Neurophysiological studies of reading fluency

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Summary

Developmental dyslexia is a neurobiologically based learning disorder that impairs a child's ability to read and write. To minimize the detrimental effects of dyslexia, it is important to provide optimal intervention at the youngest possible age. Early diagnosis of dyslexia, which is a prerequisite for early intervention, is thus called for. In this light, event-related potential (ERPs), i.e., electrical brain responses registered at the scalp, are particularly useful in distinguishing poor from normal readers at the initial stage of reading acquisition. This is because ERPs can be elicited using non-attentive paradigms and hence are less contaminated by confounding factors such as task demand, attention and motivation than behavioural measurements. In the current PhD project, we therefore used ERPs to investigate early neurophysiological markers of dyslexia in beginning readers of Dutch (second graders).

Chapter 1 provided theoretical backgrounds of the studies reported in this thesis. One of the most influential theoretical accounts of reading, the dual route cascaded (DRC) model (Coltheart, Rastle, Perry, & Langdon, 2001), proposes that skilled reading proceeds in two pathways, i.e., a lexical/orthographic route supporting whole word recognition and a sublexical/phonological route converting letter strings into phonological representations. While the former requires fast, automatic recognition of visual word forms, the latter necessitates mastery of grapheme-to-phoneme conversion rules, for which intact auditory discrimination is a pre-requisite (impaired auditory discrimination leads to underspecified phonological representations). In the following chapters, we thus investigated early markers of dyslexia in two domains, i.e., visual word recognition and auditory discrimination. A major methodological contribution of this dissertation is that we used generalized additive modelling (GAM; Wood, 2006) to analyse the ERP data. As a nonlinear regression approach, GAM can be used to model the complete, nonlinear shape of the ERP signal over time. Moreover, by accommodating nonlinear interactions, GAM allows us to use raw reading scores, rather than the categorical factor "control vs. dyslexic", to index reading ability. In this way, we are able to characterize the relation between reading fluency and the ERP patterns of interest on a continuous, fine-grained scale.

Chapter 2 aimed to investigate the relation between fast visual specialization for print (words or word-like letter strings) and reading fluency. When presented with print, fluent adult readers activate fast, specialized visual brain processes, which underlie the basis for efficient recognition of print input. At the neurophysiological level, specialized visual processing of print is indexed by the N170 ERP component: in alphabetic languages, print consistently elicits larger N170 responses than visual baseline (e.g., symbols), especially in the left hemisphere. Such a tuning effect develops rapidly within the first two years of schooling in typically developing children, and is believed to reflect reading expertise associated with one's own language. The finding of absent/attenuated tuning effect in children with dyslexia, on the other hand, has generated expectations that the print N170 may help distinguish poor from normal readers at an early age. In this study, we thus investigated whether the N170 print tuning effect has already merged in beginning readers of Dutch, and, if yes, whether the size and the lateralization pattern of this tuning effect are systematically related to reading fluency. To fulfil these objectives, we recorded the ERPs of a group of Dutch children with varying reading abilities while they were performing a repetition detection task with words, pseudowords and symbol strings. Offline analyses of the ERP data (using GAM) demonstrated a robust N170 print

tuning effect in the left hemisphere, as well as a positive, almost linear relation between reading fluency and the size of the tuning effect. Overall, our findings lend support to the validity of the N170 print tuning effect as a neurophysiological marker of emerging dyslexia.

Chapter 3 aimed to investigate the relation between auditory discrimination and reading fluency. Converging evidence from research on the aetiology of developmental dyslexia has pointed to deficient phonological processing, which itself may originate from a more fundamental deficit in auditory perception and discrimination. At the neurophysiological level, the ERP component indexing the accuracy of auditory discrimination is the mismatch negativity (MMN). So far, the literature on MMN studies with dyslexics has been highly inconsistent, with some studies finding reduced MMN in the dyslexic group and others finding normal MMN. This disparity is partly caused by methodological differences across studies regarding, for example, deviance size (the size of the difference between standard and deviant stimuli), temporal/spectral features of stimulus materials, and time window of analysis. In the current study, we aimed to test whether the presence/size of the mismatch negativity can reliably distinguish poor from normal readers. To fulfil this objective, we used a passive oddball paradigm to elicit mismatch responses. Both speech (syllable) and nonspeech (tone) stimuli were used, with the size of the deviant stimulus manipulated. Overall, the size of the mismatch response was not systematically related to reading score in either condition. For the tones, exploratory analyses revealed a positive, albeit moderate, correlation between reading score and the size of the MMN to small deviants in the left hemisphere. For the syllables, mismatch responses were found, also for small deviants, at midline electrodes in time windows corresponding to the classic MMN and a late discriminative negativity (LDN); the size of these mismatches, however, was not reliably related to reading performance. Taken together, these findings do not support the validity of the mismatch response as a neurophysiological marker of dyslexia: the relation between reading fluency and the presence/size of the mismatch response is not robust and is highly dependent on a wide range of methodological factors.

Chapter 4 aimed to investigate N170 tuning for print in Chinese. So far, print-tuning studies in non-alphabetic languages have been scarce and tended to yield inconsistent results, especially regarding the lateralization pattern of such a tuning effect. Moreover, it remains difficult to control for confounds of low-level stimulus features. Clearly, additional studies are needed to investigate N170 tuning for print in non-alphabetic languages. The outcome of such research may also shed light on the underlying mechanism of neural specialization for print, i.e., whether the print N170 is triggered by grapheme-to-phoneme conversion or by visual familiarity with a particular script. Motivated by such a scenario, in the current study we investigated N170 tuning for logographic Chinese and for *pinyin*, a phonetic system that transcribes Chinese characters into Latin alphabet. Different from previous print-tuning studies in Chinese, we adopted a cross-linguistic design in which native Chinese adults and Dutch adults (who could not read Chinese) detected immediate repetitions with logographic characters, pinyin and symbol strings. Since the two groups viewed the same set of stimuli, any between-group difference in their patterns of tuning, as indexed by the contrast between print (character or pinyin) and control stimuli (symbol string), must be triggered by their differential experience with the Chinese script rather than by differences in low-level stimulus features between print and control stimuli. We found that both groups responded more strongly to characters than to symbols, but the character – symbol difference was significantly left lateralized in the Chinese group only; the Dutch group demonstrated a bilateral topography instead. With respect to pinyin, both Chinese and Dutch participants showed larger N170 responses to pinyin than to symbol strings; the left-hemispheric modulation, however, was absent in both groups, presumably because it is uncommon to process pinyin in long strings. Taken together, our findings suggest that logographic characters evoke enhanced, left-lateralized N170 responses as do alphabetic words, and that such a tuning effect is clearly driven by script familiarity, rather than by differences in visual features between print and control stimuli. Since grapheme-to-phoneme conversion seldom exists in logographic Chinese, our results tend to support the visual familiarity account of the print N170. We acknowledge however, that phonological activation in general, if not grapheme-phoneme conversion in particular, may also contribute to the N170 print-tuning effect.

Chapter 5 concluded the dissertation with a general discussion of all findings collected. Along both lines of research, i.e. visual word recognition and auditory discrimination, we assessed very basic aspects of perceptual processing that constitute critical first steps in deciphering visual/oral language codes. The reason for this selection is twofold. First, given our dedication to *early* diagnosis of developmental dyslexia, it is important to focus on aspects of perceptual/language processing that can be easily tested with ERPs under non-attentive paradigms. Secondly, since several widely-implemented remediation programs are based on the assumption of basic visual or auditory perception deficits in dyslexia, it is crucial to examine the empirical basis of these intervention plans. Overall, our findings suggest that the N170 print tuning effect is a valid neurophysiological indicator of dyslexia, one that can be readily elicited by implicit reading tasks and robustly detected at the individual level. On the other hand, the relation between reading ability and the mismatch negativity is less systematic, and is highly dependent on a series of methodological factors. All in all, the outcome of this thesis contributes to the understanding of the neurobiology of normal and impaired reading acquisition. In particular, the application of GAM illustrates an innovative way of studying the nonlinear dynamics of brain activities on a fine-grained, continuous scale.