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Behavioral and neurophysiological effects of morphological awareness training on spelling and reading

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Abstract Behavioral and neurophysiological effects of a computer-aided morphological training protocol were examined in German-speaking children from Grades 3 to 9. Study 1 compared morphological awareness, reading, and spelling skills of 34 trained children with an untrained control group of 34 children matched for age, sex, and intelligence. All participants in the training group showed increases in morphological awareness, but only students from secondary school improved significantly in reading and spelling competences. In Study 2, a subsample of 8 trained children with poor spelling and reading abilities and 10 untrained children with higher language competencies underwent an electroencephalography testing involving three different language tasks. The training resulted in decreased theta-activity and increased activity in lower (7–10 Hz) and upper alpha (10–13 Hz). These findings reflect more effortful and attention-demanding processing after the training and suggest that children with poor spelling and reading abilities use the acquired morphological knowledge in terms of a compensatory strategy.

Keywords Morphological training · Compensatory strategy · Spelling · Reading · EEG · Reading and spelling development

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Introduction

There is a large body of evidence that phonological awareness—the ability to reflect on and manipulate phonological components of a language—plays a major role for reading and spelling acquisition (Bradley & Bryant, 1983; Lundberg, Frost, & Petersen, 1988) and there is a long tradition of intervention studies showing that phonological awareness training improves reading and spelling abilities (Nunes, Bryant, & Olsson, 2003; Tijms & Hoeks, 2005). Recent studies suggest that phonological awareness is not the only meta-linguistic ability that accounts for reading and spelling skills (e.g., Nagy, Berninger, & Abbott, 2006) which has resulted in growing numbers of studies focusing on the training of morphological awareness (Arnbak & Elbro, 2000; Berninger et al., 2008; Elbro & Arnbak, 1996; Lyster, 2002). In the present paper behavioral and neurophysiological effects of morphological awareness training designed by Kargl and Purgstaller (2009) were investigated in two studies. Study 1 evaluated the effectiveness of morphological awareness training in German-speaking children with average to below-average spelling and reading abilities in two different age groups (Grade 3–4 vs. Grade 5–9). In Study 2 neurophysiological correlates of training were investigated in two groups with different spelling and reading abilities using measures of oscillatory electroencephalography (EEG) activity.

Morphological awareness

Morphological awareness is defined as the ability to be aware of and manipulate the smallest meaningful units of language, namely morphemes (Arnbak & Elbro, 2000). The word *unbreakable*, for example, consists of three morphemes: The prefix *un*, the root *break* and the suffix *able*. However, this definition neglects unproductive, non-affix morphemes that only exist in bound forms (e.g. German: *Him—Himbeere* or English: *cran—cranberry*). These simple examples show that morphemes are not the smallest meaningful but the smallest lexical units to build words (see Bhatt, 1991).

An important morphological principle in German is morpheme constancy, which means that the spelling of a morpheme remains constant in different contexts: For example, the German root *les* [read] is always written in a consistent fashion: *lesen* [to read], *Vorlesung* [lecture], *unleserlich* [unreadable]. While morpheme constancy is one of the basic principles of German orthography, in other languages the spelling of a morpheme may change (e.g., English: *swim, swimming*) or the morphological system itself may differ (e.g., there are no infixes in German). Thus, although morphological awareness can be considered as an important strategy in literacy acquisition, it differs across languages due to differences in the morphological systems.

Morphological awareness training

The major advantage of spelling and reading training based on morphological principles is its high economy (Elbro & Arnbak, 1996). According to

Scheerer-Neumann (1979) the 200 most frequently used morphemes constitute about 85% of the words in the German lexicon. Therefore, instead of learning each single word by heart, training the most commonly used morphemes seems to be more reasonable. Following the principle of morpheme constancy described above, the correct spelling of a multitude of words can easily be derived by morphological spelling rules (see also Elbro & Arnbak, 1996).

Some authors claim that the usage of different reading and spelling strategies during development depends on the orthographical transparency-level of a language. It is hypothesized that in languages with a higher grapheme-phoneme-consistency (e.g., German, Finnish, or Norwegian) the initial steps of literacy acquisition might occur earlier and with more ease than in languages with a lower predictability of sound–symbol linkage (e.g., English or Danish; Shaywitz, Morris, & Shaywitz, 2008; Ziegler & Goswami, 2005). Thus, it could be possible that morphological awareness is less important for transparent languages (e.g., German) because phonological strategies might more effectively be used in those languages. However, even in languages with a higher grapheme-phoneme-consistency like German there are many spelling problems which cannot be solved by phonological training. The correct spelling of the German word *Fahrrad* [bicycle] consisting of the two roots *fahr* [drive] and *rad* [wheel], for example, is based on the correct usage of a morphological strategy as the word's pronunciation does not give any information the double 'r'.

Recent studies have provided evidence that morphological awareness training might be effective in improving reading and writing competences in various languages regardless of their transparency level. Arnbak and Elbro (2000) proved the effectiveness of morphological training in Danish. They found that trained dyslexic children gained significantly in morphological awareness, reading comprehension, and in spelling morphologically complex words after oral morphological awareness training. Lyster (2002) tested Norwegian children and showed that morphological awareness training was as effective as phonological training in improving reading skills, even at an early stage of reading development. In a Dutch training study, Tijms and Hoeks (2005) evaluated the effect of a computer-based training protocol which focused on phonological awareness, but additionally contained morphological components. The trained children improved in reading and spelling after the training, but it is not clear if this training effect can specifically be attributed to either the morphological or the phonological components of the training or to the combination of both.

Most importantly for the present study, Walter et al. evaluated the effects of a computer-aided morphological training protocol on spelling ability in German (Walter, 1986; Walter, Bigga, & Bischof, 1995; Walter, Rodiek, & Landgrebe, 1989; Walter, Schliebe, & Barzen, 2007). In their studies, learning disabled children worked on computer software which required solving German cloze tests with missing morphemes. The authors found a positive effect of the morphological awareness training on knowledge of morphological word segmentation, spelling ability, and capitalization-competence. In Walter et al. (2007) the training effect was apparent not only immediately after the training but also in a follow-up test session 10 weeks later. Hence, the findings from the studies of Walter et al.suggest that learning disabled children can benefit from morphological awareness training in a relatively transparent language like German.

Neurophysiological correlates of reading and spelling ability

A major objective of measuring brain correlates of reading and spelling ability and investigating related training protocols is to understand the neuronal bases of learning disabilities in this domain. Studies using functional magnetic resonance imaging (fMRI) have shown that reading impairment is related to a dysfunction in left-hemispheric posterior brain systems (e.g., Shaywitz et al., 2002). This also seems to apply for the German language as Kronbichler et al. (2006) found a dysfunction of left posterior areas in German dyslexic readers. Training studies using fMRI have, moreover, shown that behavioral changes through remediation are accompanied by changes in brain activation. At a gross level, two types of result patterns were observed. Some studies found that training led to a normalization of brain function. As an example, Aylward et al. (2003) investigated the effect of a general reading treatment on phoneme and morpheme mapping and found that the improvements in the morpheme mapping task were associated with an increased activation in brain regions engaged in normal readers. The second pattern of results which repeatedly emerged was that training protocols result in additional, presumably compensatory, activation (e.g., Eden et al., 2004).

The results of training studies using fMRI allow a differentiated localization of changes in brain activation following an intervention. However, the temporal resolution of fMRI is inherently poor due to the slow time constant of the hemodynamic response. The method of EEG, in contrast, allows the investigation of the dynamics of neural activity with a high temporal resolution. In particular, there is growing interest in the functional formation of neuronal networks and their interaction during cognitive information processing in general (Bastiaansen & Hagoort, 2003; Fink, 2005; Grabner, Fink, Stipacek, Neuper, & Neubauer, 2004; Grabner, Neubauer, & Stern, 2006) and during language processing in particular (Bastiaansen, van der Linden, ter Keurs, Dijkstra, & Hagoort, 2005; Grabner, Brunner, Leeb, Neuper, & Pfurtscheller 2007; Hald, Bastiaansen, & Hagoort, 2006). A well-established approach to investigate the dynamics of functional network formation is the analysis of induced EEG activity (Bastiaansen & Hagoort, 2003). In contrast to evoked activity, which can be regarded as (time- and phase-locked) response of a quasi-stationary system to an event (i.e., event-related potentials), induced activity refers to functional changes in the oscillatory brain activity, reflecting the dynamic interactions within as well as between brain structures. The quantification of event-related synchronization (ERS) and desynchronization (ERD) has proved to be a particularly useful and appropriate measure in this context (cf. Pfurtscheller & Lopes da Silva, 2005). This method calculates the percentage amount of band power increases (ERS) or decreases (ERD) in any frequency band from a pre-stimulus reference interval to an activation interval.

The functional significance of bandpower changes in different frequency bands is increasingly better understood in the domain of language processing. Bandpower increases (ERS) in the theta band were found to be associated with semantic information processing (Bastiaansen et al. 2005; Grabner et al., 2007) and with the maintenance of information in working memory (Klimesch, 1999). Alpha power increases (ERS), in contrast, are often discussed to reflect cortical idling whereas its decline (ERD) is thought to indicate active information processing (Bastiaansen & Hagoort, 2003). In addition, there is converging evidence that alpha oscillations can be separated into two distinct frequency bands supporting different functions (Klimesch, 1999; Fink, Grabner, Neuper, & Neubauer 2004; Pfurtscheller & Lopes da Silva, 2005). ERD in the lower alpha band (7–10 Hz) emerges topographically widespread over the scalp and is assumed to reflect general task demands and attentional processes, whereas the upper alpha band (around 10–13 Hz) is topographically restricted and reflects task-specific cognitive information processing. Higher frequency oscillations in the beta (approx. 13–30 Hz) and gamma (around 40 Hz) band were found to be associated with syntactic rather than semantic processes in language comprehension (cf. Bastiaansen & Hagoort, 2006).

Oscillatory measures of EEG activity have also turned out to be sensitive to individual differences in reading and spelling ability, even though the findings do not yet provide a consistent picture. Coombes, Janelle, Duley, and Conway (2005) found that dyslexic adults display less theta activity during a sequential motor task than an age- and IQ-matched control group. Klimesch et al. (2001) investigated variations in lower and upper event-related alpha band power (ERBP; similar to ERS/ERD) and tonic theta power during three language-based conditions (reciting visually presented numbers, corresponding number words, and pseudo-words). Dyslexic children made significantly more errors than controls only in the pseudo-word condition but were lacking an accompanying increase in theta ERBP in occipital regions which was apparent in the controls. They interpreted this result as an inability of dyslexic children to encode and process pseudo-words in visual working memory. Based on previous oscillatory EEG studies, Coombes et al. (2005) proposed two different patterns of theta activity found in dyslexics: an increased frontal theta activity representing a decreased ability to process language-related information, and a decrease in occipital theta, indicative of an inability to access working memory. Spironelli, Penolazzi, and Angrilli (2008) investigated the significance of the theta band with regard to the temporal dynamics of word reading. They found that dyslexics display a delayed peak of theta activation compared to a control group. Additionally, dyslexics showed higher theta activation in the right hemisphere while the control group displayed higher theta activity in the left hemisphere.

Concerning EEG activity in the alpha band, there is evidence that dyslexics are characterized by a lack of task related reduction of alpha activity (Duffy, Denckla, Bartels, Sandini, & Kiessling, 1980) indicating reduced attention in dyslexic children (Rippon & Brunswick, 2000). Klimesch et al. (2001) investigated lower and upper alpha separately. In the lower alpha band, dyslexics showed an increased response to words and pseudo-words at right hemispheric sites. The upper alpha band exhibited a highly selective response to words at left frontal sites but for controls only, whereas dyslexics displayed larger alpha power already during the reference interval. They concluded that dyslexics have a lack of attentional control during the encoding of words.

The effects of morphological awareness training on oscillatory EEG activity have, to our knowledge, not been investigated so far.

Aims and research questions

The aim of Study 1 was to examine the effectiveness of computer-aided morphological awareness training recently developed by Kargl and Purgstaller (2009). Native German speaking children (3th–9th Grade) with average to below-average spelling and reading competences participated in the study. A training and control group matched for age, sex, and non-verbal intelligence were tested with regard to morphological awareness, reading and spelling before and after training. Based on previous studies showing beneficial effects of morphological awareness training on reading (Arnbak & Elbro, 2000; Lyster, 2002) and spelling competences (Walter, 1986; Walter et al., 1989, 1995, 2007), we expected that the training protocol would enhance morphological awareness and lead to an improvement of the spelling and reading abilities in the training group. In addition, training effects were examined in two different age groups, viz. primary (3rd–4th Grade) and secondary (5th–9th Grade) school, as it is unclear at which age morphological awareness training leads to improvement in reading and spelling performance. While some studies have shown a positive training effect of morphological training for children in kindergarten (e.g., Lyster, 2002), other authors, in contrast, claim that the impact of the morphological awareness on reading and spelling increases in the course of the development of these competences (Casalis, Colé, & Sopo, 2004; Deacon & Kirby, 2004; May, 2000).

The aim of Study 2 was guided by the objective of investigating neurophysiological correlates of the specifically designed training by comparing the oscillatory EEG activity of two groups of children with different spelling and reading abilities during the performance of three different language tasks (detection of spelling mistakes, capitalization case sensitivity, and morphological relatedness). In particular, ERS and ERD in the following language-related frequency bands were examined: theta (4–7 Hz), lower alpha (7–10 Hz), and upper alpha (10–13 Hz). Only the group with lower spelling ability participated in morphological awareness training while the control group did not get any intervention. This group selection was guided by the objective to investigate the nature of morphological training gains in children with low spelling and reading abilities. In this regard, two different result patterns can emerge: on the one hand, training might lead to an equalization of the brain activity of the lower ability group to that of the higher ability group, similar to the "normalization" of brain activity of the training group shown in the fMRI study of Aylward et al. (2003). On the other hand, it is possible that after training the brain activity of the trained group would differ even more from that of the control group. This would suggest that morphological awareness training provides knowledge that can be used in terms of a compensatory strategy (e.g., Elbro & Arnbak, 1996).

Study 1

Method

Participants

Overall, 94 children with German as their mother tongue from schools in Graz, Austria (3th–9th Grade; 8–18 years) participated in the training study. Thirty-four children belonged to the training group. From the remaining pool of 60 children, 34 'statistical twins' were selected to form a control group matched in age, spelling ability, non-verbal intelligence (see Table 1), and sex (each group consisted of 15 girls and 19 boys). Although all participants were recruited towards the end of the regular school year, they were tested and trained during the summer holidays when they were not receiving any institutionalized education. All parents or guardians of the children gave written informed consent.

Experimental design and material

All children were tested before (pretest) and after (posttest) the summer holidays in groups of 5–20 children of the same grade. Pre and posttest included measures of morphological awareness, spelling, and reading ability. Except for the reading test, the same test form was administered in the pretest and posttest. The non-verbal intelligence was only measured in the pretest-session. Each test session took about 2 h including a break of 15 min. During the summer holidays, the children of the experimental group participated in computer-aided morphological training and received additional instructions on morphological principles.

Non-verbal intelligence. To measure participants' non-verbal intelligence, Raven's standard progressive matrices (SPM) were used (Raven, 1960). For reasons of time-economy the test was given with the shorter time limit of 20 min proposed by Raven.

Reading. Reading ability was measured with the German reading assessment SLS [*Salzburger Lese-Screening*] developed by Mayringer and Wimmer (2003, 2005). This short reading test gives a reliable index of basal reading competence focusing on the reading rate. Two versions (SLS 1-4 and SLS 5-8) are available which can be applied from Grade 1 to 8. Furthermore, there are two parallel forms for each version with parallel-test reliabilities between 0.90 and 0.91.

Table 1 Descriptive data (mean, standard deviation in brackets) of the training and control group in the pretest of Study 1

Variables	Training group	Control group
Non-verbal intelligence (raw score)	37.38 (8.58)	36.03 (7.26)
Age (in years)	11.76 (1.79)	11.47 (1.58)
Spelling (*T*-values)	44.68 (5.09)	44.09 (4.81)
Reading (*T*-values)	43.71 (9.87)	48.30 (9.52)

Spelling. Spelling ability was assessed with the German spelling test HSP [*Hamburger Schreib-Probe*] developed by May (2000). This instrument provides a reliable (internal consistencies for Grades 3–9 between 0.80 and 0.96) measure of general spelling competence. An advantage of the HSP is its broad applicability as test forms and specific norms exist for Grades 1–9. Therefore, this test can be seen as a powerful instrument for comparing spelling abilities of different age groups. With respect to the age range under investigation, the HSP comprises 38 (3rd Grade), 42 (4th Grade), and 49 (5th–9th Grade) words to compute general spelling ability.

Morphological awareness. The German spelling test HSP also provides specific scores for the following three spelling strategies: alphabetical, orthographical and morphological. The score for the morphological spelling strategy was used as a reliable (internal consistencies for Grades 3–9 between 0.75 and 0.89) measure of morphological awareness in the present study. It is based on the number of correctly spelled critical morpheme positions which are letter groups in a word that require morphological rather than phonological or orthographical knowledge. For example, the German word *Fahrrad* [bicycle] is written with two ‘r’s which cannot be inferred from the pronunciation of the word but follows the morphological principle of morpheme-constancy: both morphemes *Fahr* [to drive] and *rad* [wheel] remain constant, and the composition of the two morphemes leads to the double ‘r’. In contrast to orthographical rules that give information how single morphemes are spelled correctly, morphological rules refer to the question of how to operate with morphemes. Thus, the silent ‘h’ in the word *Fahrrad* counts for the orthographical strategy score while the position *rr* counts for the morphological strategy score of the HSP. The number of critical morpheme positions in the different age versions is 10 (3rd Grade), 15 (4th Grade), and 20 (5th–9th Grade).

In a control analysis on the specificity of the training for morphological strategies, we also used the scores for the alphabetical and orthographical strategies. The number of critical word positions is 20 alphabetical and 15 orthographical for the 3rd Grade, 25 and 20 for the 4th Grade, and 30 and 25 for the 5th–9th Grade version of the HSP. Please note that some words included two critical positions (e.g., critical orthographical and morphological positions); therefore, the number of words to compute the general spelling ability is lower than the sum of the strategy-related word positions. Since the number of words and critical positions differ between the age versions, we used standardized *T*-scores to investigate age effects.

Training

The computer-aided training program “MORPHEUS”, developed by Kargl and Purgstaller (2009), included 16 different playful exercises dealing with morphemes (see Table 2). The training material (morphemes) is based on the German basic vocabulary for 4th-Graders (Augst, 1989). After each exercise, the training software gives feedback about the percentage of correctly solved items. An exercise is considered to be mastered successfully when the percentage of correctly performed items is at least 75%. This implies that participants do not work through the program at a fixed pace. The morphological training was provided as software (to be easily

Table 2 Exercises of the training software MORPHEUS

Exercises	
1. Finding suffixes	Choose the suitable suffix for a given root out of three alternative suffixes
2. Ordering word parts	Morphemes are flying around on the screen. They have to be ordered so that they add up to meaningful words
3. Matching of word-families	Each word of a list has to be assigned correctly the one out of three different roots it is related to
4. Counting morphemes	Indicate the number of morphemes a given word consists of
5. Identification of nouns	Nouns have to be identified from a number of words belonging to different categories (parts of speech)
6. Identification of category (part of speech)	Assign each word of a list to the correct grammatical category
7. Sorting words after prefixes	Match given words with the prefix they start with
8. Sorting words after suffixes	Match given words with the suffix they end with
9. Counting morphemes	Indicate the number of morphemes a given word consists of
10.–12. Transcription of words	Given words have to be copied (transcribed)
13. Identification of roots	Mark the root of given words
14. Counting and transcription of morphemes	Indicate the number of morphemes a word consists of and then write down each morpheme separately
15. Splitting up words	Split up words into its morphological components
16. Solving a morpheme-cloze	Fill in missing morphemes in a cloze text

installed on any home PC) and carried out within 2–3 weeks during the summer holidays for about 60 min per day.

In addition to the exercises on the PC, children participated in five lessons of 2 h at the *Institute for Reading and Spelling* [Lese-Rechtschreib-Institut] in Graz, where morphological principles of the German language were explained by certified teachers. These lessons took place in small groups of 3–5 children of the same grade level. Furthermore, children had to complete exercises in a manual to ensure the transfer of the learned material from the keyboard of the PC to the handwriting. This manual consists of 102 short exercises dealing with morphemes. The words used in the manual were again taken from the pool of the German basic vocabulary for 4th-Graders (Augst, 1989). Half of the exercises were completed at the institute during the five lessons where a teacher explained the exercises and controlled the homework. The remaining exercises were done by the children individually at home. Taken together, trained children spent about 30–40 h on the three parts of the intervention (about 15 h on training software, 10 h on the five lessons, and 10 h on the manual). Hence, the applied morphological training protocol can be regarded as an intensive intervention program.

To control effects of other activities such as reading books, playing computer games or watching TV, a questionnaire asking for the hours per week children spent on these activities was filled in by the parents. No group differences were found in these control variables (*p*s > 0.19).

Results

In order to examine the training effects on reading, spelling, and morphological awareness, analyses of variance (ANOVAs) for repeated measures were performed, including TIME (pre- and posttest) as within-subject factor as well as GROUP (training vs. control group) and GRADE (primary vs. secondary school) as between-subjects factors. In case of violations of the sphericity assumption, degrees of freedom were adjusted by means of the most conservative Greenhouse-Geisser correction. The probability of a Type-I error was maintained below 0.05. The descriptive statistics of the reading and spelling abilities at pre- and posttest for the training and control group are presented in Table 3.

Reading

In a first step, statistical analyses for basal reading competence were performed. The ANOVA showed a significant TIME × GROUP × GRADE interaction, $F(1,59) = 7.29$, $p < 0.01$, $\eta 2 = 0.11$, and a main effect of GROUP, $F(1,59) = 5.45$, $p < 0.05$, $\eta 2 = 0.09$. As depictured in Fig. 1, only trained secondary school children were able to improve their reading ability after the intervention. Neither trained primary school children nor untrained children showed a significant gain in reading competence.

Spelling ability

Analyses for spelling ability yielded a similar picture as for reading competence: most importantly, there was a three-way interaction of TIME, GROUP, and GRADE, $F(1,64) = 9.97$, $p < 0.01$, $\eta 2 = 0.14$, revealing that again only trained secondary school children displayed a significant gain in spelling ability after training (see Fig. 2). Neither the untrained children nor the trained primary school children had a significant performance change in spelling ability from pre- to posttest. In addition to this, the main effects of GRADE, $F(1,64) = 9.56$, $p < 0.01$, $\eta 2 = 0.13$, and the interactions of TIME × GROUP, $F(1,64) = 7.91$, $p < 0.01$, $\eta 2 = 0.11$, as well as TIME × GRADE, $F(1,64) = 5.68$, $p < 0.05$, $\eta 2 = 0.08$, reached significance.

Table 3 Descriptive data (means, standard deviations in brackets) of the training and control group in the pre- and posttest of Study 1 for general spelling competence, the three different spelling strategies of the HSP, and the general reading competence (SLS; *T*-values)

Variables	Pretest		Posttest	
	Training group	Control group	Training group	Control group
General reading competence	43.74 (10.04)	48.81 (9.20)	44.88 (11.60)	49.27 (8.78)
General spelling competence	44.68 (5.09)	44.09 (4.81)	46.35 (4.76)	43.59 (6.04)
Alphabetical strategy	42.24 (6.94)	40.15 (8.57)	41.94 (4.84)	41.59 (7.02)
Orthographical strategy	43.38 (6.56)	42.71 (6.52)	45.15 (6.46)	42.94 (6.94)
Morphological strategy	41.32 (7.55)	42.65 (7.60)	44.53 (8.23)	41.44 (8.75)

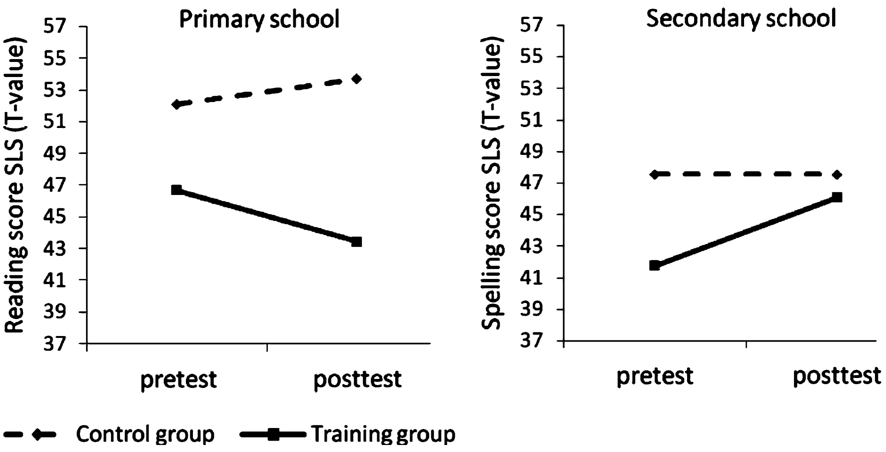

Fig. 1 Changes in the reading score of the control and the training group from pre- to posttest—separately for primary and secondary school children

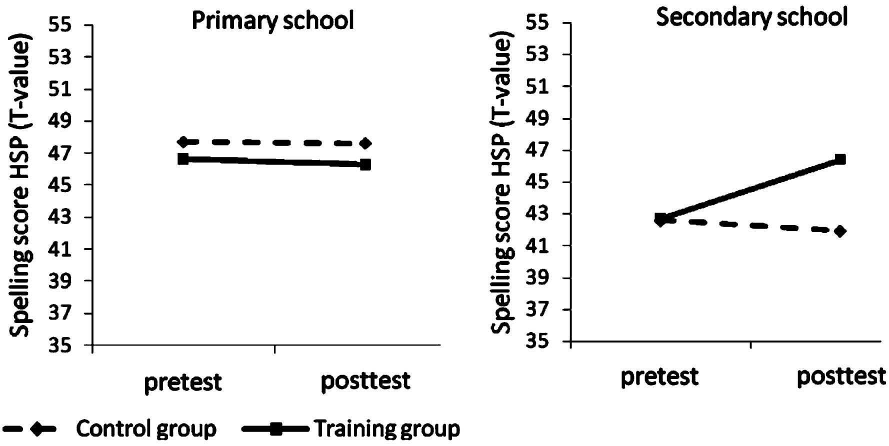

Fig. 2 Changes in the spelling score of the control and the training group from pre- to posttest—separately for primary and secondary school children

Morphological strategy

The analyses of the morphological strategy score of the HSP revealed no significant three-way interaction, but a significant interaction between TIME × GROUP, $F(1{,}64) = 11.43$, $p < 0.01$, $\eta 2 = 0.15$. This indicates that trained children from primary as well as from secondary school improved their morphological strategy use from pre- to posttest while no improvement was observed in the control group (see Fig. 3). Furthermore, a significant main effect of TIME was found, $F(1{,}64) = 4.22$, $p < 0.05$, $\eta 2 = 0.06$.

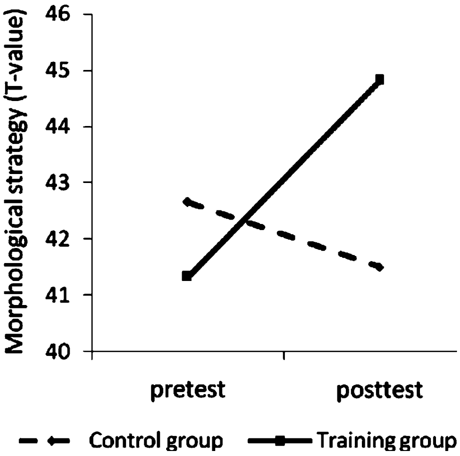

Fig. 3 Changes in the morphological strategy score (HSP) of the control and training group from pre- to posttest

Specificity of training effect

In order to investigate whether the observed training effect is specific to competences concerning morphological awareness, training gains in the three different spelling strategies (alphabetical, orthographical, and morphological) provided by the spelling test HSP were compared. An ANOVA with the within-subject factors STRATEGY and TIME was performed, including only the scores of the training group. Analyses revealed a significant interaction between TIME × STRATEGY, $F(2,66) = 3.97$, $p < 0.05$, $\eta 2 = 0.11$. As depicted in Fig. 4, the training group improved mainly in the morphological strategy and, to a smaller extent, in the orthographical one. As expected, there was no improvement in the alphabetical strategy. These results suggest that the morphological training program had a rather specific effect on children's linguistic abilities.

Discussion

Similar to the studies of Walter (1986) and Walter et al. (1995, 1989, 2007), we found a positive effect of computer-aided morphological training on morphological awareness. In reading and spelling abilities, this effect was moderated by grade, revealing that only secondary school children benefited from the intervention. Since younger children improved in morphological awareness without gaining in reading and spelling competences it may be speculated that they acquire morphological knowledge, but do not use it efficiently for spelling and reading processes. This fact does not implicate that children are not able to use morphological strategies at an earlier point of language development. It is known from previous studies that children can use simple morphological strategies already at the beginning of reading and spelling acquisition (Berko, 1958; Kemp, 2006; Treiman & Cassar, 1996). However, results of the present study showed no improvement in younger children in reading and spelling after morphological awareness training. Treiman and Cassar

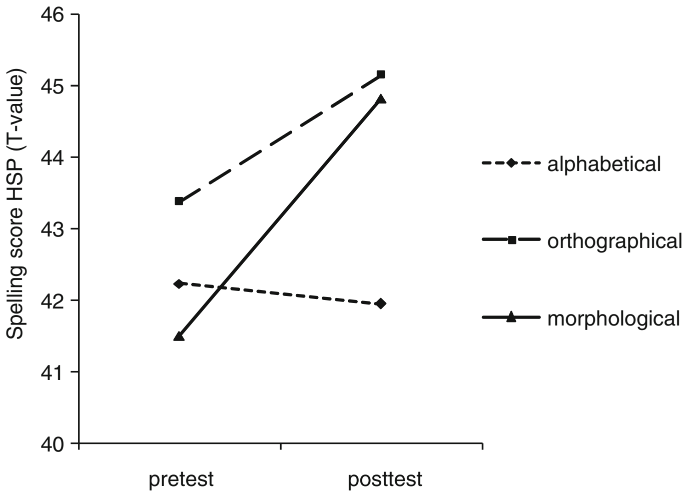

Fig. 4 Changes in the three spelling strategies of the HSP from pre- to posttest—only for the training group

(1996) hypothesized that young children can only use morphological strategies on tasks with few competing demands on their attention. Concerning this argument, it is possible that the spelling and reading tests used in our study were too complex so that younger children were not able to apply their acquired morphological knowledge on these tasks. Furthermore, it could also be hypothesized that the effective application of morphological knowledge may require that other competences (phonological awareness, orthographical knowledge) have already been well-developed (cf. May, 2000; Reuter-Liehr, 1993). However, our data does not provide direct evidence for this assumption. To determine the impact of different strategies during language development further studies examining both, phonological and morphological awareness within a developmental framework are needed.

Nevertheless, our findings are in line with recent models on the development of reading and writing skills (May, 2000; Richards et al., 2006). Accordingly, normal spelling goes through different stages: an initial phonological stage, followed by an orthographic stage, and a morphological stage. In the phonological stage word reading/encoding operates with strategic mapping of phonemes onto graphemes. In the orthographic stage most words are represented in the autonomous orthographic lexicon where they can quickly be retrieved from memory. In the final stage morphological strategies are increasingly applied in reading and writing processes. There is empirical evidence supporting this developmental framework. Accordingly, phonological strategies dominate in the early stage of the language development (Schneider et al., 1997; Lyster, 2002) but lose impact in later development when orthographic and morphological strategies gain importance (Müller & Brady, 2001). Even though the study of Lyster (2002) revealed a positive effect of morphological awareness training on reading already in kindergarten the present study provides further evidence that the impact of morphological spelling rules increases during spelling and reading development, as has previously been proposed by a number of authors (Carlisle, 1988; Casalis et al., 2004; Deacon & Kirby, 2004; May, 2000; Nagy, Diakidoy, & Anderson 1993). However, such stage-models should be considered as rather simplified frameworks which only represent reading and spelling development approximately, hence, the different stages should be regarded as smooth transitions with overlapping areas between the stages (Henderson, 1992; Varnhagen, McCallum, & Burstow 1997).

Surprisingly, the age-related effect of morphological awareness training seems to be valid for English and German, even though they represent languages with very different levels of grapheme-phoneme-consistency. The German language is characterized by a higher grapheme-phoneme-consistency compared to the English language which has a less transparent orthography. Ziegler and Goswami (2005) conclude that grapheme-phoneme recoding skills are developed faster in transparent orthographies. Thus, it would be reasonable that in languages, such as German, morphological strategies become important at an earlier stage. However, Bierwisch (1976) and Topsch (1979) argued that the transparency of German is limited and the usage of phonological strategies in German might lead to many mistakes in reading and spelling. Evidence from the present study suggests that morphological awareness might be as important at a similar point in language development for German as for other languages.

The results of Study 1 give information about the effectiveness of the morphological training protocol on improving behavioral performance in reading, spelling, and morphological awareness. However, the neurocognitive processes underlying the behavioral changes in morphological awareness still remain unknown. In Study 2 we investigated the neurophysiological correlates of the training effects using EEG.

Study 2

Method

Participants

From the pool described in Study 1 only right-handed children who received informed consent from their parents were allowed to participate in the EEG-study. Ten children of the training group met these criteria and participated in both, the pre- and the posttest EEG-session. A total of 22 children were tested before and after the summer holidays. Two children had to be excluded from further analyses due to extensive EEG artifacts. The remaining eight children (4 girls, 4 boys) of the training group were compared with respect to their brain activity before and after training with 12 children (8 girls, 4 boys) of the control group. The two groups did not differ significantly in age and nonverbal intelligence but, as intended, the control group showed higher scores in the reading and spelling test than the training group (see Table 4).

Table 4 Descriptive data (mean, standard deviation in brackets) of the training and control group in the pretest of Study 2

Variables	Training group	Control group
Non-verbal intelligence (raw score)	35.13 (9.09)	40.83 (8.78)
Years of age	11.87 (1.64)	10.67 (1.30)
Spelling (*T*-values)***	41.89 (5.09)	52.50 (3.23)
Reading (*T*-values)**	42.33 (4.86)	59.41 (13.39)

*** $p < 0.001$; ** $p < 0.01$

Experimental tasks

During the EEG measurement in the pre- and posttest the children had to solve the following three visually presented morphological tasks using two response buttons on an external keyboard. Parallel versions of the tasks (involving different stimuli) were used in the pre- and the posttest. To ensure that children were familiar with the words used as stimuli in the three tasks, highly frequent words based on the German basic vocabulary for 4th-Graders (Augst, 1989) were chosen. To evaluate the validity of the tasks presented during EEG measurement correlations between morphological strategy of the HSP and the reaction times of the tasks were calculated. As presented in Table 5, high correlations were found, indicating the involvement of morphological strategies in the presented tasks. As expected, the highest correlations were observed for the task assessing morphological relatedness.

Detection of spelling mistakes (DM). In this task participants had to decide whether a presented word was spelled correctly or not (cf. *orthographic mapping* in Richards et al., 2006). The experimental material consisted of 50 items: 20 words with morphological positions spelled correctly (e.g., *Wäsche* [clothes]), 20 words with orthographically incorrect spelling but constructed after phonological principles (e.g., *Menner* instead of *Männer* [men]), and 10 words spelled totally incorrectly (e.g., *trönken* instead of *trinken* [to drink]). In this task, children who solely rely on phonological strategies should not be able to detect most of the misspelled words from the second category, because they may appear correct when applying phonological rules. In fact, in order to perform well on this task it is necessary to consider morphological spelling rules.

Capitalization case sensitivity (CCS). This task was chosen because in German, morphological spelling rules can effectively be used for a correct capitalization. The suffix of a word (which is a morpheme) gives information about which lexical

Table 5 Correlation coefficients between morphological strategy and reaction times during the EEG tasks – separately for pre- and posttest

Variables	Pretest	Posttest
DM × morphological strategy	−0.51*	−0.47*
CCS × morphological strategy	−0.58**	−0.46*
MOR × morphological strategy	−0.65**	−0.55*

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

category a word belongs to. For example, the suffix—*nis* can only be found in nouns or the morpheme—*lich* can exclusively stand at the end of adjectives or adverbs. Following the rule that "nouns begin with a capital letter, verbs, adjectives, and adverbs with a lower-case one" a great number of words can be spelled in accordance with these capitalization rules. In line with this argumentation, Walter et al. (1995) found that in German, morphological awareness training leads to improved capitalization-case-sensitivity. For this reason the CCS task was presented during EEG measurement as a morphological task in Study 2.

In this task participants had to decide whether a given word has to be written with a capital letter or not. The 60 items which were presented in uppercase letters only constituted: 10 concrete nouns, 10 concrete non-nouns, 20 abstract nouns as well as 20 abstract non-nouns. For example: *VERHÄLTNIS* [RELATION] as abstract noun or *TISCH* [TABLE] as concrete noun, both spelled with capital letters in German, or *LUSTIG* [FUNNY] as abstract non-noun, or *GRÜN* [GREEN] as concrete non-noun, both spelled without capital letters.

Morphological relatedness (MOR). In this task, pairs of words were presented one above the other. Participants had to decide whether the bottom word was related to the top word or not (cf. *morpheme mapping* in Aylward et al., 2003). The task included a total of 40 items: 20 related and 20 unrelated words. For example: *warm—Wärme* [warm - warmth] as related words or *warm—warnen* [warm—warn] as morphologically unrelated words with similar phonological characteristics.

Procedure

In pre- and posttest, the EEG session started with mounting the electrodes and checking the electrode impedances. Subsequently, the child was seated in a comfortable chair in the EEG recording room. Measurement started with two sequences under resting conditions—the first one with eyes closed, the second one with eyes open, each lasting 2 min. Then participants began to work on the three tasks described above. The presentation order of the tasks was counterbalanced. After each task the child was free to take a break of about 3 min. At the end of the test session, 2 more 2-min resting EEG sequences (with eyes closed and eyes open, respectively) were recorded. In total, the EEG session took about 1 h.

Apparatus/EEG recording

EEG-signals were recorded by means of gold electrodes (9 mm diameter) located in an electrode cap in 33 positions (according to the international 10–20 system with interspaced positions). All electrodes were referenced against a common reference placed on the nose; a ground electrode was located on the forehead. To register eye movements, an electrooculogram (EOG) was recorded bipolarly between two gold electrodes diagonally placed above and below the inner as well as the outer canthus of the right eye. This electrode placement allowed for detecting both, vertical and horizontal eye movements using only one EOG channel. The EEG signals were filtered between 0.1 and 100 Hz; an additional 50 Hz notch filter was applied to avoid power line contamination. Electrode impedances were kept below 5 Ω for the

EEG and below 10 Ω for the EOG. Trigger signals for the stimulus presentation and the responses were also recorded. All signals were sampled at a frequency of 250 Hz.

Event-related synchronization/desynchronization

Cortical activity during performance of the three tasks was quantified by means of event-related-synchronization or desynchronization (ERS or ERD) in the EEG (Pfurtscheller & Lopes da Silva, 2005). This method calculates the percentage amount of bandpower increases (ERS) or decreases (ERD) in any frequency band from a pre-stimulus reference interval (R) to an activation interval (A), using the following formula:

$$\mathrm{ERS/ERD} = \frac{A - R}{R} \times 100$$

Decreases in power from the reference to the activation interval are expressed as negative values (ERD), while task-related increases in power are expressed as positive values (ERS).

As depicted in Fig. 5, a 1,000 ms time interval (2,000-3,000 ms) during presentation of a fixation cross for 3,500 ms served as pre-stimulus reference interval for ERS/ERD calculation. As activation interval—while participants were working on the experimental tasks—a 1,000 ms time window directly after stimulus presentation (4,000–5,000 ms) was defined.

For both, the reference and the activation intervals, EEG data were carefully checked for artifacts by visual inspection. Trials containing artifacts caused by muscle tension, eye blinks or eye movements in one of the two intervals were excluded from further analyses. Only correctly solved trials were included in the statistical analyses.

EEG signals were filtered by applying a Fast-Fourier-Transformation (FFT) filter separately for each analyzed frequency band (theta: 4–7 Hz; lower alpha: 7–10 Hz; and upper alpha: 10–13 Hz). Subsequently, power estimates were obtained by squaring filtered EEG signals, and then band power values (μV^2) were averaged for both the pre-stimulus reference period and the activation interval separately. The ERS/ERD was calculated with the averaged reference and activation bandpower values separately for each electrode, frequency band, and participant.

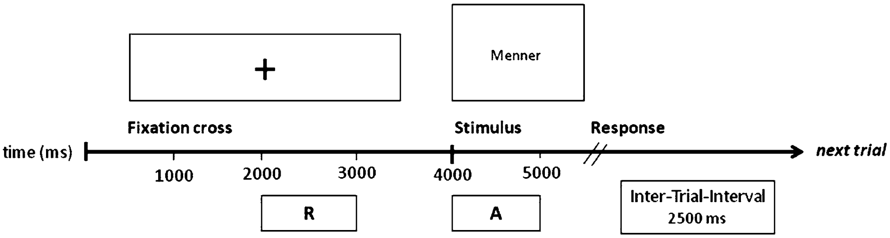

Fig. 5 Schematic time course of the experimental task (R = reference interval; A = activation interval)

For statistical analyses, electrode positions were aggregated as follows (cf. Fink & Neubauer, 2006): anteriofrontal left (FP1, AF3), anteriofrontal right (FP2, AF4), frontal left (F3, F7), frontal right (F4, F8), frontocentral left (FC1, FC5), frontocentral right (FC2, FC6), centrotemporal left (C3, T3), centrotemporal right (C4, T4), centroparietal left (CP1, CP5), and centroparietal right (CP2, CP6), parietotemporal left (P3, T5), parietotemporal right (P4, T6) parietooccipital left (PO3, PO5, O1), parietooccipital right (PO4, PO6, O2). The midline electrodes (FZ, CZ, PZ) were not included in the analyses as we were interested in potential hemispheric differences.

Results

Task performance

Training effects in the three tasks on the number of correct trials and the reaction times were investigated by computing an ANOVA for repeated measures with the within-subject factors TIME (pre- and posttest) and TASK (DM, CCS, MOR) as well as the between-subjects factor GROUP (training vs. control group).

The ANOVA for the number of correct trials revealed a significant main effect of TASK, $F(2,36) = 25.67$, $p < 0.001$, $\eta 2 = 0.59$. DM (71.81%) showed the lowest solution rate, followed by MOR (82.71%), and CCS (90.73%) as the easiest task. Similarly, the ANOVA for the reaction times revealed a significant main effect of TASK, $F(2,36) = 9.00$, $p < 0.01$, $\eta 2 = 0.33$. The reaction times observed in DM (3.78 s) were longer than in CCS (2.85 s) and MOR (2.90 s). There was also a main effect of GROUP, $F(1,18) = 13.75$, $p < 0.01$, $\eta 2 = 0.43$, with the control group showing faster reaction times. There were no significant training effects on either number of correct trials or in reaction time.

Event-related synchronization/desynchronization

In order to examine effects of training on brain activation, ANOVAs for repeated measures were performed on the ERS/ERD-values. To facilitate interpretability of the data, analyses were performed separately for the three examined frequency bands (theta, lower alpha, and upper alpha) as well as for the three experimental tasks (DM, CCS, and MOR). The ANOVA design included the variables TIME (pre- and posttest), HEMISPHERE (right and left), and AREA (anteriofrontal, frontal, frontocentral, centrotemporal, centroparietal, parietotemporal and parieto-occipital) as within-subject factors as well as GROUP (training vs. control group) as between-subjects factor. In case of violation of sphericity assumptions, degrees of freedom were adjusted by means of the most conservative Greenhouse-Geisser correction. The probability of a Type-I error was maintained below 0.05.

Theta band. In all three tasks, a main effect of GROUP was found, with the control group generally showing more theta ERS than the training group (DM: $F(1,18) = 4.62$, $p < 0.05$, $\eta 2 = 0.20$; CCS: $F(1,18) = 5.70$, $p < 0.05$, $\eta 2 = 0.24$; MOR: $F(1,18) = 5.92$, $p < 0.05$, $\eta 2 = 0.25$). Furthermore, in the task CCS a main effect of AREA, $F(3.03, 54.50) = 4.94$, $p < 0.01$, $\eta 2 = 0.22$, as well as an

AREA × GROUP interaction, $F(3.03, 54.50) = 4.26$, $p < 0.01$, $\eta 2 = 0.19$, were observed. For this task the difference between the two groups in theta ERS was especially strong in parietooccipital areas.

A training effect in the theta band was observed for the task MOR only, as reflected in a significant four-way interaction, $F(2.83,50.91) = 3.10$, $p < 0.05$, $\eta 2 = 0.15$. This interaction was analyzed in detail by calculating separate ANOVAs for each hemisphere, revealing an interaction of TIME, AREA, and GROUP only in the right hemisphere. The theta ERS of the two groups diverges in the posttest in centroparietal and parietotemporal areas: The training group was characterized by a slight decline in theta-ERS from pre- to post-test while the control group showed a small increase in ERS in these areas.

Lower alpha band. Similar to the theta band, there was a training effect for the MOR task, characterized by a significant TIME × HEMISPHERE × GROUP interaction, $F(1,18) = 8.35$, $p < 0.05$, $\eta 2 = 0.32$. While the control group showed no change in the lower alpha band from pre- to posttest, the training group displayed a decrease in ERS and an increase in ERD in this band, which was more strongly pronounced in the right than in the left hemisphere (see Fig. 6).

A training effect was also found for the task CCS (TIME × HEMISPHERE × AREA × GROUP; $F(3.13,56.41) = 2.79$, $p < 0.05$, $\eta 2 = 0.13$). Only the training group showed a decrease in ERS in all areas except for (anterio-) frontal regions. In contrast to the results for the task MOR, this effect was stronger in the left hemisphere.

The decrease of ERS in lower alpha power that was observed for the training group in the other two tasks, was also found in the DM task, but it failed to reach statistical significance: TIME × AREA × GROUP, $F(3.21,57.76) = 2.24$, $p = 0.09$, $\eta 2 = 0.11$. Moreover, a significant interaction between TIME × HEMISPHERE, $F(1,18) = 5.13$, $p < 0.05$, $\eta 2 = 0.22$, was found in the DM task, reflecting a small increase in ERS in the right hemisphere and a small decrease of ERS in the left one.

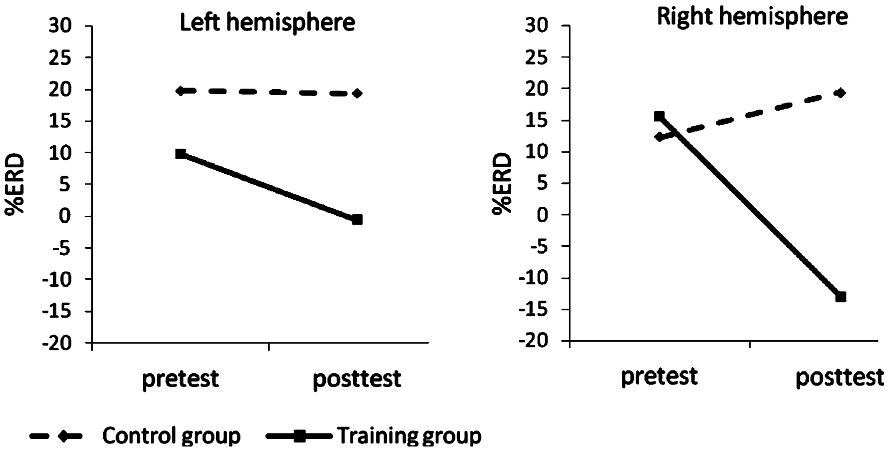

Fig. 6 Task-related activation change in lower alpha band during the MOR task of training and control group for pre- and posttest—separately for the two hemispheres

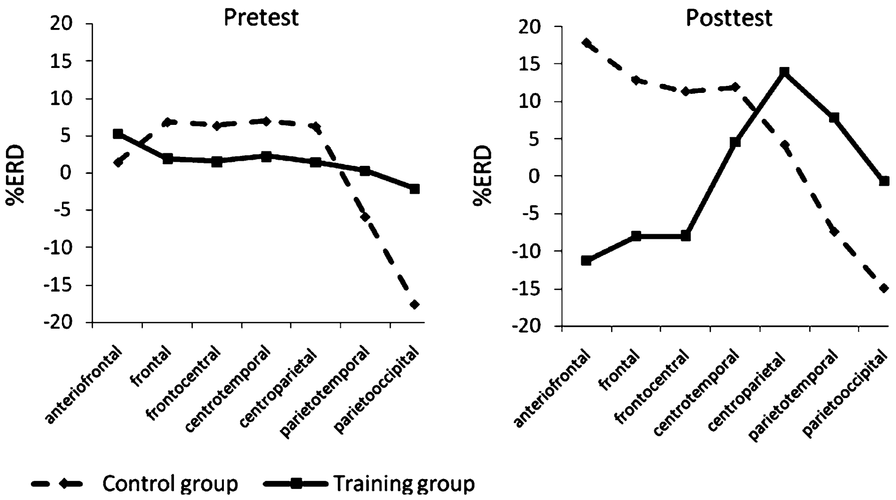

Fig. 7 Task-related activation pattern in upper alpha band during the MOR task for the different brain areas of training and control group—separately for pre- and posttest

Upper alpha band. A training effect in the upper alpha activation was again found for the task MOR with a significant interaction between the variables TIME, AREA, and GROUP, $F(3.21, 57.72) = 2.98$, $p < 0.05$, $\eta 2 = 0.14$. Children of the training group showed an increase of ERD in frontal regions, and, thus, after training their pattern of brain activation was even more dissociated from that of children of the control group (see Fig. 7).

Furthermore, analyses revealed main effects of AREA for the tasks CCS, $F(2.69, 48.43) = 3.94$, $p < 0.05$, $\eta 2 = 0.18$, and MOR, $F(2.57, 46.19) = 3.82$, $p < 0.05$, $\eta 2 = 0.18$, with stronger upper alpha ERD in occipital areas.

For the tasks DM and MOR significant interactions between AREA and GROUP (MOR: $F(2.57, 46.19) = 4.16$, $p < 0.05$, $\eta 2 = 0.19$; DM: $F(3.11, 56.01) = 7.41$, $p < 0.001$, $\eta 2 = 0.29$) were found. The control group was characterized by upper alpha ERS in frontal areas and a strong ERD in occipital regions, whereas the training group showed a result pattern in the opposite direction, with a small ERD in frontal areas and a marginal ERS in occipital regions (see also Fig. 7).

Discussion

The EEG analyses revealed that the morphological training protocol was accompanied by significant changes in brain activation from pre- to post-test. The results were most consistent for the morphological relatedness (MOR) task requiring morphological mapping. In this task, training-related changes in oscillatory EEG activity were observed in all three frequency bands. Specifically, the training group showed a decline in theta and in lower alpha-ERS, and an increase in upper alpha-ERD in frontal regions. In addition, training effects were found in the tasks CCS and DM with a decrease in lower alpha-ERS in the training group. Since the analyzed frequency bands differ in their functional significance (Bastiaansen & Hagoort, 2003; cf. also Fink et al., 2004), the obtained results are discussed separately in the following sections.

Theta

Children with poor reading and spelling competence were characterized by lower theta ERS than children with higher reading and spelling ability. This strong effect was observed during all three experimental tasks employed in this study. The difference between the groups in theta activation was somewhat more strongly pronounced in posterior regions during the CCS task. Similar activation topography was observed also in the other two tasks. This finding fits nicely with those of previous studies which found a lower theta activity for poor readers in occipital regions (Coombes et al., 2005; Klimesch et al., 2001).

In the study of Bastiaansen et al. (2005) lexical-semantic tasks were used as stimulus material. They employed tasks similar to the MOR task used in this study. However, the results are still different: Bastiaansen et al. (2005) located higher theta power in left hemispheric regions, viz. left occipital and midfrontal areas while in the present study no hemispheric effect was found (see also Hald et al., 2006).

The fact that children with poor reading and spelling ability are characterized by less theta activation during language tasks can be tentatively interpreted as impairment in processing language-specific information. Specifically, the decreased theta activity in lower ability children (which was strongest in posterior brain regions in the MOR task) could be indicative of impairment in lexical-semantic retrieval of verbal information (cf. Bastiaansen & Hagoort, 2006).

Interestingly, the training group did not show an increase of theta activity in the MOR task after training which would have indicated a convergence in brain activity towards the control group. On the contrary, a decrease in theta activation was observed in posterior–parietal regions of the right hemisphere, resulting in a further dissociation of the two groups with respect to theta activity. Following the argument that posterior theta ERS is related to lexical-semantic retrieval (Bastiaansen & Hagoort, 2006), the present result may indicate a decreasing reliance of the training group on these processes after morphological training.

Lower alpha

In contrast to the theta band, the groups did not generally differ in lower alpha activity. However, a change in activation in the training group was observed after training. Generally, after training a decrease in lower alpha ERS was found for the training group in all three tasks.

It is known that EEG activity in the lower alpha band (which is topographically more widespread) is related to general attentional processes and that an increase of lower alpha ERD is associated with higher attentional processes (cf. Klimesch, 1999). The widespread increase of ERD in the lower alpha band which was observed in the training group can be interpreted within this framework. It appears plausible that the trained children need to invest more attentional resources in order to apply the newly acquired morphological knowledge on language tasks.

Again, the changes after training led to a dissociation of the two groups with regard to their activation patterns. Trained children showed a decrease in lower alpha power while the control group did not change from pre- to posttest.

Upper alpha

ERD in the upper alpha band is regarded to reflect task-specific information processing and was found to emerge topographically restricted to those brain areas that are involved in task processing (Pfurtscheller & Lopes da Silva, 2005). The analyses in this frequency band revealed general differences between the groups which were—only in the MOR task—moderated by training.

The control group was characterized by a small upper alpha ERS in frontal areas and strong ERD in posterior regions, while the training group showed less activation in occipital regions. After training, the ERD in frontal regions strongly increased in the training group whereas the control group displayed an increase in ERS in frontal regions. Thus, after training the trained children's profile of brain activation dissociated from that of the control children. In fact, after training they showed the opposite profile from the control group, with ERD in frontal areas and a marginal ERS in occipital regions.

The anterior-posterior activation asymmetry in the training and control group may reflect a differential reliance on attentional and memory processes of both groups. Several training studies have shown an activation shift from anterior to posterior regions with increasing training or practice (Gevins & Smith, 2000; Grabner et al., 2006; Habib, McIntosh, & Tulving, 2000). This effect has been interpreted to reflect a functional reorganization or redistribution of cortical resources through training and practice (Kelly & Garavan, 2005). Practice or training leads to the development of more efficient task strategies which demand less task-unspecific attentional and working memory resources of the frontal lobe more task-specific processing resources of posterior brain regions. In line with this, Grabner et al. (2006) as well as Staudt and Neubauer (2006) found higher anterior activation in individuals with lower achievement or domain-specific knowledge and higher posterior activation in individuals with higher achievement or knowledge. In the present study, we found that the control group with good reading and spelling abilities displayed a small frontal ERS (deactivation) but a strong posterior ERD (activation; see Fig. 7). The training group, in contrast, started with a topographically undifferentiated activation in the pre-test but showed strong frontal ERD (activation) increases in the post-test whereas posterior regions showed a slight ERS (deactivation). This pattern of results may reflect the fact that the children in the control group were able to automate task processing whereas the children in the training group with poorer verbal skills required more controlled information processing and attentional resources after training.

General discussion

These results showed that the morphological training protocol is an effective instrument for improving morphological awareness in German-speaking children.

However, only secondary school children seem to be able to appropriately use the newly acquired morphological knowledge to improve reading and spelling skills. This was interpreted in the framework of developmental stage models: it may be speculated that basic competences such as phonological awareness must be well-developed before morphological strategies can be applied effectively for reading and spelling processes.

An important restriction of the present studies is the absence of an alternative training protocol in the control group. Consequently, it may be argued that the performance gains in the training group are not specific to morphological training but may solely reflect some kind of Hawthorne effect. However, the specificity of the training effect as illustrated in Fig. 4 provides a strong argument against this possibility. The strongest training effect was observed for the morphological strategy while there was no influence of training on the alphabetical (phonological) strategy.

The specificity of the training effect gives information about which competences were improved through morphological training. The mechanisms lying behind these improvements were investigated in Study 2 by analyzing the EEG activity of a subsample of participants with different spelling and reading abilities.

In all of the three analyzed frequency bands (theta, lower alpha, and upper alpha) dissociations between the two groups in brain activity were found after training. Thus, the hypothesis that morphological training leads to convergence in brain activation of the two groups is not supported by these data. The observed training-related decreases of power in upper alpha in frontal regions and lower alpha in general suggest a more effortful, controlled, and attention-demanding processing after training. Thus, the results of Study 2 provide the first evidence that morphological awareness training may not immediately lead to a more automatic handling with written language. In contrast, morphological training seems to provide children with an alternative strategy to solve written language problems. The decrease in theta activity, indicative of lexical-semantic information processing, adds further evidence to the view that the investigated training does not improve the automatic retrieval of lexical-semantic information.

Considering previous evidence showing long-term effects of morphological training (Walter et al., 1995, 2007) it would be interesting to examine brain activation of the trained group in a follow-up study some months later. It is possible that after some time the new strategies become more automatic which may be accompanied by a convergence in brain activation of the two groups.

In conclusion, the results of Study 1 show that the morphological awareness training protocol was effective in improving morphological strategy irrespective of children's age. Positive effects on reading and general spelling performance emerged only in secondary school children, suggesting that older children are better able to apply the acquired morphological knowledge in spelling and reading processing appropriately. Study 2 provides first evidence that morphological awareness training is accompanied by changes in oscillatory EEG activity related to language processing. The present data comparing children with poor and good reading and spelling skills suggest that training leads to diverging rather than converging brain activation patterns of both groups. This may indicate the use of compensatory strategies in children with poor reading and spelling skills.

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