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First and Second Language in the Brain: Neuronal Correlates
of Language Processing and Spelling Strategies

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Abstract

Up to today, there is still little known about the dynamics of second language (L2) processes. This study explores for the first time oscillatory brain activity by means of event-related synchronization and desynchronization (%ERS/ERD) of L2 (English) processes in native German (L1) speaking children. Specifically, potential differences in oscillatory EEG dynamics between phonological and orthographic-morphological spelling strategies in L1 and L2 processes were examined. %ERS/ERD was recorded for theta (4 – 7 Hz) and two alpha frequency bands (7 – 10 Hz and 10 – 13 Hz), while 33 children were working on a task requiring either phonological or orthographic-morphological spelling strategies. Generally, it was observed that L2 processing elicited more theta %ERS than L1 processing which suggests a stronger involvement of processes such as semantic encoding and retrieval of the less familiar L2. The highest level of theta %ERS was revealed for the 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 of the lower alpha frequency band revealed a higher level of lower alpha %ERD in L1 compared to L2. This could be related to a limited elaboration of L2 due to the lower proficiency level of the subjects in L2 compared to L1. Stronger upper alpha %ERD was observed in posterior regions which may indicate visual and word form processing.

Keywords: EEG, ERS/ERD, Alpha, Theta, Second language, Spelling strategies

Zusammenfassung

Bis heute besteht kein einheitliches Bild über die kortikale Organisation von Zweitsprachen. Die vorliegende Studie untersuchte erstmals anhand von EEG-Synchronisation und -Desynchronisation (event-related synchronization, %ERS; desynchronization, %ERD) die oszillatorische Gehirnaktivität in der Zweitsprache Englisch (L2) bei Kindern mit deutscher Muttersprache (L1). Dabei wurden potenzielle Unterschiede in der Gehirnaktivität zwischen phonologischen und orthographisch-morphologischen Rechtschreibstrategien in der Erst- und Zweitsprache untersucht. 33 SchülerInnen bearbeiteten Wörter, die falsch oder richtig geschrieben waren, und deren korrekte Lösung entweder eine phonologische oder orthographisch-morphologische Rechtschreibstrategie erforderte. Während der Bearbeitung der experimentellen Aufgaben wurde die %ERS/ERD im Theta- (4 – 7 Hz), im unteren Alpha- (7 – 10 Hz) und im oberen Alpha-Frequenzband (10 – 13 Hz) erhoben. Es konnte gezeigt werden, dass bei L2-Sprachprozessen generell mehr Theta %ERS vorhanden war als bei L1-Sprachprozessen. Diese Beobachtung lässt eine stärkere semantische Kodierung und/oder einen semantischen Abruf der weniger beherrschten L2 vermuten. Die stärkste %ERS im Theta-Frequenzband zeigte sich bei der Bearbeitung jener L2-Aufgaben, deren korrekte Lösung eine orthographisch-morphologische Rechtschreibstrategie erforderte. Dies könnte auf eine intensivere lexikalische Verarbeitung bei der orthographisch-morphologischen Rechtschreibstrategie in L2 im Vergleich zu der phonologischen Rechtschreibstrategie in L2 und der orthographisch-morphologischen Rechtschreibstrategie in L1 hinweisen. Im unteren Alpha-Frequenzband zeigte sich in L1 eine höhere %ERD als in L2. Vor dem Hintergrund, dass die ProbandInnen ein relativ geringes Sprachniveau aufwiesen, könnte dieses Ergebnis mit einer weniger elaborierten Verarbeitung der L2-Informationen in Zusammenhang stehen. Im oberen Alpha-Frequenzband war ein höheres %ERD Level in posterioren Gehirnregionen zu beobachten, was mit visuellen Prozessen und der Verarbeitung der Wort-Formen in Verbindung gebracht werden könnte.

1 Introduction

Language is one of the most important aspects of communication, and therefore plays an important role in human lives. It becomes more and more important nowadays to know a second language. Consequently, in the last decade, relevant research in this field has rapidly grown. Nevertheless, up to the present no consistent picture about potential neural substrates 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 a review see Fabbro, 1999, Chapter 25; cf. Midgley, Holcomb, & Grainger, 2009). (1) First language (L1) and second language (L2) words may be processed separately in distinct areas of the brain, each language having its own language network. (2) All languages could be represented in the same cortical networks and processed in a very similar way. (3) Two languages may be organized within the same brain regions, but in distinct neuronal networks. (4) A combination of these hypotheses, assuming that two languages are represented in the same as well as in distinct brain regions (for a review see Fabbro, 1999, Chapter 25; 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 explored neuronal substrates of phonological and orthographic-morphological strategies involved in L1 and L2.

1.1 Theoretical framework

Phonological and morphological awareness. The written units in our alphabetic system consist of phonological as well as morphological information (Casalis, Colé, & Sopo, 2004). Phonological awareness describes the ability to analyze sound units in words, such as syllables or phonemes (Klicpera, Gasteiger-Klicpera, & Schabmann, 2007, Chapter 1),

whereas morphological awareness refers to the ability to understand the structure of a word as a combination of morphemes and to manipulate these (Bhatt, 1991). Morphemes are defined as the smallest lexical units and we can distinguish three different kinds of morphemes. The word “unbelievable”, for instance, contains the following three morphemes: the prefix “un”, the root “believe”, and the suffix “able”. 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). 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. Morpheme consistency implies that morphemes do not change in different word constructions which is an important principle of German orthography (cf. Landerl, Wimmer, & Frith, 1997), e.g. “*sprechen*” (speak), “*Versprechen*” (promise), “*unaussprechlich*” (unspeakable). On the contrary, speech and writing in other languages (e.g. English; cf. Landerl et al., 1997) show inconsistent morphological systems, e.g. cut, cutting. 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). Thus, English with its different orthographic structure is a complex second language to learn. Depending on the orthographic transparency level (grapheme-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). Consequently, it could be assumed that morphological awareness is less important for children learning languages with transparent orthography (e.g. German) than for children learning languages with inconsistent grapheme-phoneme mapping (e.g. English) as phonological strategies may be used more effectively in these languages (cf. Weiss, Grabner, Kargl, Purgstaller, & Fink, 2010).

First language acquisition. Functional models of language acquisition provide insights into language processing and, thus, seem to be helpful to understand the underlying neuronal processes of language (cf. Bastiaansen & Hagoort, 2006).

There are two main theoretical perspectives concerning reading and spelling development in L1. The first suggests 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). Thus, according to this position, it may be assumed that different strategies, such as phonological or morphological strategies, should be used in a similar way. 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, Chapter 13; cf. May, Vieluf, & Malitzky, 2000). Taking the stage theories into consideration, it could be hypothesized that the more basic phonological strategy is generally more internalized than other strategies (e.g. morphological strategies), as it is acquired first. Thus, when comparing phonological strategies to morphological ones it may be assumed that different neurophysiological mechanisms are involved in these two distinct processes.

Second language acquisition. Generally, it has been shown that abilities in L1 and L2 are related (cf. Cummins, 1979; cf. Cummins, 2009; cf. Jeuk, 2010, Chapter 2). In his “developmental interdependence” hypothesis, Cummins (1979) suggests that L1 skills influence the development of L2 competences. It is well-known that while learning a second language, a transfer from the first to the second language occurs in different aspects of language processing (cf. MacWhinney, 1997, Chapter 4). These observations correspond quite closely with models of L2 acquisition, such as the “revised hierarchical model” by Kroll and Steward (1994). This model is one of the most popular ones among a variety of hierarchical models concerning the organization of L1 and L2 lexica (cf. French & Jacquet, 2004). It suggests that word-to-concept connections within L2 words are linked to L1 words

(word association) and are also directly linked to the general semantic concept (concept mediation). 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). Hence, it should take non-fluent readers longer to process L2 words than L1 words because L2 information has to be linked to the L1 lexicon first. Furthermore, it may be assumed that school children (non-fluent in L2) involve similar brain regions in L1 and L2 processes due to the involvement of the L1-lexicon. Due to the translation from L2 to L1, additional brain regions may be activated, or the level of activity may differ within the same brain areas when comparing L2 to L1.

A neurolinguistic theory of bilingualism by Paradis (2004, Chapter 2) describes two different memory systems which are central in second language acquisition: Conscious declarative (explicit) and procedural (implicit) memory. The author assumes that in L1 implicit knowledge is used, whereas the learner accesses metalinguistic, explicit knowledge when processing L2 (Paradis, 2004, Chapter 2). Furthermore, Paradis (2004, Chapter 2) postulates that in L1 acquisition children initially gain implicit language competences followed by metalinguistic knowledge. While learning L2 later on, this order reverses in the sense that language acquisition is carried out by increasing the automatization of explicit competences. According to Paradis' theory, L1 and L2 are represented in the same brain areas but used in quantitatively different ways, as gaps of implicit knowledge in L2 have to be compensated by involving certain cerebral areas more intensively (Paradis 2004, Chapter 4). Furthermore, it should be more complex to solve L2 tasks, due to the fact that L2 processing is not as internalized as in L1.

1.2 Neurophysiological framework

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 brain areas of the left hemisphere (e.g. Hoeft et al., 2006; Shaywitz et al., 2007; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). Moreover, Shaywitz et al. (2007) suggest that the activation in occipitotemporal regions increases with age and seems to be the neuronal circuit of reading. 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). Findings by Bolger, Hornickel, Cone, Burman, and Booth (2008), who presented visually inconsistent and consistent phonological and orthographic word pairs to their subjects, suggest that frontal brain regions in the left hemisphere as well as the posterior cingulate cortex are involved in integrating phonological as well as orthographic information. Regarding phonological awareness, it has been shown that an improvement of this competence is associated with more 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). Furthermore, Shaywitz et al. (2004) demonstrated the involvement of frontal brain regions in phonological processing.

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 L2 speakers who acquired

L2 late (> 6 years of age), and/or were low proficient and/or had a low L2 exposure, showed higher levels of activation during L2 processing than during L1 processing. This was observable for both word-level production e.g. in the left frontal lobe, and for word-level comprehension, e.g. in the left frontal and parietal cortex (e.g. Chee, Hon, & Soon, 2001; Wartenburger, Heekeren, Abutalebi, Cappa, Villringer, & Perani, 2003; Yetkin, Yetkin, Haughton, & Cox, 1996; cf. Indefrey, 2006; cf. Perani & Abutalebi, 2005). The higher level of cortical activation during L2 processes could indicate the recruitment of additional resources due to higher cognitive demand (e.g. Chee et al., 2001; Golestani, Alario, Meriaux, Le Bihan, Dehaene, & Pallier, 2006; cf. Indefrey 2006). Moreover, Chee et al. (2001) found that in addition to regions of the left hemisphere, low proficient subjects involved right inferior frontal areas in L2 during a semantic judgment. Interestingly, other studies regarding language comprehension indicate less activation in relevant regions (e.g. in frontal and temporal regions) in L2 compared to L1 (e.g. Dehaene et al., 1997; Perani et al., 1996). Less neural activation in L2 comprehension processes compared to those of L1 may be indicative of a restricted elaboration of the lexical information received (Abutalebi, Cappa, & Perani, 2001). In another fMRI study by Xue, Dong, Jin, Zhang, and Wang (2004), ten to twelve year old Chinese children who had been studying their L2 English since the age of eight, were asked to make a semantic judgment on the question, whether two presented words shared the same semantic category or belonged to different ones. It was shown that a similar left hemispheric network was activated both in L2 and in L1, including the fusiform, prefrontal (Broca's area), and parietal cortex (Xue et al., 2004). These findings indicate that semantic processing at a single-word level in L2 involves the same cortical brain regions as in L1, even when L2 is acquired later in life and the proficiency level is low. Further, Stowe and Sabourin (2005) conclude in their review that this finding seems to hold true for various language processes (e.g. word level meaning, comprehension, and phonological processing). However, this assumption only refers to qualitative similarities of L1 and L2 processing, whilst

concerning quantitative differences between L1 and L2 processing, a different picture emerges. 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; for a review see Stowe & Sabourin, 2005). This assumption is also in line with Paradis' hypothesis (2004) in which he postulates that the same brain areas are activated for L1 and L2, but are used in quantitatively different ways, as in L2 a gap of implicit competences is present which is compensated with a greater involvement of explicit knowledge (Paradis, 2004, Chapter 4).

Hemodynamic activation studies provide detailed and important information about the involvement of brain structures in different language processes. However, in order to achieve a better overall understanding of language processes, these findings have to be supplemented with studies which are able to investigate the dynamics of neural activity with high temporal resolution such as the electroencephalography (EEG) which records neuronal activity in milliseconds (Altenmüller, Münte, & Gerloff, 2005, Chapter 31).

EEG studies analyzing event-related potentials (ERPs) indicate that linguistic aspects show certain activity characteristics reflected e.g. in time, polarity, and scalp distribution of potentials, such as N400, P600 or a left anterior negativity (cf. Kaan, 2007 for a review).

Ojima, Nakamura, Matsuba-Kurita, Hoshino, and Hagiwara (2011) tested 322 school children with different proficiency levels over a time period of three years, presenting L1 and L2 words in a semantically congruent or incongruent context. The ERP data suggest that developmental stages of children's L2 correspond with L1 acquisition (e.g. a negative component, and a late positivity), implying that the neural basis of L1 and L2 are the same (Ojima et al., 2011). In contrast, Midgley et al. (2009) found differences in ERP waveforms during L1 and L2 word recognition in late bilinguals and low proficient subjects, indicating divergent ways of processing L2 compared to L1 words (delay of anterior negativity and larger negativities in posterior parts in L2 compared to L1). Considering these findings, it may be assumed that there are fewer links between semantic and lexical representations in L2,

while with increasing L2 proficiency, higher connectivity and integration of L2 items in the lexical-semantic network might occur (cf. Midgley et al., 2009). This assumption seems to be in line with the aforementioned model by Kroll and Stewarts (1994).

ERP data appear to be in correspondence with hemodynamic studies. 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).

A disadvantage of the ERP method as used in some of the above-mentioned studies is that in order to increase the signal-to-noise ratio, EEG signals are averaged over single trials (Pfurtscheller & Lopes da Silva, 1999). Thus, oscillatory activity which is not phase-locked to an event is likely to be cancelled out (cf. Bastiaansen & Hagoort, 2006; Pfurtscheller & Lopes da Silva, 1999). Hence, other methods might be also helpful in order 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.

Event-related desynchronization/synchronization. %ERD/ERS has turned out to be a valid method to measure oscillatory brain dynamics in language processes (e.g. Bastiaansen, van der Linden, ter Keurs, Dijkstra, & Hagoort, 2005; Grabner, Brunner, Leeb, Neuper, & Pfurtscheller, 2007).

The rhythmic EEG amplitude reflects synchronous firing of neurons (Singer, 1993), thus indicating changes in synchrony of oscillatory firing patterns related to linking brain regions of the same functional neuronal network (cf. Bastiaansen & Hagoort, 2006). 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 & Silva da Lopes, 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. Klimesch, Pfurtscheller, Mohl, & Schimke, 1990; Fink, Grabner, Neuper, & Neubauer, 2005). 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 et al., 2005; Bastiaansen, van Berkum & Hagoort, 2002; 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).

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 & Brunia, 2001), and an increase in theta oscillatory activity for left occipital regions was observed which might indicate the processing of the visual word form (Cohen et al., 2000). Similar oscillatory activation patterns were found in another study by Bastiaansen et al. (2005) during semantic information processing (including theta power increase in left temporal and occipital cortices). Additionally, qualitative differences in the theta frequency band were found, showing theta power increase at left temporal sites only while processing words involving primarily semantic information (compared to primarily syntactic words). This might indicate that these areas are related to the retrieval of the meaning of the lexical items (Bastiaansen et al., 2005).

Concerning morphological awareness, Weiss et al. (2010) showed that during a morphological task, similar to the one applied in the present study, school children elicited both strong upper alpha %ERD in occipital brain regions and %ERS in the theta frequency band occipitally. Further, compared to children with better reading and spelling abilities, poor readers and poor writers displayed a lower level of theta %ERS in posterior regions during a morphological task. This may be indicative of the involvement of these regions in morphological language processes (Weiss et al., 2010). These findings are in line with most of the aforementioned %ERD/ERS results (e.g. Bastiaansen et al., 2005; Bastiaansen et al.,

2008), as well as with hemodynamic neuroimaging studies of reading and phonological awareness (e.g. Frost et al., 2009; Shaywitz et al., 2007; Turkeltaub, 2003).

Very few studies used %ERD/ERS measures in second language research. A study by Grabner et al. (2007) examined oscillatory activity patterns of L1 and L2 during language translation. The authors emphasized that lexical retrieval processes of L1 as well as L2 involve similar %ERD/ERS patterns as observed in L1 processes of semantic information (Grabner et al., 2007). This indicates for example the involvement of upper alpha %ERD in frontal brain regions and theta %ERS in posterior cortices (Grabner et al., 2007). Ihara and Kakigi (2006) analyzed potential %ERD/ERS differences in processing L1, L2, and pseudoletters (a letter which looks like a real letter but does not exist) among adults, which revealed no significant differences between L1 and L2. However, %ERD was elicited in a broader alpha band (lower and upper alpha) when processing L2 letters compared to L1 letters, which suggests that L1 and L2 cortical oscillatory activity networks differ in occipitotemporal regions associated with visual perception (Ihara & Kakigi, 2006).

Hemodynamic as well as EEG studies suggest that there are differences between L1 and L2 activity patterns when processing native language compared to a second language. However, considering the aforementioned research, it should be noted that brain activity in language processing appears to change as a function of age (e.g. Hahne, Eckstein, & Friederici, 2004; Schlaggar, Brown, Lugar, Visscher, Miezin, & Petersen, 2002), so that the comparison of findings in adults and children is bound to limitations. In addition, the languages of L1 and L2 varied across different studies, so that it might be questioned in which way the findings depend on the kind of language studied. However, universal syntactic processing at least within Indo-European languages was shown to be similar (Rossi, Gugler, Friederici, & Hahne, 2006), and thus, semantic processes might show similar patterns as well. Moreover, it has to be mentioned that until now, the functional relation between

hemodynamic aspects, ERPs and %ERD/ERS, which measure different facets of neuronal activity, remains mostly unclear (Bastiaansen et al., 2005).

1.3 Aims and research questions

Considering the aforementioned studies, it becomes obvious that we do not know yet how L1 and L2 language processing are reflected at the level of the brain, especially when the dynamic perspective is taken into consideration. Relatively few studies have analyzed the oscillatory brain responses in relation to language until now (cf. Bastiaansen & Hagoort, 2006). Moreover, to our knowledge only a few studies used the method of %ERD/ERS in the field of second language research (e.g. Grabner et al., 2007; Ihara & Kakigi, 2006). Thus, the aim of the present study was to explore whether school-age children use the same or different oscillatory activity networks in processing L1 and L2. We assume that during the presented visual lexical decision task (detection of spelling mistakes), the semantic lexicon will be activated to automatically process the presented words. Posterior regions seem to be involved in lexical-semantic retrieval (e.g. in theta and upper alpha frequency bands; e.g. Bastiaansen & Hagoort, 2006; Weiss et al., 2010). Therefore, it may be hypothesized that oscillatory activity will be found in these regions. Furthermore, we will specifically analyze oscillatory EEG activity related to phonological vs. orthographic-morphological spelling strategies. In doing so, neurophysiological correlates of L1 (German) and L2 (English) will be investigated by comparing oscillatory EEG activity of school children during the performance of a language task (in L1 and L2) requiring either phonological or orthographic-morphological strategies. With reference to stage theories, morphological awareness is usually developed later than phonological awareness. Thus, it could be assumed that phonological strategies are more consolidated and, therefore, applied with less effort.

Considering the reviewed literature, it appears reasonable to hypothesize that oscillatory synchrony is involved in language processing. To learn more about the complex dynamics involved in L1 and L2 processes, we studied oscillatory activity using the

%ERD/ERS measure. EEG activity in the alpha and the theta frequency band seems to be sensitive to lexical-semantic processing of language (Grabner, et al., 2007; Weiss et al., 2010), and therefore, we focused on these two frequency bands here. The subjects in the present study acquired L2 later in childhood (on average they started learning L2 with approximately seven years). Thus, they could be considered as rather low proficient. Therefore, significant differences in oscillatory activity patterns between L1 and L2 processes may be assumed. Several brain regions were found to be involved in L1 and L2 processing. Among others, involvement of frontal and occipital regions in language processing was reported (e.g. Bastiaansen & Brunia, 2001; Midgley et al., 2009; Xue et al., 2004; Yetkin et al., 1998). Thus, it can be assumed that in the present study these regions might be involved during language processing as well. However, the existing findings are rather inconsistent and no %ERD/ERS results concerning L2 processes in children currently exist. Therefore, this study could make a nice contribution to literature in this particular context.

2 Method

2.1 Participants

Thirty-three healthy children (24 girls, 9 boys) from three schools in Graz, Austria, participated in this study. The subjects attended the 6th Grade and, on average, they were eleven years old ($M = 11.36$, $SD = 0.55$). They were recruited on a voluntary basis and all parents of the children gave written informed consent.

Three participants were excluded from the study as their mother languages were not German. All of the remaining subjects were native German speakers and right-handed. The average age of second language (English) acquisition was seven years ($M = 6.67$, $SD = 1.68$), thus, our subjects can be defined as “secondary bilinguals” (Wei, 2007, p. 7) or as “late bilinguals” (Fabbro, 1999, p. 107). Considering that the children had been studying English for approximately four to five years in school, they can be described as low proficient English

speakers. On average, the subjects reached school grades¹ of 1.79 ($SD = 0.99$) in German and 1.91 ($SD = 1.68$) in English. Socio-demographic and personal data of the subjects were assessed via a self-constructed questionnaire for the children and their parents (see appendices A and B). The amount of hours the children were involved with English outside school (e.g. with homework, reading books or watching English TV) varied from 1/2 hour to 20 hours per week, while 70 percent indicated five or less hours. None of the participants took private lessons and most of the subjects (81.8%) had a workplace of their own at home. The majority (81.8%) had siblings, while almost half of the participants (45.5%) were first and 31.3% second born. Around half of all mothers and fathers had a university degree. Approximately half of the participants stated to read two to three books monthly (range 1 – 25). On average, the subjects spent weekly 7.21 hours ($SD = 4.83$; range 1 – 20) reading books, 5.89 hours watching TV ($SD = 4.14$; range 0 – 20) and 3.83 hours playing computer games ($SD = 3.9$; range 0 – 20).

The level of subjects' German and English abilities was measured by means of psychometric tests which are described in detail in Chapter 2.2. Generally, German spelling ($MT^2 = 56.8$, $SD = 7.63$) and particularly basal reading competences in German ($MRQ^2 = 121.06$, $SD = 15.3$) were above average. The participants' English writing skills were also above average ($MT^2 = 60.16$, $SD = 4.22$). The subjects reached about the half of the maximal possible English spelling score ($MCP^2 = 53.11$, $SD = 15.89$). Further, they gave the correct answers to approximately 75% of the maximal possible correct solutions of the test that was measuring English reading comprehension, vocabulary and grammar proficiency ($MCP^2 = 75.27$, $SD = 15.17$).

¹ Austrian school grades reach from 1 (very good) to 5 (failed).

² RQ = Reading Quotient, average range 89-111; T = T-scores; CP = percentage of correctly spelled words

2.2 Psychometric Tests

Prior to the EEG sessions, participants were screened with two psychometric tests in German and three in English. This was done in order to provide a good overall assessment of the children's German and English abilities.

Measures for the assessment of German language abilities. In order to measure subjects' German spelling ability, we used the "Hamburger Schreibprobe" (HSP 5-9; May, Vieluf, & Malitzky, 2000). This test (internal consistency for Grade 6 = .91, see May et al., 2000) does not only provide information on general spelling competence, but gives also information about the use of specific writing and spelling strategies (alphabetical, orthographical and morphological), and thus, provides insights into the specific learning level of an individual.

Reading ability in German was measured by means of the well-established German-speaking reading test "Salzburger Lese-Screening" (SLS 5-8; Mayringer & Wimmer, 2005), which provides a reliable index of basal reading competence focusing on the reading rate. In this test, seventy sentences were presented to the subjects and within a time period of three minutes subjects had to decide whether a sentence is correct or not.

Measures for the assessment of English language abilities. We assessed participants' English skills using a general language multiple choice exam for students, "The European Language Certificates" (telc English A2 School; telc GmbH, 2010). Specifically, we used the "Language Elements" subtest to assess vocabulary and grammatical knowledge and the subtest "Reading Comprehension".

In order to assess their level of writing skills, students were administered a German-speaking subtest "Briefe Schreiben" (writing letters) of the test battery "Diagnostischer Leistungstest Englisch" (DLE 5/6; Doyé & Lüttge, 1977). This subtest requires examinees to write a letter to a fictive English friend, while it considers both orthography and grammar.

Further, a self-constructed English cloze test “Test of English spelling” (TES) by Kargl and Purgstaller (2010) was presented (see appendix C), aiming at measuring the students’ ability to distinguish between the sound and the spelling structure of a word in both German and English (e.g. new letter combinations in English compared to German like “th” or “ea”). The cloze consists of 55 sentences, and within each sentence a word is missing (e.g. “_____ one of the drinks.”, missing word: “Choose”). The procedure is as follows: The experimenter reads each sentence to the subjects who are then asked to fill in the missing words. For the test score, the correct spelling of a word as well as the kind of spelling mistake was taken into account. Within the group of spelling mistakes, it was differentiated between consonants, vowels and morphemes.

To additionally measure participants’ temporary mood during the EEG session as a control variable, they were asked to work on the German-speaking version of the State-Trait-Anxiety Inventory (STAI; Laux, Schaffner, and Spielberger, 1981).

2.3 Experimental task

In order to investigate potential differences between the first language German (L1) and the second language English (L2) as well as differences between phonological and orthographic-morphological spelling strategies, four different variants/blocks of a spelling task (i.e. “Detection of Spelling Mistakes”, DM) were constructed, each variant consisting of 26 words (see Figure 1; see appendix D).

DM task - German (L1)	DM task - English (L2)
Block 1: 13 correctly spelled 13 phonologically incorrectly spelled e.g.: srtahlen	Block 2: 13 correctly spelled 13 phonologically incorrectly spelled e.g.: creatvi
Block 3: 13 correctly spelled 13 phonologically correctly but morphologically incorrectly spelled e.g.: Becker	Block 4: 13 correctly spelled 13 phonologically correctly but morphologically incorrectly spelled e.g.: realy

Figure 1. Description and examples of the phonological and morphological “Detection of Spelling Mistakes” (DM) task in German (L1) and English (L2) presented during the EEG measurement sessions.

Similar to Weiss et al. (2010), we used the task “Detection of Spelling Mistakes” (DM). The DM items consist of correctly and incorrectly spelled words, which were visually presented during the EEG measurements. Participants are required to make a right/wrong judgment as quickly and as accurately as possible for each word by pressing one of two response buttons (right vs. wrong) on an external keyboard. In order to make sure that the children were familiar with the presented words, we solely included frequent German as well as frequent English words. The DM task was realized in four different variants/blocks (see Figure 1), consisting of 26 words (13 correct and 13 incorrect words) each, resulting in a total number of 104 items. Specifically, two different types of incorrect words for each language (L1 and L2) were presented: 13 words that were orthographically or morphologically incorrectly spelled but still constructed according to phonological principles (pseudowords that sound like real words; block 3 and 4, see Figure 1), and 13 words spelled totally incorrect (block 1 and 2, see Figure 1). Words with orthographic-morphologically incorrect spelling, which are constructed according to phonological principles, appear to be correct when solely applying phonological rules. In order to solve these items correctly and to detect spelling mistakes in these words, it is necessary to additionally apply orthographical or morphological

spelling rules. Children who rely exclusively on phonological strategies should, therefore, show more difficulties in detecting spelling mistakes in words with orthographical or morphological misspelling constructed after phonological principles (block 3 and 4, see Figure 1) than in words which are spelled totally incorrect (block 1 and 2, see Figure 1). To detect the spelling mistakes in words which are spelled completely incorrect (block 1 and 2), only a relatively basic phonological strategy is needed, which involves the use of phonematic knowledge to write a word (e.g. awareness about grapheme-phoneme mapping or sound sequences). Thus, these kinds of tasks are referred to as “phonological task” in the following. Although the so-called pseudowords (block 3 and 4) require orthographical and/or morphological strategies, which include the knowledge of linguistic rules or morphological knowledge in terms of metalinguistic skills, we prefer to use only the term “morphological task” due to the difficulties in distinguishing between these two strategies in L2.

2.4 Procedure

The participants of the present study were recruited by contacting school principals of high schools and by providing information sheets for the teachers and parents (see appendix E). The first screening included five psychometric tests as described above and took place in small groups at the respective school or at the university. After a short instruction explaining what the children had to expect, the subjects completed a questionnaire concerning personal and socio-demographic data (see appendix A). Given that the German-speaking psychometric tests took a shorter time to complete, they were presented first, followed by the three measures assessing English language skills. Overall, this first session lasted approximately 1 ½ hours including a ten minute break.

The second session included individual EEG measurements. All sessions started with a brief explanation of the experimental procedure followed by mounting the electrodes and assessing the temporary mood of the participants (STAI; Laux et al., 1981). Once the electrode impedances were checked and the students sat in a comfortable armchair, the

measurement started by recording two resting EEG sequences with eyes open and eyes closed for two minutes each. Afterwards, the experimental tasks were presented in a counterbalanced order to control for effects of task sequence. The stimuli of a task block were shown separately word by word in the center of the computer screen in font size 50. Depending on the reaction time of the participants, each task block lasted around seven minutes. Before we recorded the EEG, a thorough introduction for each task was presented and five task examples were practiced using exactly the same paradigm as in the actual test. After the first two task blocks, the participants were free to take a five minute break. Subsequent to the test session, another 2-minute resting EEG sequences were recorded. In total, the EEG sessions lasted approximately 1 ½ hours. As soon as the data collection for the study was finished, the parents of the participants received an individual test profile explaining their children's (behavioral) test results (see appendix F) and a photo of the students wearing an electrode cap.

2.5 EEG Recording

The EEG was recorded with a BrainvisionBrainAmp Amplifier (Brain Products) and analyzed using Matlab (version 7.10.0 [R2010a]; MathWorks, Natick/US).

A set of 33 silver chloride electrodes (9 mm diameter), carefully attached to the scalp with adhesive electrode cream, was positioned according to the International Electrode (10-20) Placement-system to record EEG signals. An additional electrode on the forehead was used as ground electrode and the reference electrode was located on the nose. Furthermore, the electrooculogram (EOG) was recorded bipolarly with two electrodes placed diagonally above as well as below the inner and outer canthus of the right eye to register horizontal and vertical eye movements. We filtered the EEG signals between 0.1 Hz and 100 Hz. To avoid power line contamination, we additionally applied a 50 Hz notch filter. For the EEG the electrode impedances were kept below 5 k Ω , and for the EOG below 10 k Ω . Further, trigger signals for the stimulus presentation and the responses were recorded and all signals were sampled at a frequency of 500 Hz.

2.6 EEG Analyses

Brain activity during performance of the experimental tasks was quantified by means of event-related-desynchronization (%ERD) or -synchronization (%ERS) of EEG bandpower in different frequency bands. Specifically, %ERD/ERS indicates the percentage of decrease or increase in averaged EEG bandpower from the reference (R) to the activation (A) interval ($\%ERD/ERS = ([R - A] / R) \times 100$). Positive values indicate decreases (%ERD) and negative values reflect increases (%ERS). These changes in band power were analyzed within the theta (4 – 7 Hz), the lower alpha (7 – 10 Hz) and the upper alpha band (10 – 13 Hz).

As presented in Figure 2, a fixation cross was shown for 3000 ms representing the reference interval (R) before the task item appeared on the computer monitor. The entire individual response time was defined as activation interval (A). After each word a blank screen was shown for 2500 ms. In this inter-trial interval the children were free to move and to blink.

Figure 2. Schematic time course and EEG measurement intervals for the experimental task (“Detection of Spelling Mistakes”, DM). After the presentation of the fixation cross for 3000 ms (R = reference interval), a correctly or incorrectly spelled word was shown on the screen (Stimulus) requiring a right/wrong judgment by pressing a response button illustrated as “//”. The time from stimulus onset until button press (//) was defined as individual response time (A = activation interval). Shortly after the response, a blank screen was presented for 2500 ms, followed by the next trial.

Given that brain activity patterns associated with wrongly solved or with relatively long-lasting test trials are difficult to interpret, only correctly solved trials that had been solved within a time period of maximal twelve seconds were included in the analyses. The remaining EEG data were carefully checked individually for artifacts (eye blinks, muscle artifacts, etc.) by visual inspection. Time periods containing artifacts were excluded from further analyses. The power of background activity was computed for the reference and the activation intervals for each single trial after squaring band-pass filtered signals.

As in our previous studies (e.g. Weiss et al., 2010), we aggregated the data for different electrode locations for subsequent statistical analyses. The aggregation of the electrode positions was as follows: Anteriofrontal left (FP1, AF3), anteriofrontal right (FP2, AF4), frontal left (F3, F7), frontal right (F4, F8), frontocentral left (FC1, FC5), frontocentral right (FC2, FC6), centrottemporal left (C3, T3), centrottemporal right (C4, T4), centroparietal left (CP1, CP5), centroparietal right (CP2, CP6), parietotemporal left (P3, T5), parietotemporal right (P4, T6) parietooccipital left (PO3, PO5, O1), and parietooccipital right (PO4, PO6, O2). As we were also interested in potential hemispheric differences, the midline electrodes (FZ, CZ, PZ) were not included in the analyses of EEG data.

3 Results

3.1 Behavioral Results

In order to analyze the relation between the proficiency level of the first language (German, L1) and the second language (English, L2), Pearson correlations for the psychometric test scores were performed. As expected, we found moderate to high positive correlations between almost all psychometric test results in L1 and L2, suggesting that the proficiency level in these two languages is related to a considerable extent (see Table 1).

Table 1

Pearson correlations of psychometric measures in German (L1) with psychometric measures in English (L2).

English measures	German measures		
	Reading speed (SLS)	Spelling (HSP)	Morphological strategy (HSP)
Spelling (TES)	0.37*	0.55**	0.69**
Correct morphological spelling (TES)	0.42*	0.65**	0.64**
General language knowledge (telc)	0.47**	0.53**	0.48**
Writing (DLE)	0.26	0.40*	0.41*

** $p < 0.01$; * $p < 0.05$

To evaluate the validity of the task presented during EEG measurement (i.e. DM task), we conducted correlations between the psychometric test data and the EEG performance data of the DM task. DM task performance was operationalized by means of correctly solved trials (score) and individual reaction times (RT). As presented in Table 2, the performance data of the DM task in German display a pattern of moderate to high correlations with reading speed, spelling, and morphological strategy measures. The correlation between the HSP morphological strategy and the morphological variant of the DM task reveals a comparatively strong relation, suggesting that the morphological strategy plays an important role in solving the morphological EEG tasks correctly.

Table 2

Pearson correlation of psychometric measures in German (L1) with performance data during the EEG session for the German experimental DM task separately for both strategies.

Psychometric measures	EEG task performance			
	Score		RT	
	Morphological task	Phonological task	Morphological task	Phonological task
Reading speed (SLS)	0.47**	0.31	-0.63**	-0.56**
Spelling (HSP)	0.63**	0.48**	-0.61**	-0.68**
Morphological strategy (HSP)	0.69**	0.44*	-0.53**	-0.47**

Note. Score = correctly solved trials, RT = reaction time in seconds, Morphological task = EEG task which requires the use of orthographic-morphological strategies for correct solving, Phonological task = EEG task which only requires a phonological strategy.

** $p < 0.01$; * $p < 0.05$

As shown in Table 3, a moderate to high relation of the L2 morphological variant of the DM task scores with all English psychometric measures was observed. The high correlation between the morphological variant of the DM task in L2 and the TES morphological strategy measure indicates the involvement of morphological strategies in solving the experimental task. Considering the phonological variant of the DM task in L2, a significant correlation with writing was observed, implying that especially the writing skills of the children were important to solve the phonological task. Also, performance data (i.e. RT) reveal strong correlations of the two L2 tasks with spelling and morphological strategy, indicating that the participants solved the L2 DM task faster when they had higher scores in spelling and in the morphological strategy measure.

Table 3

Pearson correlations of psychometric measures in English (L2) with performance data during the EEG session for the English experimental DM task separately for both strategies.

Psychometric measures	EEG task performance			
	Score		RT	
	Morphological task	Phonological task	Morphological task	Phonological task
Spelling (TES)	0.62**	0.29	-0.41*	-0.52**
Morphological strategy (TES)	0.49**	0.33	-0.48**	-0.60**
General language knowledge (telc)	0.34	0.25	-0.07	-0.31
Writing (DLE)	0.46**	0.46**	-0.04	-0.21

Note. Score = correctly solved trials, RT = reaction time in seconds, Morphological task = EEG task which requires the use of orthographic-morphological strategies for correct solving, Phonological task = EEG task which only requires a phonological strategy.

** $p < 0.01$; * $p < 0.05$

To summarize, the correlations between morphological strategies and the DM task in both languages imply that the operationalization of task performance during the EEG measurement can be considered as successful.

In a next step, potential differences between L1 and L2 as well as differences between the morphological and the phonological variants of the DM task were analyzed (in considering the task performance scores and the individual reaction times as dependent variables). For this purpose, analyses of variance (ANOVAs) for repeated measures including the variables LANGUAGE (L1, L2) and STRATEGY (phonological, orthographic-morphological) as within-subjects factors were performed. Post-hoc analyses were conducted by Tukey HSD post-tests.

The ANOVA for scores revealed a significant main effect of LANGUAGE ($F [1, 32] = 43.95$, $p < 0.01$, $\eta_p^2 = 0.58$), indicating a higher score in L1 than in L2. The main effect STRATEGY reached also significance ($F [1, 32] = 14.78$, $p < 0.01$, $\eta_p^2 = 0.32$). When comparing phonological and morphological tasks, it was shown that subjects solved more

items correctly in the former. Furthermore, a significant LANGUAGE x STRATEGY interaction was observed ($F [1, 32] = 10.21, p < 0.01, \eta_p^2 = 0.24$), showing that the English morphological variant of the DM task (words with orthographic-morphologically incorrect spelling but constructed after phonological principles) had the lowest score compared to the three other types of tasks (see Table 4; verified by post hoc analyses by means of the Tukey HSD test, $p < .01$). These findings suggest that the morphological task in L2 was more difficult than the phonological L2 task and the L1 tasks. The analyses of reaction times during the performance of the DM task yielded no significant effects.

Table 4

Descriptive statistics of performance data in the German (L1) and the English (L2) variant of the DM task separately for the morphological and the phonological task.

DM tasks	<i>M</i>	<i>SD</i>
Score		
Phonological task (German)	23.55	2.22
Morphological task (German)	23.45	2.68
Phonological task (English)	22.67	2.09
Morphological task (English)	20.45	2.68
RT		
Phonological task (German)	3.17	1.20
Morphological task (German)	3.12	1.34
Phonological task (English)	2.94	1.01
Morphological task (English)	2.84	0.96

Note. *M* = mean, *SD* = standard deviation, Score = correctly solved trials, RT = reaction time in seconds.

Additionally, we performed an ANOVA for repeated measures, including the variables LANGUAGE (L1 vs. L2) and STRATEGY (phonological vs. orthographic-morphological) as within-subject factors to analyze potential differences in word length between the languages and strategies. A significant main effect of LANGUAGE ($F [1, 25] = 69.23, p < 0.01, \eta_p^2 = 0.74$) was observed, revealing that the words of the German-speaking variants of the DM task

contained generally more letters ($M = 9.31$, $SD = 1.26$) than the words in English ($M = 6.21$, $SD = 1.28$).

3.2 Neurophysiological Results

In order to investigate potential differences between L1 and L2 as well as differences between the phonological and orthographic-morphological strategy at the neurophysiological level, ANOVAs for repeated measures were computed separately for the %ERD/ERS values in the theta, lower and upper alpha frequency band. The ANOVA design included LANGUAGE (German vs. English), STRATEGY (phonological vs. orthographic-morphological), HEMISPHERE (left vs. right) and AREA (anteriofrontal, frontal, frontocentral, centrottemporal, centroparietal, parietotemporal, and parietooccipital) as within-subject variables.

In cases where sphericity assumptions were violated, degrees of freedom were adjusted by means of the most conservative Greenhouse-Geisser correction and Greenhouse-Geisser Epsilons (ϵ) are indicated. Post-hoc analyses were conducted by Tukey HSD post-tests.

Theta band. Statistical analysis of the %ERD/ERS values in the theta frequency band showed a significant main effect of LANGUAGE ($F [1, 32] = 11.87$, $p < 0.01$, $\eta_p^2 = 0.27$), indicating that the subjects show generally more theta %ERS during task performance in L2 than in L1. A significant main effect of HEMISPHERE ($F [1, 32] = 8.30$, $p < 0.01$, $\eta_p^2 = 0.21$) indicated that overall, the right hemisphere exhibits more %ERS compared to the left hemisphere. Furthermore, the main effect AREA ($F [2.29, 73.32] = 7.69$, $p < 0.01$, $\eta_p^2 = 0.19$, $\epsilon = 0.38$) reached significance, suggesting stronger theta %ERS in parietotemporal and parietooccipital areas (p 's $< .05$ in the post hoc comparisons). Beside the main effects, a significant interaction between LANGUAGE, STRATEGY and HEMISPHERE ($F [1, 32] = 4.54$, $p < 0.05$, $\eta_p^2 = 0.12$) was observed, revealing that only while working on the L2 morphological task, the right hemisphere exhibits significantly higher levels of theta %ERS

than the left hemisphere (as verified by Tukey post hoc tests, $p < .01$), whereas no hemispheric differences were apparent for the other task variants (see Figure 3 and Figure 4). Alternatively, post hoc analyses yielded a significantly higher level of theta %ERS in L1 while using orthographic-morphological (as opposed to phonological) strategies in both hemispheres, whereas in English this difference was only shown in the right hemisphere (p 's $< .05$ in the post hoc analyses).

Figure 3. %ERS in the theta frequency band. Interaction between LANGUAGE, STRATEGY, and HEMISPHERE.

Figure 4. %ERD/ERS maps in the theta frequency band. Interaction between LANGUAGE, STRATEGY and HEMISPHERE. Negative values reflect %ERS (red), positive values %ERD (blue).

Lower alpha band. We observed a significant main effect of LANGUAGE ($F [1, 32] = 4.92, p < 0.05, \eta_p^2 = 0.13$), suggesting a higher level of lower alpha %ERD while working on the DM task variants in L1 than in L2. The significant main effect of HEMISPHERE ($F [1, 32] = 7.24, p < 0.05, \eta_p^2 = 0.18$) suggests that the left hemisphere was associated with more %ERD than the right one. Furthermore, the analysis yielded a significant interaction between STRATEGY and AREA ($F [3.36, 107.56] = 2.99, p < 0.05, \eta_p^2 = 0.09, \varepsilon = 0.56$), indicating a higher level of lower alpha %ERD at anteriofrontal sites in using phonological strategies, as compared to applying orthographic-morphological strategies (see Figure 5; $p < .01$ in post hoc analyses). Moreover, the significant HEMISPHERE x AREA interaction ($F [3.52, 112.71] = 3.28, p < 0.05, \eta_p^2 = 0.09, \varepsilon = 0.59$) showed that the differences between the hemispheres in lower alpha %ERD were especially strong in frontocentral and centrottemporal areas, showing higher %ERD in the left hemisphere (as revealed by specific post hoc comparisons, $p < .01$).

Figure 5. %ERD in the lower alpha frequency band. Interaction between STRATEGY and AREA.

Additionally, follow-up ANOVAs for repeated measures, separately for both the phonological and orthographic-morphological strategies were conducted, including LANGUAGE, HEMISPHERE, and AREA as within-subject factors. These separated analyses showed different main effects. The ANOVA for orthographic-morphological strategies revealed a significant main effect of LANGUAGE ($F [1, 32] = 5.39, p < 0.05, \eta_p^2 = 0.14$), implicating stronger lower alpha %ERD in L1 compared to L2. The ANOVA conducted for the phonological strategy discovered one significant main effect of HEMISPHERE ($F [1, 32] = 8.54, p < 0.05, \eta_p^2 = 0.21$), indicating that the subjects exhibited a higher level of lower alpha %ERD in the left compared to the right hemisphere.

Upper alpha band. With respect to the %ERD/ERS in the upper alpha band, we observed a significant main effect of HEMISPHERE ($F [1, 32] = 13.13, p < 0.01, \eta_p^2 = 0.29$), demonstrating generally stronger %ERD in the left than in the right hemisphere during task performance. Also, the main effect AREA reached significance ($F [2.26, 72.43] = 7.2, p < 0.01, \eta_p^2 = 0.18, \varepsilon = 0.38$). The subsequent post hoc analyses revealed higher %ERD in parietotemporal and parietooccipital areas compared to anteriofrontal, frontal and

frontocentral areas (p 's < .05). In addition, we observed a significant interaction of STRATEGY x HEMISPHERE (F [1, 32] = 4.8, p < 0.05, η_p^2 = 0.13), showing that subjects exhibit higher levels of upper alpha %ERD in the left hemisphere when applying phonological strategies than when applying orthographic-morphological strategies (as verified by post hoc tests, p < .01).

In addition, we conducted follow-up ANOVAs for repeated measures separately for L1 and L2. The ANOVA design for both L1 and L2 included the within-subject factors STRATEGY, HEMISPHERE, and AREA. The ANOVA for L1 revealed a significant main effect of HEMISPHERE (F [1, 32] = 11.48, p < 0.01, η_p^2 = 0.26), indicating stronger upper alpha %ERD in the left hemisphere than in the right hemisphere (see Figure 6). The analysis conducted for L2 revealed an interaction of STRATEGY x HEMISPHERE (F [1, 32] = 4.32, p < 0.05, η_p^2 = 0.12), showing stronger upper alpha %ERD in the left hemisphere compared to the right hemisphere only while applying phonological strategies (p 's < .01 in the post hoc analyses) but not when applying orthographic-morphological strategies (see Figure 7).

Figure 6. %ERD in the upper alpha frequency band. Main effect HEMISPHERE.

Figure 7. %ERD in the upper alpha frequency band. Interaction between STRATEGY and HEMISPHERE.

4 Discussion

In the present study, behavioral and neurophysiological effects in German (L1) and English (L2) language processes were investigated in a sample of school children. Furthermore, we specifically studied potential differences between phonological and orthographic-morphological spelling strategies.

4.1 Behavioral findings

As expected, we found that L1 and L2 abilities which were assessed by means of psychometric tests are closely related (see Table 1). The “developmental interdependence” hypothesis by Cummins (1979) assumes that good skills in L1 influence learning of L2. Even though the relation between L1 and L2 in the present study does not allow linking these two factors causally, the findings may be interpreted carefully to be in line with Cummins’ assumption. However, the relation of L1 and L2 is likely to be influenced by other variables as well, i.e. cognitive variables, personality and motivation (cf. Bickes & Pauli, 2009, Chapter 10; cf. Cummins, 1991, Chapter 4). It was shown that the use of morphological strategies in L1 or in L2 is related to the performance and response time in the respective morphological DM task (see Table 2 and 3). The comparatively high relation between the performance data in the morphological variant of the DM task and the morphological strategies as obtained by psychometric measures suggests that morphological abilities may play a crucial role in solving the morphological items in L1 and L2. This indicates that the experimental manipulation was successful in operationalizing morphological operations. It was also shown that the HSP morphological spelling strategy is related to the phonological DM task (see Table 2). Considering stage theories and metalinguistic theories of language acquisition, which postulate an association between phonological and morphological awareness (cf. Berninger et al., 2010; Frith, 1985, Chapter 13), the moderate relation between the morphological strategy and the phonological DM task in the present study does not seem surprising.

Regarding the “revised hierarchical model” (Kroll & Steward, 1994), it may be suggested that due to the additional lexical link from L2 to L1, task performance in L2 should be associated with longer response times than in L1. This was not apparent in our behavioral data. However, this observation should be considered with some reservation because German words were generally longer than English words of the DM task. This might be the reason that no differences in the reaction time measures were found.

Analyses of the behavioral performance data revealed the lowest solution rate for the morphological DM task in L2 compared to the phonological task in L2 and the DM tasks in L1. This could suggest that the L2 morphological task was more complex for the children than the other tasks. Regarding L2, these results seem to be in agreement with the hypothesis that in order to acquire morphological strategies and use these effectively for processing language, the phonological strategy has to be developed and mastered first, as postulated by relevant stage theories. Stage theories hypothesize that L1 spelling acquisition has different stages (e.g. Frith, 1985, Chapter 13; May et al., 2000). First, reading occurs in a phoneme-grapheme mapping, which is described as phonological stage. Second, most words in the orthographical stage are assumed to be directly retrieved from memory. This stage is followed by a morphological stage for which it is suggested that morphological strategies are used for literacy processes (cf. May et al., 2000). Stage theory postulations are supported by some studies, showing that children in their initial stages of literacy development rely on phonological awareness skills (e.g. Share, 1999). In the present study, the difference between the application of phonological and orthographic-morphological strategies in L2 might be due to the fact that the children started to learn their L2 at the average age of seven. Therefore, it may be suggested that in our sample the phonological strategy had already been consolidated when the children were tested, but that the orthographic-morphological strategy was not fully developed up to that time point. Contrary to L2, in the present study no behavioral differences were found between the use of phonological and orthographic-morphological strategies in L1.

It may be assumed that in contrast to L2, the orthographic-morphological strategies of the children in L1 were already well developed at this point of their literacy acquisition (average age eleven years). As German is their L1, they had enough time to internalize the morphological strategy well and were able to master this strategy successfully.

4.2 Neurophysiological findings

The EEG analyses revealed that the %ERD/ERS in different EEG frequency bands were sensitive to L1 and L2 processes. Generally, %ERD was observed in the lower- and upper alpha frequency band, whereas %ERS was revealed in the theta frequency band. Significant differences between both languages and between both strategies were found, differing in each frequency band. As the three frequency bands vary in their function (cf. Fink et al., 2005; cf. Klimesch et al., 1990), the results are discussed separately for each frequency band.

Theta band. Significant effects were observed in the theta frequency band which is known to be sensitive to various language processes (e.g. Bastiaansen & Hagoort, 2006). First, as expected, a larger theta %ERS was revealed in parietotemporal and parietooccipital brain regions for L1 and L2. There is a large body of evidence which suggests that posterior brain regions are involved in reading and integrating letters (Hoeft et al., 2006; Turkeltaub et al., 2003). It was suggested that occipitotemporal regions are the neural circuit of reading (Shaywitz et al., 2007). Theta power increase was found to be related to processes during the retrieval of information from long-term memory (Klimesch, 1999; Klimesch et al., 2001). In this vein, Bastiaansen et al. (2005) specifically observed an increase of theta power while the subjects were reading semantically rich words, suggesting that %ERS in (left) temporal and occipital regions is involved in the retrieval of words' meaning. We presented words which were semantically meaningful. Thus, the higher level of %ERS in parietotemporal regions while processing L1 and L2 is probably related to automatically processing the lexical-semantic meaning of the word from long-term memory. Furthermore,

the posterior network seems to be important for phonological awareness (Frost et al., 2009; Turkeltaub et al., 2003) and morphological awareness (Weiss et al., 2010). Weiss et al. (2010) used an experimental design that was similar to ours and showed involvement of theta %ERS in posterior regions during morphological processes in children. Additionally, the higher level of posterior theta %ERS in the present study could also be related to visual processing and may reflect processing of the visual word form of the DM words (cf. Cohen et al., 2000).

Regarding L1 processing, a stronger increase of theta power when applying the orthographic-morphological strategy compared to the phonological strategy was revealed by the four-way ANOVA. When examining the phonological strategy in L1, a low level of theta %ERS was observed which might indicate that using the rather basic phonological strategy in L1 does not require much language encoding or retrieval. While applying the orthographic-morphological strategy, the stronger %ERS could possibly indicate that this strategy may require the retrieval of lexical information from long-term memory (cf. Bastiaansen & Hagoort, 2006).

More theta %ERS was observed when applying strategies in L2 compared to applying strategies in L1. This allows for the assumption that L2 is not as internally stored in the lexical memory system as L1 due to the fact that it is learned later in life than L1 and is not used on a daily basis. Moreover, it could be the case that words in L2 are linked to the L1 lexicon and, therefore, show a higher level of %ERS (cf. Kroll & Steward, 1994). Most interestingly, only while applying orthographic-morphological strategies in L2, a hemispheric difference was present, revealing stronger theta power increase in the right hemisphere than in the left hemisphere (see Figure 3). When interpreting this effect, it has to be mentioned that hemispheric differences in the orthographic-morphological strategy in L2 were already present with regard to theta bandpower in the reference interval (lower theta power in the right compared to the left hemisphere). Thus, the higher level of %ERS in the right compared to the left hemisphere, while applying the orthographic-morphological strategy in L2, has to

be interpreted with some caution. It may be suggested that the stronger %ERS in the right hemisphere compared to the left hemisphere in this case, could reflect a more intense and/or elaborate lexical search and retrieval processing than it is needed when applying the other strategies. The strong involvement of the right hemisphere while applying the L2 orthographic-morphological strategy might also compensate lower proficiency in L2 (cf. Chee et al., 2001). This compensatory factor seems plausible considering the assumption by Paradis (2004, Chapter 4). He postulates that children who traditionally learn L2 in school after the age of seven, and thus show low L2 proficiency, rely on the declarative memory system to a greater extent than they do in L1. Specifically in the beginning of acquiring L2, the right hemisphere seems to be involved to a greater extent in verbal communication, which is regarding to Paradis (2004, Chapter 4) due to the compensation of the lack of implicit knowledge in L2.

The stronger theta %ERS in the right hemisphere compared to the left hemisphere, only occurs while applying the orthographic-morphological strategy in L2. This coincides with the behavioral findings concerning the lower solution rate of the L2 items requiring orthographic-morphological strategies (see Table 4). It might be assumed that the orthographic-morphological strategies in L2 are not as internalized as the phonological strategy in L2 and both strategies in L1. The assumption that the development of morphological strategies follows the consolidation of the phonological strategy seems to be supported by our findings, at least concerning lexical-semantic aspects of language. Röhm, Klimesch, Haider, and Doppelmayr (2001) showed that increased language processing demands, which imply increased working memory load, are related to theta power increase. Thus, one can assume that the L2 task requiring orthographic-morphological strategies is more demanding in comparison to the L2 phonological task and the L1 morphological task. In conclusion, assuming that morphological awareness is acquired later than phonological awareness, it seems plausible that the low proficient subjects in the present study had more

problems in processing morphological aspects than they did in processing phonological information.

Lower alpha band. Lower alpha emerges topographically rather widespread and was found to reflect basic attentional processes (cf. Klimesch, 1999). Generally, stronger decrease of lower alpha power in applying the phonological strategy compared to applying the orthographic-morphological strategy was found at anteriofrontal sites (see Figure 5). The stronger %ERD might thus reflect the differential engagement of attentional processes during these distinct language processes. At first glance this may seem surprising since the phonological strategy is supposed to be the more basic one. However, when considering the appearance of the words in the phonological DM tasks, it might be speculated that while reading words spelled totally incorrect, it is rather irritating to be not able to pronounce the word properly (in contrast to pseudowords). Thus, the processing of totally incorrectly spelled words might require more mental effort. On the contrary, orthographically incorrectly spelled words which are constructed after phonological principles (morphological task) might not need as much attention to figure out the meaning since the meaning becomes immediately obvious when reading the word. Related to this, Shaywitz et al. (2004) showed that increased task-related activity in the left inferior frontal gyrus is related to phonological training which substantiates the involvement of frontal regions in phonological processing.

No differences in lower alpha %ERD/ERS between L1 and L2 were present when applying the phonological strategy. This finding may indicate that information in L2 concerning the phonological strategy are processed in a similar manner as L1 information requiring phonological awareness. This might be due to the fact that the phonological strategy is a rather basic strategy and becomes internalized first when learning L2. Thus, with the age of eleven years, the subjects may have been relatively aware of this strategy, so that the phonological strategy in L2 was processed similarly to the phonological strategy in L1. At the same time, analyses conducted for the orthographic-morphological strategy revealed

differences in processing L1 versus L2. While using the orthographic-morphological strategy in L1, a higher level of lower alpha %ERD was elicited than in L2. Taking the behavioral data into consideration, it was shown that less morphological items in L2 were solved correctly than in L1. Thus, one could have expected this effect to be the other way around, in presuming that the English task was more complex than the German morphological task, and therefore requires more attention. One possible explanation for this discrepancy may be the lower proficiency level of the subjects in L2 compared to L1. In this vein, Abutalebi et al. (2001) demonstrated that hemodynamic neuroimaging studies showed less neural activation in L2 than in L1 language comprehension processes in less proficient subjects. Consequently, it might be that the activity differences can be explained by a limitation of L2 skills for the low proficient subjects who acquired L2 with around seven years of age in the present study (cf. Abutalebi, 2001). Linguistic information in L2 might underlie a limited elaboration of the linguistic material while using the not fully developed orthographic-morphological strategies, reflected by less %ERD than in L1. Furthermore, in this context it has to be mentioned that L1 words were longer than L2 words, which might possibly as well contribute to a higher attentional level.

Upper alpha band. Upper alpha band is known to be sensitive to specific task requirements and is found to emerge rather topographically restricted in task-relevant brain areas (Pfurtscheller & Lopes da Silva, 2005). Analyses in the upper frequency band showed relatively similar patterns in L1 and L2. It was revealed that overall parietotemporal and parietooccipital regions showed a higher level of %ERD than frontal regions (anteriofrontal, frontal, frontocentral). As already discussed for the theta frequency band, this effect may indicate visual processing and may also be related to processing the word forms (Cohen, 2000; cf. Ihara & Kakigi, 2006). Also, the stronger posterior %ERD may reflect sensory-semantic memory processes of the long-term memory system which is often found above parietooccipital areas (for a review see Klimesch, 1999). However, one difference

within L1 and L2 (for both languages respectively) was shown in the upper alpha band. In L1 the left hemisphere dominated while applying both strategies, whereas in L2 this hemispheric difference was only observed while applying the phonological strategy in L2 (stronger %ERD was shown in the language-dominant left hemisphere compared to the right hemisphere). This hemispheric difference was not apparent when applying orthographic-morphological strategies in L2. It seems that processing phonological information in L2 is similar to language processing in L1 (both show more %ERD in the left hemisphere). Concerning the missing hemispheric difference while applying orthographic-morphological strategies in L2, it becomes obvious, looking at the oscillatory activity pattern, that the missing hemispheric difference can be attributed to a lower level of %ERD in the left hemisphere. Consequently, it might be speculated that the left hemisphere works less efficient in applying orthographic-morphological strategies than while applying the phonological strategies in L2. This may indicate limited processing of morphological information in L2.

4.3 General Discussion

This is to our very best knowledge the first study which has investigated oscillatory EEG dynamics by means of %ERD/ERS in the context of L1 and L2 processes in school children. Generally, it was shown that language processes in L2 elicited more theta %ERS than in L1. This might be linked to semantic encoding and retrieval of the less known L2. Furthermore, the strongest theta %ERS was shown for the orthographic-morphological strategy in L2, indicating a more intense way of lexical retrieval for this strategy. Thus, it might be suggested that the morphological strategy in L2 is not as developed as the more basic phonological strategy in L2 and the orthographic-morphological strategy in L1. This presumption is in line with the behavioral data, which showed that most mistakes were made in the L2 task that required orthographic-morphological strategies. The higher level of lower alpha %ERD in L1 in comparison to L2 might suggest a limited elaboration of L2 due to the lower proficiency level in L2 compared to L1. However, this interpretation has to be

taken with some caution, as the words in L1 were longer than the L2 words which could also contribute to the higher level of %ERD reflecting attentional processes. Hemispheric differences in L2 were only observed during the phonological strategy (stronger %ERD in the left hemisphere), suggesting that the orthographic-morphological strategy in English is not as internalized and, therefore, the missing of the typically left-dominant language processes might indicate a not yet fully developed strategy.

Our findings stand partly in contrast to previous studies which stated more activity during L2 processes (mostly hemodynamic studies, e.g. Chee et al., 2001; Yetkin et al., 1996; cf. Indefrey, 2006; cf. Perani & Abutalebi, 2005). Furthermore, we have not found differences in the frontal region between oscillatory activity in L1 and L2. This might be due to task differences in the present study compared to other studies (we used highly frequent words in which children showed a high response rate). Furthermore, our participants were pre-pubertal children and might be less proficient in L2 than the low proficient participants in other studies. Moreover, the DM task presented in the present study consisted of words across different semantic categories. It is assumed that the meaning of words influences the cortical representation of processing linguistic information (Pulvermüller, 1999). Thus, our findings might be influenced by the words' meanings.

In conclusion, the present study supports the assumption that oscillatory (de-) synchrony plays a functional role in L1 and L2 processes. Our findings provide new insights into how language, specifically a second language, is dynamically represented in the brain. Moreover, it shows neurophysiological differences between different spelling strategies. This information may provide a deeper understanding of L1 and L2 in relation to different spelling strategy mechanisms in the brain, which provide valuable insights into how language is acquired. Thus, this information can help e.g. in the optimization of teaching instructions or the development of language trainings.

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Appendix A

Personal and socio-demographic questionnaire for the children

Datenblatt für UntersuchungsteilnehmerInnen

Testdatum: _____

Code: _____

Liebe(r) Freund(in) der Forschung!

Bitte beantworte alle Fragen nach bestem Wissen. Alle Angaben werden streng vertraulich behandelt und in anonymisierter Form elektronisch gespeichert.

Nachname:	
Vorname:	
Wie lautet deine Telefonnummer?	
Geschlecht: (bitte ankreuzen)	☐ männlich ☐ weiblich
Mit welcher Hand schreibst du? (bitte ankreuzen)	☐ links ☐ rechts ☐ beide
In welchem Jahr bist du geboren?	
In welche Klasse gehst du?	
Welche Schule besuchst du?	
Was ist deine Muttersprache?	☐ Deutsch ☐ andere: _____ Wenn „andere“: Seit wann sprichst du Deutsch? _____ Sprichst du zu Hause Deutsch? _____
Warst du schon mal länger als ein halbes Jahr im englischsprachigen Ausland?	☐ ja → wie lange? _____ Monate ☐ nein
Wie alt warst du, als du angefangen hast Englisch zu lernen?	
Bist du sprachbegabt?	☐ gar nicht ☐ kaum ☐ mittelmäßig ☐ ziemlich ☐ sehr
Wie viele Stunden beschäftigst du dich mit Englisch außerhalb der Schule (z.B. Hausaufgaben, englische Bücher oder Filme)?	_____ Stunden pro Woche
Wie viele Bücher liest du?	_____ Bücher pro Monat
Welche Note hattest du letztes Schuljahr in Mathematik ? (bitte ankreuzen)	☐ Sehr Gut (1) ☐ Gut (2) ☐ Befriedigend (3) ☐ Genügend (4) ☐ Nicht Genügend (5)
Welche Note hattest du letztes Schuljahr in Deutsch ? (bitte ankreuzen)	☐ Sehr Gut (1) ☐ Gut (2) ☐ Befriedigend (3) ☐ Genügend (4) ☐ Nicht Genügend (5)
Welche Note hattest du letztes Schuljahr in Englisch ? (bitte ankreuzen)	☐ Sehr Gut (1) ☐ Gut (2) ☐ Befriedigend (3) ☐ Genügend (4) ☐ Nicht Genügend (5)

Appendix B

Personal and socio-demographic questionnaire for the parents

Projekt „Neurophysiologische Korrelate der Muttersprache Deutsch und der Fremdsprache Englisch“

Elternfragebogen

Ich bitte eineN ErziehungsberechtigteN, die nachfolgenden Fragen zu beantworten. Die Angaben werden selbstverständlich vertraulich behandelt und ausschließlich in anonymer Form für die Studie verwendet.

Vor- und Nachname: _____ Telefonnummer: _____

Vor- und Nachname des Kindes: _____

Kinderanzahl _____

Geschwisterposition des Kindes: ☐ 1. Kind ☐ 2. Kind ☐ 3. Kind ☐ ____ Kind

1. Muttersprache des Kindes: ☐ Deutsch ☐ andere: _____

Wenn „andere“: Spricht Ihr Kind zu Hause Deutsch? ☐ ja ☐ nein

Seit wann spricht Ihr Kind Deutsch? _____

2. Höchste abgeschlossene Ausbildung der Mutter:

☐ Pflichtschule ☐ Lehre ☐ Meisterprüfung ☐ Fachschule ☐ Matura

☐ Akademie ☐ Universität

3. Höchste abgeschlossene Ausbildung des Vaters:

☐ Pflichtschule ☐ Lehre ☐ Meisterprüfung ☐ Fachschule ☐ Matura

☐ Akademie ☐ Universität

4. Hat Ihr Kind einen ungestörten Arbeitsplatz für die Hausübungen?

☐ ja ☐ nein ☐ teilweise

5. Erhält Ihr Kind Nachhilfestunden? ☐ ja ☐ nein

Wenn ja, in welchem Fach? _____

Wie viele Stunden pro Woche? _____

6. Schätzen Sie bitte ab, wie viele Stunden pro Woche Ihr Kind mit folgenden Tätigkeiten verbringt:

Fernsehen: _____ Stunden Computer spielen: _____ Stunden

Lesen: _____ Stunden

7. Mit welcher Hand schreibt Ihr Kind?

☐ links ☐ rechts ☐ beiden Händen

8. Welche Noten hatte Ihr Kind am Ende des letzten Schuljahres?

Deutsch:

☐ Sehr Gut (1)

☐ Gut (2)

☐ Befriedigend (3)

☐ Genügend (4)

☐ Nicht Genügend (5)

Englisch:

☐ Sehr Gut (1)

☐ Gut (2)

☐ Befriedigend (3)

☐ Genügend (4)

☐ Nicht Genügend (5)

Mathematik:

☐ Sehr Gut (1)

☐ Gut (2)

☐ Befriedigend (3)

☐ Genügend (4)

☐ Nicht Genügend (5)

Appendix C
English cloze test “Test of English spelling” (TES; Kargl & Purgstaller, 2010)

Name _____

Datum _____

1. _____ your hands, please.
2. I would like to have a glass of water, because I'm _____.
3. _____ one do you like?
4. Going to London was a big _____.
5. No, his life was not in _____.
6. They all laughed about that _____.
7. Susan is very _____, isn't she?
8. Can you _____ the bread?
9. The _____ is climbing up the tree.
10. Please put the _____ on the letter.
11. This boots are made of _____.
12. This is a _____ question.
13. Look, the fields of green _____.
14. The _____ is swimming.
15. The dog _____.
16. What a beautiful _____.
17. I don't like _____.
18. There are a lot of white _____ on the field.
19. Can you give me the _____, please?
20. _____ is her favourite season.
21. Some girls wear a _____.
22. The police caught the _____.
23. We bought this in the _____.
24. _____ one of the drinks.
25. The Queen is not _____.
26. I bought a _____ instead of a car.
27. He had to stop because of a flat _____.
28. Let's go _____.
29. Can I _____ on you?
30. There are fresh _____ in the bathroom.
31. You are not allowed to use your mobile phone in this _____.
32. He works with _____ people.
33. Can you give me the _____ with the cheese?
34. This is the _____ part of the story.
35. The magician _____ at the end of the show.
36. The singer has got a beautiful _____.

37. I like _____ chips.
38. What kind of _____ do you like?
39. Do you _____ a good restaurant?
40. Peter _____ for the exam.
41. The hero _____ against the dragon.
42. All the _____ were laughing.
43. He travelled to many _____ in Europe.
44. An apple is much _____ than chocolate.
45. You can _____ find a way out.
46. _____ your hair is very hard.
47. It's a great _____ to meet you.
48. Jerusalem is one of the _____ cities in the world.
49. Come on, let's sing _____.
50. The _____ of the film was expensive.
51. This is not cheap, it is _____.
52. We know a good _____.
53. Everyone is a _____ somewhere.
54. Tom's _____ was the best.
55. It is _____ past eight.

Missing words which were read to the children by the experimenter:

1. Wash,	2. thirsty,	3. Which,	4. adventure,	5. danger,
6. joke,	7. nice,	8. cut,	9. monkey,	10. stamp,
11. leather,	12. difficult,	13. grass,	14. swan,	15. barks,
16. evening,	17. meat,	18. sheep,	19. salt,	20. Autumn,
21. skirt,	22. burglar,	23. drugstore,	24. Choose,	25. amused,
26. bicycle,	27. tyre,	28. outside,	29. count,	30. towels,
31. area,	32. disabled,	33. plate,	34. main,	35. disappeared,
36. voice,	37. potato,	38. clothes,	39. know,	40. learned,
41. fought,	42. persons,	43. cities,	44. healthier,	45. easily,
46. Cutting,	47. pleasure,	48. oldest,	49. altogether,	50. making,
51. expensive,	52. lawyer,	53. foreigner,	54. answer,	55. half

Appendix D

“Detection of spelling mistakes” (DM) presented during the EEG sessions

(0 = incorrectly spelled items, 1 = correctly spelled items)

morphological task (L1)	phonological task (L1)	morphological task (L2)	phonological task (L2)
0 Gebeude	1 Häufigkeit	0 buitl	1 wishes
0 lenglich	0 verschärfen	1 beautifully	1 putting
1 Müdigkeit	1 abbestellen	1 where	0 arriv
0 ferlesen	1 Annäherung	0 uptsairs	1 swimming
1 Läufer	0 herumwefen	1 second	0 bicycl
1 pausieren	0 tielbar	1 follow	0 cleen
1 geräuschlos	1 Gebäude	0 wahsing	1 difference
1 auffädeln	0 Spingschnur	0 cimena	0 feight
0 Forteil	1 verbindlich	0 counrty	1 university
1 Verhängnis	0 Speilplatz	1 stayed	1 started
0 ferteilen	1 lärmend	0 tonght	1 page
1 Nachsichtigkeit	1 Neuigkeit	0 puhsing	0 realy
1 vorsichtig	0 herbeigen	1 cloudy	0 pullower
0 notiren	0 lansgam	0 accidnet	0 wich
0 radiren	1 auffangen	1 Thursday	0 Englisch
1 vorlassen	0 Dankbarkiet	1 private	1 sunny
1 lackieren	1 spazieren	1 head	1 June
0 Müdichkeit	0 Gebutstag	1 around	0 wery
1 abbrennen	1 alarmieren	0 vsit	0 diferent
0 erreichen	1 Durchsichtigkeit	0 ditry	1 while
0 vorätig	0 anbeiten	0 peolpe	0 ofice
1 Verbrennung	0 Geißkanne	1 heating	1 lake
0 ausenden	1 blockieren	0 earyl	1 many
0 Wichtichkeit	1 anständig	0 exucse	0 playd
0 ferlaufen	0 Schuldilbung	1 village	0 schort
1 verbeugen	0 verdeinen	1 traffic	1 equally

Appendix E

Information Sheet

Informationsblatt

Forschungsprojekt zur Gehirnaktivierung von Schülern und Schülerinnen bei der Bearbeitung von Englischaufgaben

Englisch ist eine sehr komplexe Sprache, die nicht einfach zu lernen ist. Um Englisch und die damit verbundenen Prozesse besser zu verstehen, führt die Karl-Franzens-Universität Graz in Zusammenarbeit mit dem Lese-Rechtschreib-Institut Graz eine Studie zur **Gehirnaktivierung bei der Verwendung von Englisch** durch.

Die von der ÖNB geförderte Studie dient der **Entwicklung eines Englischtrainings** und in weiterer Folge der Entwicklung und Optimierung neuer Lese-Rechtschreibtrainingskonzepte.

Um mehr Verständnis und Erkenntnisse über das Training zu gewinnen und um den Lerneffekt zu gewährleisten, werden zunächst grundlegende neurophysiologische Prozesse bei dem Gebrauch von Englisch untersucht.

Was passiert im Gehirn, wenn Englisch gelesen wird?

Im Elektroenzephalogramm (EEG) wird die Gehirnaktivierung bei der Bearbeitung verschiedener Englischaufgaben erhoben, um festzustellen, welche Bereiche für den Erwerb der englischen Sprache relevant und wichtig sind.

Außerdem wird mit Hilfe von normierten Testverfahren der aktuelle Leistungsstand in Deutsch und Englisch erhoben. Auf Grundlage dieser Tests kann individuelles Feedback an die Schüler und Schülerinnen gegeben werden. **Zusätzlich wird ein Englisch-Führerschein ausgegeben**, der den aktuellen Stand der Sprachkompetenz angibt, so dass die Schüler und Schülerinnen wissen, in welchen Bereichen sie schon gut sind und welche Bereiche noch geübt werden sollten. Dieses Wissen ist von hoher Bedeutung, um gezielt bestimmte Bereiche üben und verbessern zu können. Des Weiteren bekommen die Schüler und Schülerinnen **als Dankeschön für die Teilnahme** ein individuelles EEG-Foto und ein Bild der eigenen Gehirnwellen zugeschickt.

Die Teilnahme an der Studie umfasst **zwei Termine** an der Karl-Franzens-Universität Graz, die jeweils ca. zwei Stunden in Anspruch nehmen:

1. Termin: diagnostische Testung der Rechtschreib- und Lesefähigkeiten in Deutsch und Englisch (Fragebögen)
2. Termin: Teilnahme an einer EEG-Untersuchung

Leider können wir **nur Schüler und Schülerinnen der zweiten AHS** aufnehmen, die rechtshändig sind und deren **Muttersprache Deutsch** ist.

Die Englischkenntnisse Ihrer Tochter / Ihres Sohnes werden präzise eingeschätzt und sie / er hat die Möglichkeit in die „Welt des wissenschaftlichen Arbeitens“ einzutauchen.

Wir freuen uns, wenn wir Ihr Interesse geweckt haben und Sie unsere Arbeit an diesem praxisrelevanten Forschungsprojekt unterstützen.

Nähere Informationen und Terminvereinbarungen ab sofort:

Tel.: 0650/3212206 (Mo.-Fr. zw. 11 und 17 Uhr) oder
per E-Mail: patricia.weber@uni-graz.at

Wir bitten Sie, diese Information auch an andere Eltern und Interessierte weiterzuleiten.

VIELEN DANK!

Mit freundlichen Grüßen,
Patricia Weber, Priv.-Doz. Mag. Dr. Andreas Fink (Projektleiter)

Appendix F

Example of an individual test profile

Rückmeldung zu den Testergebnissen im Rahmen des Projekts „Gehirnaktivierung in den Sprachen Deutsch und Englisch“

Carolin Hoffmann hat an der Testung im Rahmen des Projekts „Gehirnaktivierung in den Sprachen Deutsch und Englisch“ teilgenommen.

Folgende Testverfahren kamen bei der Testung zum Einsatz:

Die **Hamburger Schreib-Probe (HSP)** (Peter May, 2002) bildet ein diagnostisches Gesamtkonzept für die Erfassung der Rechtschreibfähigkeit in der Schule. Ihr Konzept zielt sowohl auf die Ermittlung der Rechtschreibleistung insgesamt, als auch auf die Erfassung des orthographischen Strukturwissens, das sich in der Beherrschung grundlegender Rechtschreibstrategien zeigt.

Normen: **Der Durchschnittsbereich liegt bei einem Prozentrang von 40 – 60.**

(Anmerkung: Der Prozentrang kennzeichnet die Position einer individuellen Leistung innerhalb einer Vergleichsgruppe. Zum Beispiel besagt ein Prozentrang von 55, dass 55% aller Kinder der Altersgruppe schlechtere Ergebnisse zeigten und 45% weniger Fehler machten.)

Das **Salzburger Lese-Screening (SLS)** (Mayringer & Wimmer, 2003) ist ein standardisiertes Testverfahren zur Beurteilung der basalen Lesefertigkeit. Unter basaler Lesefertigkeit wird die Fertigkeit des fehlerfreien, schnellen und mühelosen Lesens verstanden. Dabei geht es nicht um das an Sprachkompetenz und Wissensvoraussetzungen gebundene Textverständnis, sondern um den technischen Aspekt der Umwandlung der Schriftform von Sprache in die Lautform.

Normen: **Der Durchschnittsbereich liegt bei AHS SchülerInnen bei einem Lesequotienten von 89 - 111.**

Der **telc** (The European Language Certificates) **English A2 School** (telc GmbH, 2010) wird zur Erfassung der allgemeinen Englischfähigkeiten eingesetzt. Es wurden zwei Subtests dieses Testverfahrens vorgegeben: „Sprachbausteine“, zur Erhebung des Wortschatzes und der grammatikalischen Fähigkeiten, und der Subtest „Leseverstehen“, welcher Aufschluss über das Leseverstehen im Zusammenhang mit dem Herauslesen des Wesentlichen, dem detaillierten Lesen und dem selektiven Lesen gibt.

Der **Diagnostische Leistungstest Englisch für die fünfte und sechste Jahrgangsstufe (DLE 5/6)** (Doyé & Lüttge, 1977) dient der Erfassung schulnaher Leistung. Im Rahmen der Testung wurde der Subtest „Briefe Schreiben“ eingesetzt, welcher das freie Schreiben misst. Hierbei werden die Orthographie sowie die grammatikalische Schreibung berücksichtigt.

Der **Englische Lückentext (ELT)** (Kargl & Purgstaller, 2010) misst vor allem, ob die Unterschiede in der Laut-Buchstabenstruktur zwischen Deutsch und Englisch beherrscht werden. Nicht nur die Zahl der falsch geschriebenen Wörter ist entscheidend, sondern es werden auch bestimmte Lupenstellen

analysiert. Es gibt Lupenstellen auf der Ebene der schwierigen Konsonanten, der Vokalschreibungen und der grammatikalischen Kompetenz. Dazu gehören etwa schwierige, neue Buchstabenkombinationen wie das „th“ oder „ea“.

Wichtiger Hinweis: Da die Testwerte unter besonderen Rahmenbedingungen zustande gekommen sind (z.B. Testung in Gruppen), können die hier rückgemeldeten Testergebnisse nicht die von einem/r Fachpsychologen/in durchgeführte Individualdiagnose ersetzen.

Im Folgenden sind die individuellen Ergebnisse in den jeweiligen Testverfahren angeführt:

Hamburger Schreib-Probe (HSP)

Profil zur Hamburger Schreibprobe (in %)

Prozentränge HSP:

	Prozentrang	Durchschnitt
Anzahl richtiger Wörter	60	40 - 60
Anzahl Graphemtreffer	57	40 - 60
Alphabetische Lupenstellen	23	40 - 60
Orthographische Lupenstellen	58	40 - 60
Morphematische Lupenstellen	69	40 - 60

Beschreibung der einzelnen Rechtschreibstrategien:

Alphabetische Strategie

Zur Erfassung der Fähigkeit, artikulierte Laute mit Buchstaben bzw. Buchstabenkombinationen schriftlich festzuhalten ("Verschriftlichung der eigenen Artikulation").

Orthographische Strategie

Zur Erfassung der Fähigkeit, einfache Laut-Buchstaben-Zuordnungen unter Beachtung orthographischer Prinzipien und Regeln zu erweitern und zu modifizieren. "Orthographische Elemente" sind zum einen solche, die sich der Lerner als von der Verschriftlichung der eigenen Artikulation abweichend merken muss („Merkelemente“, z.B. doof, Fußballmannschaft). Zum

anderen sind dies Elemente, deren Verwendung hergeleitet werden kann ("Regelemente", z.B. Spinnennetz, Schmetterling).

Morphematische Strategie

Zur Erfassung der Fähigkeit, bei dem Herleiten der Schreibungen die morphematische Struktur der Wörter zu beachten. Sie erfordert sowohl die Erschließung des jeweiligen Wortstammes (Bedeutungswissen, z.B. Staubsauger, Rauber), als auch die Zerlegung komplexer Wörter in Wortteile (Strukturwissen, z.B. Fahrrrad, Geburtstag).

Salzburger Lese-Screening (SLS)

Lesequotient	Durchschnittlicher Lesequotient
105	89 - 111

telc English A2 School

Subtest	Prozentwert von 100 %
Sprachbausteine (Wortschatz und Grammatik)	96 %
Leseverstehen	75 %

(Telc English A2 school ist ein Multiple Choice Test. Die Prozentangaben beziehen sich auf die richtig bearbeiteten (angekreuzten) Antworten.)

Diagnostische Leistungstest Englisch (DLE 5/6) – Subtest: Briefe Schreiben (BS)

	Prozentwerte von 100%
Wie viel Prozent der Wörter wurden richtig geschrieben (Orthographie)	94 %
Wie viel Prozent der Sätze wurden grammatikalisch richtig geschrieben (Grammatik)	64 %
	Prozentrang
Gesamtes Ergebnis	86

Englischer Lückentext (ELT)

Profil zum Englischen Lückentext (in %)

Erreichte Prozent im ELT:

Fehlerqualität	Prozent
Anzahl richtiger Wörter	55 %
Lupenstellen Morpheme	64 %
Lupenstellen Konsonanten	88 %
Lupenstellen Vokale	71 %

Beschreibung der Lupenstellen:Lupenstellen Morpheme

Zur Erfassung von grammatikalisch gebundenen Phänomene wie beispielsweise „-ed“ bei der regulären Past Tense.

Lupenstellen Konsonanten

Zur Erfassung der Schreibung schwieriger Laute wie beispielsweise. „th“ oder „wh“.

Lupenstellen Vokale

Zur Erfassung der Schreibung schwieriger Vokale oder Zwielaute wie beispielsweise „ea“ oder „aught“.