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First and second language in the brain: Neuronal correlates of language processing and spelling strategies

Patricia Weber[a], Nadja Kozel[a], Christian Purgstaller[b], Reinhard Kargl[b], Daniela Schwab[a], Andreas Fink[a,*]

[a] Institute of Psychology, University of Graz, Austria
[b] Institute for Reading and Spelling, Graz, Austria

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ABSTRACT

This study explores oscillatory brain activity by means of event-related synchronization and desynchronization (%ERS/ERD) of EEG activity during the use of phonological and orthographic-morphological spelling strategies in L2 (English) and L1 (German) in native German speaking children. EEG was recorded while 33 children worked on a task requiring either phonological or orthographic-morphological spelling strategies. L2 processing elicited more theta %ERS than L1 processing (particularly at bilateral frontal and right posterior parietal sites) which might suggest a stronger involvement of semantic encoding and retrieval of the less familiar L2. The highest level of theta %ERS was revealed for the orthographic-morphological strategy in L2 which might indicate a more intense way of lexical retrieval compared to the phonological strategy in L2 and the orthographic-morphological strategy in L1. Analyses moreover revealed that phonological processing (both in L1 and L2) was associated with comparatively strong left-hemispheric %ERD in the upper alpha frequency band.

1. Introduction

Language is one of the most important aspects of communication, and it becomes more and more important to know a second language. Though relevant research in this field has rapidly grown, no consistent picture about potential neural mechanisms underlying the processing of second language appears to exist. Instead, there are different hypotheses of how languages are stored and processed in the human brain (for review see Fabbro, 1999; cf. Midgley, Holcomb, & Grainger, 2009). The representation of L1 and L2 in the brain may also be influenced by the level of advancement in language acquisition. Different spelling strategies might be used in different stages of language acquisition, and thus may influence the neuronal activity network. In the present study, neurophysiological correlates of processing first (L1) and second language (L2) in school-age children were investigated. Additionally, we specifically aimed at characterizing neuronal substrates of phonological and orthographic-morphological strategies involved in L1 and L2.

1.1. Theoretical framework

1.1.1. Phonological and morphological spelling strategies

Phonological awareness describes the ability to analyze sound units in words, such as syllables or phonemes (Klicpera, Gasteiger-Klicpera, & Schabmann, 2007), whereas morphological awareness refers to the ability to understand the structure of a word as a combination of morphemes (the smallest lexical units) and to manipulate these (Bhatt, 1991). It has been shown that morphological awareness plays an important role in reading development and contributes uniquely to spelling (Apel, Wilson-Fowler, Brimo, & Perrin, 2011; Deacon & Kirby, 2004; Nagy, Berninger, & Abbott, 2006; Siegel, 2008). Morphological and phonological awareness induce different spelling strategies. In applying the phonological spelling strategy, an individual uses the phoneme structure to spell words. This is often accompanied by phonologically plausible errors (e.g. “flood” → flud). Morphological spelling strategy is based on the morpheme structure of a word even if the articulation differs (e.g. “heal” – “health”). Phonetic spelling involves spelling a word purely from its sound but words comprising more than one morpheme often lead to morphematic spelling errors if solely the phonological strategy is applied (e.g. the double consonant in really is caused by the adding of the suffix “ly”. Children solely applying the phonological strategy will not be able to spell it correctly).

However, considering that different languages have different orthographies and different grapheme–phoneme mapping consistencies at the morphological level, morphological awareness in literacy acquisition may considerably vary across different languages. English has more sounds than most other languages and contains many irregular words in speech and writing due to the inconsistency in phonetic representation (Holland & Kaasa, 2005). Depending on the orthographic transparency level (graph-

* Corresponding author. Address: Institute of Psychology, Karl-Franzens-University of Graz, Universitaetsplatz 2/III, A-8010 Graz, Austria.
E-mail address: andreas.fink@uni-graz.at (A. Fink).

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eme–phoneme consistency) of the language, it might be possible that different reading and spelling strategies are used in the course of literacy acquisition (Ziegler & Goswami, 2005).

1.1.2. First and second language acquisition

There are different theoretical perspectives concerning reading and spelling development in L1. One perspective is that literacy development is an interrelated process of several metalinguistic skills across time, such as phonological, orthographical and morphological skills (cf. Berninger, Abbott, Nagy, & Carlisle, 2010). On the contrary, developmental stage theories assume that children acquire language in interdependent steps, with morphological awareness usually contributing later to literacy development than phonological awareness (e.g. Frith, 1985; cf. May, Vieluf, & Malitzky, 2000). With respect to second language acquisition, it has generally been shown that abilities in L1 and L2 are related (cf. Cummins, 1979, 2009; cf. Jeuk, 2010). Hierarchical models of L2 acquisition concerning the organization of L1 and L2 lexica, such as the "revised hierarchical model" by Kroll and Stewart (1994) suggest that L2 words are linked to L1 words as well as to the general semantic concept (cf. French & Jacquet, 2004). In the initial stage of L2 acquisition, L2 words are processed by directly translating them through the corresponding L1 words, whereas with increasing language fluency (proficiency) lexical items become more concept-mediated without translation (Kroll & Stewart, 1994).

1.2. Neurophysiological framework

1.2.1. Language processing in L1 and L2

Several studies have provided evidence of specific brain regions involved in language processing. A network which was often found to be involved in reading and in integrating letters was located in posterior (e.g. parietotemporal, occipitotemporal) brain areas of the left hemisphere (e.g. Hoeft et al., 2006; Shaywitz et al., 2007; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). Also, during language comprehension and/or production a primarily left hemispheric frontal and temporal network seems to be activated (for reviews see Gernsbacher & Kaschak, 2003; Goulven & Tzourino-Mazoyer, 2004). Regarding phonological awareness, it has been shown to be associated with activation in the left posterior network, including, among others, posterior temporal regions and the occipitotemporal cortex in children (Frost et al., 2009; Turkeltaub et al., 2003).

With respect to second language research, a controversial picture of whether L1 and L2 processes are represented separately in the human brain or share a common neural network emerges (for reviews see Indefrey, 2006; Perani & Abutalebi, 2005). One of the reasons for this discrepancy could be seen in the fact that the subject populations tend to vary more than in monolingual studies due to differences in age of L2 acquisition and variations of the L2 proficiency level (cf. Indefrey, 2006).

Results of bilingual hemodynamic neuroimaging studies using techniques such as functional magnetic resonance imaging (fMRI) or positron emission tomography (PET) were summarized by Indefrey (2006). He concludes that even though many studies find no differences between L1 and L2 processes, anatomical overlaps of hemodynamic activation patterns for certain subgroups of bilinguals are evident. Especially low proficient L2 speakers showed higher levels of activation during L2 than L1 processing.

Concerning quantitative differences between L1 and L2 processing it is suggested that the language network for L1 and L2 is used differently which seems to be the case especially for low proficient L2 speakers (e.g. Midgley et al., 2009; see also Stowe & Sabourin, 2005).

Overall, there is evidence that when processing L2, the same neuronal substrates as in L1 are involved but used in a quantitatively different way which is also related to the proficiency level and the kind of language processes (e.g. Midgley et al., 2009; for reviews see Kaan, 2007; Stowe & Sabourin, 2005). It can be assumed that L1 language areas are used less efficiently in L2 (cf. Kaan, 2007; cf. Stowe & Sabourin, 2005).

Most of the L2 studies involve different characteristics of participants and other factors, which might influence neuronal activity, e.g. the proficiency level, the age of L2 acquisition, exposure to L2, similarities between L1 and L2, and the different kinds of tasks requiring different language processes. In view of that, it appears difficult to generalize these findings (cf. Stowe & Sabourin, 2005).

In order to achieve a better overall understanding of language processes and to supplement the above findings other methods might be also helpful to capture the dynamics of language processes in the brain, such as the analysis of event-related desynchronization or synchronization of EEG activity, as used in the present study.

1.2.2. Event-related desynchronization/synchronization

Event-related desynchronization (%ERD; Pfurtscheller & Aranibar, 1979) describes a short-lasting and localized attenuation or blocking of rhythmic oscillatory activity (decrease) linked to an internally or externally-paced event (e.g. experimental task). On the contrary, event-related amplitude enhancement is described as %ERS (event-related synchronization; Pfurtscheller, 1992) and depicts an increase of oscillatory activity. A striking advantage of the %ERD/ERS measurement is its high frequency band specificity (Pfurtscheller & Lopes da Silva, 1999). Within the broad range of the alpha frequency band (about 7–12 Hz), it has been shown that at least two frequency bands can be distinguished that seem to reflect different processes (e.g. Fink, Grabner, Neuper, & Neubauer, 2005; Klimesch, Pfurtscheller, Mohl, & Schimke, 1990). It is assumed that EEG activity in the lower alpha frequency band reflects general task demands such as attentional processes and is topographically widespread over the entire scalp, whereas EEG activity in the upper alpha frequency band (about 10–12 Hz) is more often found to be topographically restricted, and is rather sensitive to stimulus-related effects and to sensory-semantic memory processes (for a review see Klimesch, 1999). Theta power (about 4–6 Hz) was found in various linguistic experimental tasks indicating that different kinds of language processing are reflected in theta oscillatory activity (e.g. Bastiaansen, van Berkum, & Hagoort, 2002; Bastiaansen, Van der Linden, Ter Keurs, Dijkstra, & Hagoort, 2005; Klimesch et al., 2001). Event-related changes within the theta frequency band seem to be related to the storage and the retrieval of information from long-term memory (cf. Klimesch, 1999). More specifically, theta power was found to be involved in the retrieval of lexical information from the mental lexicon (at least in L1; Bastiaansen & Hagoort, 2006) and in encoding new information in verbal and visual working memory (Klimesch et al., 2001; Spironelli, Penolazzi, & Angrilli, 2008).

1.2.3. Event-related desynchronization/synchronization in language processing

Several authors analyzed %ERD/ERS during L1 processing. Specifically, %ERD/ERS in language comprehension was studied, where it is assumed that memory retrieval processes are activated in order to provide information about phonology, semantics and syntax of the lexical items (cf. Bastiaansen & Hagoort, 2006; cf. Hagoort, 2005). Bastiaansen, Oostenveld, Jensen, and Hagoort (2008) for example presented a visual lexical decision task in form of real words and pseudowords (incorrect letter strings, but phonologically legal). An alpha power decrease in occipital areas was found bilaterally, often related to visual processing (e.g. Bastiaansen &