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The Role of Phonology in the Tuning of Orthographic Representations in Typical and Atypical Readers

PhD Thesis Booklet

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Introduction and main objectives

It is widely accepted that phonology plays a prominent role in both skilled visual word recognition and in learning to read (e.g. Melby-Lervåg et al., 2012). However, skilled reading is also based on high-quality orthographic representations which enable readers to recognize written words quickly and effortlessly. Although phonological processing and its role in visual word recognition has long been the focus of research, far fewer studies have targeted the nature of orthographic representations and their role. Many researchers assume that phonological recoding is involved (Perfetti, 2007) or is the primary way to establish well-specified orthographic representations (Share, 1995). However, the extent to and the circumstances in which phonology plays a role in tuning orthographic representations is not yet determined.

Several studies demonstrated the ubiquitous role of phonology in the development of skilled reading (e.g. Melby-Lervåg et al., 2012; Ziegler et al., 2010). In addition, phonological processing deficits are consistently found in individuals who struggle with learning to read. For instance, a general consensus shared by many researchers is that the core problem in developmental dyslexia is poor phonological processing (Vellutino et al., 2004). Indeed, readers with dyslexia commonly show both phonological awareness and letter-speech sound integration deficits (e.g. (Froyen et al., 2011). However, orthographic processing deficits also can be detected in developmental dyslexia (e.g. (Helenius et al., 1999; Maurer et al., 2007); thus, phonological deficits might interfere with the tuning of orthographic representations.

Moreover, deafness hinders the establishment of phonological representations and results in impoverished phonological processing. Indeed, it is well-established that people born deaf struggle with learning to read (Qi & Mitchell, 2012). Deaf readers usually exhibit poor phonological awareness skills and do not routinely activate phonological codes during silent reading (e.g. Bélanger et al., 2012; Mayberry et al., 2011). Nevertheless, the use of phonological recoding does not seems to be related to reading skills in deaf readers (Bélanger et al., 2012; Gutierrez-Sigut et al., 2017), and deaf individuals mostly exhibit unimpaired orthographic processing skills (e.g. Meade et al., 2020), suggesting that phonology might not be necessary for tuning orthographic processes in some special cases.

Overall, phonology seems to have a prominent role in refining several different orthographic processes. First, exposure to orthographic stimuli during literacy acquisition leads to improved visual perception for letters compared to unknown characters. The electrophysiological marker of this emerging expertise for print is the N170 response, which is usually larger for orthographic stimuli compared to symbol strings over the left posterior-occipital brain regions as early as 150-200 ms after stimulus onset. Although the N170 effect is

considered to reflect visual-orthographic processes, the phonological mapping hypothesis (Maurer & Mccandliss, 2007) suggests that co-activation of phonological representations during reading drives left-hemisphere lateralization of the effect. Thus, phonology seems to tune visual expertise for print, resulting in a left-lateralized N170 response.

Then, the N170 component is not only sensitive to coarse-grained visual expertise for print as indexed by differential processing of letter strings compared to symbol strings but also to fine-grained print tuning as indexed by differential processing of words compared to pseudowords (Eberhard-Moscicka et al., 2016). Maurer and Mccandliss (2007) proposed that the lexicality effect emerges when grapheme-phoneme mapping is not automatic as the lexicality effect is usually present for less skilled readers; thus, fine-grained print tuning might also be tuned by phonological recoding.

In addition, information about letter identity and letter position is essential to distinguish words that are orthographically similar (e.g. “trial”, “triad”, or “trail”). Although most studies concluded that letter position effects are orthographic in nature (e.g. Perea et al., 2011), there is some indirect evidence that hints toward the involvement of phonology in letter identity and letter order processing in skilled reading (Welcome & Trammel, 2017). It is still unknown; however, whether phonological processing directly modulates orthographic processing and it is yet to provide evidence for the contribution of phonological deficits in letter position encoding difficulties.

Finally, even lexical competition between orthographic representations seems to be modulated by phonology. In masked priming lexical decision tasks, orthographically related primes (e.g. ‘bear’) activate the target word (‘pear) and its competitors (e.g. ‘wear’, ‘bead’). Due to sublexical overlap, such orthographic neighbors tend to facilitate target processing, when the prime is a pseudoword (‘zear’). However, when the prime is a word neighbor (e.g. ‘bear’), inhibition at the lexical level overrides sublexical facilitation since the word’s competitors must be inhibited. The differential effectiveness of word versus pseudoword primes is known as the prime lexicality effect (PLE). As Elsherif et al. (2019) reported, the priming effect was also influenced by phonological precision; participants with high phonological precision showed inhibitory priming whereas participants with low phonological precision showed facilitatory priming. This also hints toward the role of phonology in the development of high-quality orthographic representations.

The main aim of this dissertation is to investigate whether phonological processing directly contributes to the development or to the deficit of these orthographic processes by examining typical and atypical readers. For an outline of the studies, see **Figure 1**.

First, we explored how phonological processing contributes to the typical development of orthographic processing. Hence, we investigated whether the emergence of the *visual expertise for print* is driven by orthographic-phonological mapping in typically developing first- and third grade readers. In addition, we also examined how orthographic-phonological mapping contributes to the development of *letter identity coding*.

In **Study 1**, we presented first- and third-graders with pairs of pseudowords and pairs of Armenian character strings in an ERP experiment. We used a novel implicit same-different paradigm in which children indicated whether the stimulus appeared in bold font; thus, the paradigm did not require overt reading. Our hypothesis was that left-lateralized coarse grained (Latin letters vs. Armenian symbols) visual expertise for print is already detectable in these novice readers and the magnitude and lateralization of the N170 effect increases from grade 1 to grade 3. In addition, the stimulus pairs were presented both in a visual-only and an audiovisual condition. The first stimulus of the pair (reference) was always presented visually; however, the second stimulus (target) was presented either visually in the visual-only condition or auditorily in parallel to the visual stimuli in the audiovisual condition. We assumed that if phonology plays a role in the emergence of visual expertise for print, audiovisual presentation of the stimuli enhances the N170 effect. Furthermore, both the pseudowords and Armenian character strings were presented in pairs that could be either identical or different in the identity of one letter. We hypothesized that if phonology exhibits an influence on letter identity processing, audiovisual presentation should increase the difference between identical and one-letter different targets for the Latin but not for the Armenian stimuli for which phonological recoding is not possible. Our results related to these hypotheses are presented in **Thesis 1, 2, 3, and 4.**

Second, we aimed to shed light on whether poor phonological abilities interfere with the tuning of orthographic representations. Thus, to further elaborate on this issue, we examined how phonological deficits in developmental dyslexia influence orthographic processing. The first question to answer was whether the *fine tuning for print and letter identity and letter order coding* show deficiencies in developmental dyslexia. In addition, we also examined how orthographic-phonological mapping contributes to the assumed deficits in the fine tuning for print and those in letter identity and letter order coding.

Thus, in **Study 2**, we presented adults with and without dyslexia with pairs of words and pseudowords in the above described implicit same-different task. Our hypothesis was that if phonology plays a role in the emergence and lateralization of the fine-grained lexical tuning of the N170, readers with dyslexia will show a different N170 lexicality effect than readers

without dyslexia, and they might exhibit less left-lateralized N170 responses. To test whether the N170 lexical effect is driven by automatic phonological recoding, we presented the targets of word and pseudoword pairs in a visual-only and an audiovisual condition. We assumed that audiovisual presentation will enhance the difference in the N170 lexicality effect between readers with and without dyslexia. Furthermore, both the word and the pseudowords pairs could be identical or different in the identity or position of the letters (pair type effect). We hypothesized that if phonology exhibits an influence on letter identity and letter order processing, readers with dyslexia will show different pair type effect than readers without dyslexia. As previous studies reported similar letter identity and letter order processing in readers with dyslexia for words but not for pseudowords, we expected to find these differences for pseudoword pairs only. In addition, we assumed based on the expected role of phonology in tuning orthographic process, that audiovisual presentation would increase the difference found between readers with and without dyslexia in letter identity and letter order encoding. Our results related to these hypotheses are presented in **Thesis 1, 2, 3, and 4.**

Third, we also assumed that the serious phonological deprivation, namely deafness, might also affect the orthographic processing. Thus, in **Study 3**, we reviewed previous studies on deaf readers exhibit both phonological and orthographic processing deficits. To test the role of phonology in the establishment of orthographic representations, we examined the *prime lexicality effect* (PLE), the index of *lexical competition* between high-quality orthographic representations in signing deaf and hearing adult readers.

In **Study 4**, we compared the PLE in deaf and hearing readers in a masked priming lexical decision task. We directly compared the effectiveness of word versus pseudoword neighbor primes to index lexical competition. When the prime is a pseudoword, facilitation occurs due to the overlapping letters; however, when the prime is a real word, lexical competition results in inhibition. Since high-quality lexical representation of the prime yields greater lexical inhibition and results in greater PLE, we assumed that, deaf participants will show reduced PLE compared to the hearing participants if phonological processing is crucial to the development of high-quality lexical representations. In addition, we hypothesized that individual differences in reading and spelling skills modulate the PLE in a way that better readers show greater PLE. To this end, we measured sentence comprehension with a Sentence verification task and orthographic skills with a Proofreading task. Our results related to this hypothesis are presented in **Thesis 5.**

Figure 1 Hypotheses Structure of the Dissertation

Study 1 **Varga, V., Tóth, D., & Csépe, V. (2020). Orthographic-Phonological Mapping and the Emergence of Visual Expertise for Print: A Developmental Event-Related Potential Study. *Child Development, 91*(1), e1–e13.**

Hypothesis:

1. Visual expertise for print is detectable in novice readers; the magnitude and lateralization of the N170 effect increases from grade 1 to grade 3 (**Thesis 1**)
2. Audiovisual presentation of the stimuli enhances the N170 effect (**Thesis 2**)
3. One-letter different targets would increase the N170 response for the Latin but not for the Armenian stimuli (**Thesis 3**)
4. Audiovisual presentation would increase the difference between identical and one-letter different targets for the Latin but not for the Armenian stimuli (**Thesis 4**)

Empirical: Implicit same-different ERP study	**Participants**: **Grade 1** children (N = 24, age = 7.08, years) **Grade 3** children (N = 17, age = 9.29, years)

Study 2 **Varga, V., Tóth, D., Amora, K. K., Czikora, D., & Csépe, V. (2021). ERP Correlates of Altered Orthographic-Phonological Processing in Dyslexia. *Frontiers in Psychology, 12,* Article 723404.**

Hypothesis:

5. Readers with dyslexia will show less left-lateralized N170 lexicality effect than readers without dyslexia (**Thesis 1**)
6. Audiovisual presentation will enhance the difference in the N170 lexicality effect between readers with and without dyslexia (**Thesis 2**)
7. Readers with dyslexia will show deficits in letter identity and letter order processing, especially for pseudoword pairs (**Thesis 3**)
8. Audiovisual presentation will increase the difference between readers with and without dyslexia in letter identity and letter order encoding (**Thesis 4**)

Empirical: Implicit same-different ERP study	**Participants**: Readers **with dyslexia** (N = 25, age = 21.12 years) Readers **without dyslexia** (N = 27, age = 21.89 years)

Study 3 **Varga, V. & Csépe, V. (2018). A szóolvasás modelljei siketek vizsgálatából származó nemzetközi adatok tükrében. *Magyar Pszichológiai Szemle, 73*(2), 299–313.**

Theoretical: comprehensive review	**Groups**: **Deaf** readers / **Hearing** readers

Study 4 **Varga, V., Tóth, D., & Csépe, V. (2021). Lexical Competition Without Phonology: Masked Orthographic Neighbor Priming With Deaf Readers. *Journal of Deaf Studies and Deaf Education*, enab040**

Hypothesis:

9. Deaf participants will show reduced PLE compared to the hearing participants (**Thesis 5**)
10. If lexical competition is based on high-quality orthographic, individual differences in reading and spelling skills modulate the PLE (**Thesis 5**)

Empirical: Masked priming lexical decision task	**Participants**: **Deaf** reader (N = 28, age = 44.89 years) **Hearing** readers (N = 28, age = 44.96 years)

Thesis 1: Visual expertise for print is not but its lateralization is impacted by phonological deficits

In **Study 2**, we investigated fine-grained visual expertise for print as indexed by the differential N170 response for words and pseudowords. In our study, participants with dyslexia exhibited deficits in both reading fluency and phonological awareness. Neither readers with dyslexia nor skilled readers showed a significant fine-grained visual expertise for print, indicating that readers with and without dyslexia processed words and pseudowords similarly. However, the N170 responses of readers with dyslexia showed a bilateral distribution. In contrast, readers without dyslexia exhibited the typical left-lateralized N170 response. In addition, in **Study 1**, both typically developing first- and third-grade children exhibited a left-lateralized N170 response for pseudowords but not for Armenian symbol string (coarse-grained visual expertise for print), indicating the responses for orthographic stimuli is left-lateralized in typical readers already after some months of reading instruction.

Publications related to this thesis point:

Varga, V., Tóth, D., & Csépe, V. (2020). Orthographic-Phonological Mapping and the Emergence of Visual Expertise for Print: A Developmental Event-Related Potential Study. *Child Development, 91*(1), e1–e13. https://doi.org/10.1111/cdev.13159

Varga, V., Tóth, D., Amora, K. K., Czikora, D., & Csépe, V. (2021). ERP Correlates of Altered Orthographic-Phonological Processing in Dyslexia. *Frontiers in Psychology, 12*, Article 723404. https://doi.org/10.3389/fpsyg.2021.723404

Thesis 2: Print tuning is enhanced by audiovisual integration in typical readers but not in readers with dyslexia

In **Study 1**, novice readers exhibited larger N170 responses for pseudowords than for Armenian symbol string (coarse-grained print tuning). Moreover, when targets were presented audiovisually, the N170 effect was enhanced compared to the visual-only condition. In **Study 2**, neither readers with dyslexia nor skilled readers showed an N170 lexicality effect (fine-grained print tuning). However, when targets were presented audiovisually, group differences in the lexicality effect emerged. Audiovisual presentation of targets resulted in a robust lexicality effect for skilled readers signified by larger N170 responses to words than to pseudowords. In contrast, presenting targets audiovisually did not enhance the lexicality effect for readers with dyslexia.

Publications related to this thesis point:

Varga, V., Tóth, D., & Csépe, V. (2020). Orthographic-Phonological Mapping and the Emergence of Visual Expertise for Print: A Developmental Event-Related Potential Study. *Child Development, 91*(1), e1–e13. https://doi.org/10.1111/cdev.13159

Varga, V., Tóth, D., Amora, K. K., Czikora, D., & Csépe, V. (2021). ERP Correlates of Altered Orthographic-Phonological Processing in Dyslexia. *Frontiers in Psychology, 12*, Article 723404. https://doi.org/10.3389/fpsyg.2021.723404

Thesis 3: Letter identity coding develops slowly; however, letter identity and letter order processing is not impacted by phonological deficit

In **Study 1**, we presented novice readers with pseudoword pairs and pairs of Armenian character strings that could be either identical or different in the identity of one letter in order to investigate the development of automatic letter identity coding. We found a pair type effect due to smaller responses evoked by identical pairs compared to one letter different pairs. However, this effect was highly similar for pairs of pseudowords and pairs of Armenian character strings. The interaction between stimulus type and pair type was weak and restricted to a few channels for both first grade and third grade readers, suggesting that the pair type effect was driven by general visual processes and automatic letter coding is not fully developed even by Grade 3. In **Study 2**, we investigated letter identity and letter order processing in readers with and without dyslexia for both word and pseudoword pairs. We found that identical pairs evoked smaller responses in the N1 time window compered to different pairs (both letter identity and letter order different pairs) regardless of their lexicality (word versus pseudoword). This was the case for the participants both with and without dyslexia. Thus, readers with and without dyslexia did not differ in letter identity and letter order processing, not even for pseudoword stimuli.

Publications related to this thesis point:

Varga, V., Tóth, D., & Csépe, V. (2020). Orthographic-Phonological Mapping and the Emergence of Visual Expertise for Print: A Developmental Event-Related Potential Study. *Child Development, 91*(1), e1–e13. https://doi.org/10.1111/cdev.13159

Varga, V., Tóth, D., Amora, K. K., Czikora, D., & Csépe, V. (2021). ERP Correlates of Altered Orthographic-Phonological Processing in Dyslexia. *Frontiers in Psychology, 12*, Article 723404. https://doi.org/10.3389/fpsyg.2021.723404

Thesis 4: Letter identity and letter order processing is modulated by audiovisual integration

In **Study 1**, we investigated whether audiovisual presentation of the target enhance the difference between identical and one-letter different targets in novice readers, especially for the Latin stimuli. As the auditory pseudoword target was always identical to the visual reference stimulus, audiovisual presentation resulted in a double mismatch between different reference–target pairs: first, between visual reference and visual target stimuli; second, between the visual target and auditory target. Therefore, we expected this double mismatch to enhance the pair type effect for pseudowords where grapheme-phoneme mapping is possible. However, while the visual expertise for print was clearly enhanced (see Thesis 2), pair type effect was quite diminished by audiovisual presentation presumably due to slow integration between the visual reference and the auditory target.

In **Study 2**, we assessed whether audiovisual presentation increases the difference between readers with and without dyslexia in letter identity and letter order coding as should be the case if phonology modulates orthographic processing. Indeed, audiovisual presentation of the target stimuli resulted in differential pair type effect for readers with and without dyslexia. In this version of the same-different task, the auditory stimuli were always identical to the visually presented target stimuli; thus, the pair type effect reflected a mismatch between the visual reference and the (visual and audiovisual) target. Readers without dyslexia showed a pair type effect in the visual condition; however, this effect disappeared when the target was presented audiovisually presumably due to the prompt integration between the visual target and the auditory target. In contrast, for readers with dyslexia the orthographic mismatch between the reference and target stimuli (identical versus different pairs) was enhanced by audiovisual presentation presumably due to sluggish audiovisual integration.

Publications related to this thesis point:

Varga, V., Tóth, D., & Csépe, V. (2020). Orthographic-Phonological Mapping and the Emergence of Visual Expertise for Print: A Developmental Event-Related Potential Study. *Child Development*, *91*(1), e1–e13. https://doi.org/10.1111/cdev.13159

Varga, V., Tóth, D., Amora, K. K., Czikora, D., & Csépe, V. (2021). ERP Correlates of Altered Orthographic-Phonological Processing in Dyslexia. *Frontiers in Psychology*, *12*, Article 723404. https://doi.org/10.3389/fpsyg.2021.723404

Thesis 5: Phonology contributes to lexical competition; however, lexical competition does not index orthographic quality in deaf readers

As we concluded in **Study 3**, phonological and semantic processing seems to be hindered by deafness, but orthographic processing is intact even in the absence of hearing, indicating that orthographic representations can be acquired without phonology. To elaborate on this, in **Study 4**, we compared the prime lexicality effect (PLE), the index of lexical competition, in deaf and hearing adults. Our results demonstrate that although hearing university students exhibited a robust PLE, deaf participants showed no evidence for PLE, while the group of hearing readers matched in age and education level also exhibited a reduced effect. Absence of PLE in deaf readers suggests that limited access to phonology hinders the emergence of lexical competition; thus, lexical competition emerges partly on the phonological level. However, the effect was differentially modulated by reading skill for the deaf and the hearing control participants. Better hearing readers showed PLE, while this was not the case for better deaf readers. More importantly, hearing readers with better orthographic skills as measured by the Proofreading task showed greater PLE, while deaf readers with better orthographic skills did not, suggesting that high-quality orthographic representations are not necessarily built through phonology in deaf readers.

Publications related to this thesis point:

Varga, V., & Csépe, V. (2018). A szóolvasás modelljei siketek vizsgálatából származó nemzetközi adatok tükrében. *Magyar Pszichológiai Szemle*, *73*(2), 299–313. https://doi.org/10.1556/0016.2018.005

Varga, V., Tóth, D., & Csépe, V. (2021). Lexical Competition Without Phonology: Masked Orthographic Neighbor Priming With Deaf Readers. *Journal of Deaf Studies and Deaf Education*, enab040. https://doi.org/10.1093/deafed/enab040

Discussion

The main findings of the present dissertation are first that phonological processing supports but does not drive the development visual print tuning. Nonetheless, phonological processing drives the lateralization of the print N170 effect. Phonology also modulates letter identity and letter order processing, but letter identity and letter order processing skills can develop despite phonological processing deficits. Finally, lexical competition is driven by phonology; however, deaf readers can still develop high-quality orthographic representations.

Altogether, our results point to the conclusion that phonology is directly involved in tuning the development of orthographic representations, at least in typically developing children. However, our finding on adults with dyslexia suggests that orthographic processes can adequately develop despite phonological processing deficits; though audiovisual presentation still modulates orthographic processing and results in orthographic processing differences between readers with and without dyslexia. Similar conclusions emerged from the studies on deaf readers. Our results on lexical competition indicated that hearing readers with better orthographic skills showed greater lexical competition, while deaf readers with better orthographic skills did not, suggesting that their orthographic representations are developed in a qualitatively different way.

Thus, the findings of the present dissertation suggest that phonological processing supports but does not drive the tuning of orthographic representations. Based on these results presented in the dissertation, I propose that phonology facilitates the acquisition of orthographic representations; however, if phonology is less available, orthographic representations can still develop through alternative pathways.

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