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DEVELOPMENT OF SENSITIVITY TO ORTHOGRAPHIC ERRORS IN CHILDREN: AN EVENT-RELATED POTENTIAL STUDY

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Abstract—To study the development of orthographic sensitivity during elementary school, we recorded event-related brain potentials (ERPs) from 2nd and 4th grade children who were exposed to line drawing of object or animals upon which the correctly or incorrectly spelled name was superimposed. Stimulus-locked ERPs showed a modulation of a frontocentral negativity between 200 and 500 ms which was larger for the 4th grade children but did not show an effect of correctness of spelling. This effect was followed by a pronounced positive shift which was only seen in the 4th grade children and which showed a modulation of spelling correctness. This effect can be seen as an electrophysiological correlate of orthographic sensitivity and replicates earlier findings in adults. Moreover, response-locked ERPs triggered to the children's button presses indicating orthographic (in)-correctness showed a succession of waves including the frontocentral error-related negativity and a subsequent negativity with a more posterior distribution. This latter negativity was generally larger for the 4th grade children. Only for the 4th grade children, this negativity was smaller for the false alarm trials suggesting a conscious registration of the error in these children.

Key words: orthography, dyslexia, event-related potentials, errors.

INTRODUCTION

To write and read correctly, it is important for children to develop an orthographic sensitivity allowing them to identify correctly and, more importantly, incorrectly spelled words. In order to do so, children and adults need to enlist domain general executive functions (Masur et al., 2013) such as error monitoring (Falkenstein et al., 2000; Horowitz-Kraus and Holland, 2015). Indeed, it has been shown that computerized training of basic executive functions via the Reading Acceleration Program improves reading considerably (Breznitz and Bloch, 2008). In the work reported in this paper we seek to delineate electrophysiological correlates of orthographic errors in children early (2nd grade) and later (4th grade) in their reading development. We follow the hypothesis that sensitivity to orthographic errors is paramount to learn to read and write correctly. We further postulate that a lack of sensitivity to orthographic errors might contribute to developmental dyslexia (henceforth dyslexia in this paper).

Dyslexia is a specific deficit in the acquisition of reading and writing that afflicts between 5 and 12% of children (Shaywitz, 1998; Warnke, 1998; Gustafson and Samuelsson, 1999; Katusic et al., 2001; Hasselhorn and Schuchardt, 2006; Landerl and Moll, 2010; Landerl et al., 2013; Moll et al., 2014). A rapid auditory processing deficit has been suggested to underlie dyslexia (Tallal, 1980; Nicolson et al., 2001). In addition, children with dyslexia have impairments in phonological processing, in particular with regard to phoneme awareness (Paulesu et al., 2001; Ramus et al., 2003; Snowling, 2001; Vellutino et al., 2004). Furthermore, it has been suggested that reading and spelling performance depends on ease of lexical access (as measured by naming tasks) and verbal working memory (Jongejan et al., 2007; Pae et al., 2010; Badian, 1996; Georgiou et al., 2012). Please note that in view of the multiple different genetic and neurobiological findings reported in relation to developmental dyslexia (recent review in Ozernov-Palchik et al., 2016), it is likely that multiple cognitive deficits contribute to the development of dyslexia. This is captured, for example, by Pennington's multiple deficit model of developmental disorders (Pennington, 2006) or by van Bergen's 'intergenerational multiple deficit model' of dyslexia (van Bergen et al., 2014).

Important for the current work, Share (1999, 2004, 2008) has pointed out that repeated decoding of words during reading is a pre-requisite for the generation of word-specific orthographic representations. According to the self-teaching hypothesis, a child is able to decode the written form and generate the corresponding spoken form (Jorm and Share, 1983; Share, 1995) and that this situation is the main mechanism to acquire word-specific orthographic representations. The translation of unfamiliar printed words into their corresponding spoken equivalents leads to the acquisition of orthographic representations. Conrad et al. (2013) point out that orthographic knowledge can be defined as "understanding of the print conventions used in a writing system." The acquisition of orthographic representations during primary

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school leads to an orthographic sensitivity at the sublexical and lexical level (Ziegler and Goswami, 2005), allowing the child to determine which spelling of a certain word (phocks or fox?) is correct. It has been pointed out that some conventions or statistical properties of the writing system are available to pre-school children that have not yet received formal reading instruction (e.g.; Cassar and Treiman, 1997; Ouellette and Senechal, 2008; Pollo et al., 2009). Indeed, orthographic knowledge can explain a significant share of reading and spelling ability, even after accounting for phonological processing abilities (Barker et al., 1992; Cunningham and Stanovich 1990; Cunningham et al., 2001).

The influence of orthography on auditory language tasks grows from early to later elementary grades suggesting increased orthographic sensitivity (Ehri and Wilce, 1980; Perin, 1983; Tunmer and Nesdale, 1982; Zecker, 1991). Also, a reduced impact of orthographic representations on auditory processing has been found in children with dyslexia compared to normal reading children (Landerl Frith and Wimmer, 1996; Zecker, 1991).

Interestingly, it has been pointed out that adult dyslexics mainly suffer from slowed reading speed, impaired spelling and reading of pseudo-words (Bruck, 1987; Felton et al., 1990; Shaywitz et al., 1999).

The current work seeks to delineate the development of orthographic sensitivity during elementary school. Automatic word recognition appears to develop between 2nd and 4th grade (Schadler and Thissen, 1981; Ehri and Wilce, 1983). For this to happen, the development of orthographic sensitivity appears to be a prerequisite. This is pointed out by Share (2004): ''Consider the implications for orthographic learning of a child who decodes the word bending as 'ben-ding.' It is these groupings that are perceived as orthographically integrated whole-word units or whole morpheme units by skilled readers . . . The accurate but slow and nonautomatic decoding of adult dyslexics . . . may be an expression of an inability to amalgamate decoded letters into cohesive units."

ERP correlates of orthographic errors

With regard to orthographic errors, a number of ERP studies (Münte et al., 1998; Newman and Connolly, 2004; Sauseng et al., 2004; Vissers et al., 2006; Braun et al., 2009) and fMRI studies (Braun et al., 2015) have addressed the detection of orthographic violations in the form of pseudohomophones. This complements behavioral studies requiring the discrimination of real words from pseudohomophones (e.g., ''rain" vs. ''rane") to study orthographic sensitivity (Olson et al., 1994a,b; Talcott et al., 2000; Goswami et al., 2001; Peterson et al., 2013; Rothe et al., 2015). Phonological analysis alone is insufficient to distinguish pseudohomophones and real words, as they sound the same. Thus orthographic sensitivity is required to perform this task.

One prior study has examined the detection of orthographic errors in children using the ERP technique (Gomez-Velazquez et al., 2013). Specifically, 28 healthy 2nd graders divided into two groups based on their naming performance had to match a line-drawing with a word which either matched the word or was orthographically or semantically incorrect. ERPs from children with average naming performance showed enhanced amplitude for a negativity peaking at 380 ms (N380) and the subsequent positive component for orthographical and semantic errors. Children with slow naming performance showed smaller differences between experimental conditions. Together with the behavioral results, these findings were interpreted to indicate that children from the slow naming group had difficulties to form associations between phonological and orthographic word forms. In a related study, Gonzalez-Garrido et al. (2014) studied three groups of Spanish-speaking high school students of high, medium, and low orthographic knowledge in the same paradigm. Amplitudes of the P150 and P450 components for orthographic errors were enhanced for the High group and the N170, a component often associated with visual word form encoding, was less lateralized to the left hemisphere in the Low group.

ERP correlates of response monitoring

Over the past 20 years, a vast number of cognitive neuroscience papers have addressed aspects of response monitoring. A seminal finding was reported independently by Falkenstein et al. (1991) and Gehring et al. (1992) who found a sharp negativity time-locked to an erroneous response in a choice reaction time task. This error-related negativity has been viewed as a correlate of performance monitoring, occurs over the midfrontal scalp and has been shown to emanate mainly from the anterior cingulate cortex (Van Veen and Carter, 2002; Herrmann et al., 2004). Additional work has shown that similar midfrontal negativities can also be obtained when one observes the errors of another person (van Schie et al., 2004) as well as in situations in which feedback stimuli provide information about the performance quality (Marco-Pallares et al., 2010). Importantly, an ERN-like response is also found for correct responses under certain circumstances (CRN, Mathalon et al., 2003). The CRN has been viewed to reflect the degree of response uncertainty (Allain et al., 2004; Falkenstein et al., 2000), the mismatch between intended and executed responses (Falkenstein et al., 1990) or different degrees of post-response conflict (Carter et al., 1998; Falkenstein et al., 2000). In the present investigation we record response-locked ERPs as we expect response uncertainty and therefore the amplitude of the ERP to vary as a function of reading and spelling ability.

In the present investigation we sought to reconfirm and to extend these earlier findings by recording from children early in their reading and writing development (2nd grade) and more advanced children (4th grade). Second rather than 1st grade children were chosen to represent children early in their development, as 1st graders' abilities might be too low to allow a meaningful investigation. Fourth graders on the other hand are at the transition to secondary school in Germany and are expected to write and read rather fluently. The development of reading and writing in German speaking children from grade 1 to grade 8 has been documented by Landerl and Wimmer (2008). By including these two groups we sought to track the development of ortho-