developed an experimental paradigm in which the same task and the same stimulus material is used to investigate both phonological and basic auditory processing. This paradigm was already used in studies with dyslexic adolescents and adults (behavioural experiments: Christmann et al., submitted for publication; Groth, Lachmann, Riecker, Muthmann, & Steinbrink, 2011; fMRI experiment: Steinbrink, Groth, Lachmann, & Riecker, 2012). As the current behavioural experiment with children employed a methodology that is strictly comparable to that introduced by Groth et al. (2011), we will concentrate in the following on this first study with the vowel length discrimination paradigm, in which two CVC syllables, presented in succession (e.g. /nap/ - /na:p/; /fIp/ - /fi:p/), were used in a *same–different* paradigm in order to test vowel length discrimination abilities in dyslexic adolescents and adults. In German, vowel length discrimination is a phonological task, as the opposition of long and short vowels is phonemic. For example, the vowels within the spoken word pairs *Schiff* (/ʃɪf/, [ship]) vs. *schief* (/ʃi:f/, [askew]) or *kann* (/kan/, [can]) vs. *Kahn* (/ka:n/, [barge]) differ in vowel length.

Three stimulus conditions were applied in Groth et al. (2011): In the first condition (phonological condition) natural speech stimuli were used to form CVC–pseudoword pairs. In German, these natural speech stimuli provide spectral as well as temporal (length) cues for discrimination. In the other two stimulus conditions (temporal conditions), a pair always contained one natural and one manipulated CVC–pseudoword. The manipulation was either a lengthening or a shortening of the quasi-stable phase of the natural vowel to the length of its long or short counterpart, respectively (e.g. long /a:/ was shortened to the length of short /a/ and vice versa). In the temporal conditions, natural and manipulated CVC–pseudowords were always paired in a way that length was the only available cue for discrimination, e.g. by combining a CVC–syllable including an original long /a:/ with a syllable containing the manipulated version of the same vowel, i.e. shortened /a:/.

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