Orthographic influences on L2 auditory word processing

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Contents

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1 Introduction

In the history of mankind, spoken language developed as a product of biological evolution around 200,000 years ago. Written language, in contrast, is a cultural invention which is believed to be not older than 4,000 years (Liberman, 1997). The primacy of speech over written language is not only represented in the history of mankind but also in the history of the individual. Children learn to speak many years before they learn to read and write. In addition, many of the world's languages do not even have a writing system. Thus, the primacy of speech over written language has led researchers to the assumption that reading and writing skills acquired during literacy acquisition profit from existing cognitive structures that were specialized on spoken language processing (Liberman, 1992).

However, as soon as reading and writing have been acquired, these literacy skills change the way spoken utterances are processed. Although written language is only secondary to spoken language, an increasing number of studies has demonstrated that learning to read and write influences the way spoken language is processed. At first sight, this evidence is remarkable given that auditory speech processing works perfectly well without orthographic information, e.g. for illiterate people. Nevertheless, accumulating evidence has been collected over the last three decades which demonstrated that "learning about orthography seems to permanently alter the way we perceive spoken language" (Ziegler, Ferrand & Montant 2004: 740).

Previous research on this field of study has been almost exclusively devoted to orthographic influences during native auditory speech processing and challenged well established models of monolingual auditory word recognition. The present thesis is aimed at extending previous findings to non-native speech processing. So far, very few studies have examined orthographic influences on non-native spoken word processing. This thesis attempts to provide further evidence for the underlying processes and mechanisms that govern the interactions between phonological and orthographic information during non-native spoken word recognition.

Given that first findings of orthographic effects on non-native auditory word processing cannot be accounted for by existing models of non-native word recognition, I will develop a working model of bilingual word recognition in the first part of this thesis. The working model is based on previous outcomes of research on auditory and visual word recognition as well as current findings on orthographic effects during auditory word recognition. Relevant findings, models and theories of native and non-native language processing will be reviewed in chapter 2 and 3. Subsequently, I will outline the working model of bilingual word recognition in chapter 4.

In the second part of this thesis, the working model will be tested in an empirical investigation. Three different experiments were conducted to investigate orthographic influences on non-native auditory word recognition with special emphasis on a cross-linguistic comparison between native and non-native participants as well as between two groups of non-native participants with different language backgrounds. Apart from the fundamental question of whether non-native auditory word recognition is affected by orthographic co-activation, the experiments were motivated by the following cross-linguistic considerations:

Usually, the primacy of spoken language over written language is not reflected in institutional second language (L2) learning. This means, unlike first language (L1) acquisition, learners of a second language who receive language instruction (e.g. at school or university) do not learn the spoken form of a word before the written form but are introduced to both forms at the same time. As a consequence, it is likely that stronger connections between orthographic and phonological representations have been established for non-native compared to native speakers. This question was addressed in the empirical part of this thesis by comparing the performance of German and Danish proficient non-native speakers of English to a group of English native speakers in three experiments on auditory word recognition with English stimuli.

Furthermore, the empirical research was motivated by the consideration that L2 learners usually acquire their second language after they have achieved full literacy in their first language. This means, essential strategies of orthographic processing are developed as a response to the characteristics of the L1 writing system which might be transferred to the processing of L2 words. The empirical part of this study explored whether the transparency of the L1 writing system, i.e. the consistency of mappings between orthographic and phonological representations, affects the degree of orthographic recruitment in L2 auditory word recognition. In other words, do German non-native speakers of English, who were raised in the transparent writing system of

German, process spoken words differently from Danish non-native speakers of English, who were raised in the opaque orthography of Danish? By testing two groups of non-native speakers from different L1 orthographic backgrounds, it was examined whether socialisation in a transparent or opaque writing system affects strategies of orthographic processing in a second language.

Motivation, methodical aspects and findings of the empirical investigation will be described in chapter 5. In chapter 6, I will summarize the main results of the experiments, discuss possible explanations for the observed findings and relate them to the working model of bilingual word recognition. Furthermore, I will discuss possible implications for L2 learning and teaching. Chapter 7 provides a concluding discussion on the contribution of the present thesis to psycholinguistic research on this field of study.

Throughout this thesis, I will use the terms native/non-native word recognition and monolingual/bilingual word recognition interchangeably. It is noteworthy that different definitions of the term *bilingual* can be found in the literature. Broadly speaking, these definitions refer to an individual who is able to speak and understand two languages. However, the definitions vary with respect to the person's proficiency in these two languages, reaching from individuals who grew up with two languages and/or master two languages to the same degree to individuals who have only minimal knowledge of a second language. If not stated otherwise, I will use the term bilingual in the present study to describe a person who acquired the first language as a child and learned the second language later in life, usually at school. This definition does not imply that people described as bilinguals have no knowledge of a third or fourth language. The definition rather highlights the combination of the two strongest languages among other languages in the mind of a (multilingual) individual (de Groot, Borgwaldt, Bos & van den Eijnden, 2002).

2 Word processing in L1

The ability to understand spoken and printed words is one of the most impressive accomplishments of the human mind. Complex processes are at work to get from the spoken or written input signal to the meaning of single words or whole sentences. Broadly speaking, the spoken or printed word has to be recognized and matched against the thousands of mental representations of words stored in the mental lexicon. The mental lexicon is like a dictionary where all words in the mind of the language user are stored. Single words are represented in the mental lexicon by lexical entries which contain different kinds of information, for instance, orthographic, phonological, semantic or syntactic representations. The actual retrieval of such information is called lexical access. Hence, recognizing words and accessing their lexical entries are central aspects of lexical processing.

In the present chapter, I will provide a closer look at the way words are processed in the mental lexicon. The chapter is aimed at presenting an overview of those aspects of monolingual auditory and visual word recognition – as well as orthographic effects on spoken word recognition – that are relevant for the development of a working model and the theoretical grounding of the empirical part of the present study.

2.1 Auditory word recognition in L1

Processing spoken words is a complex and challenging task due to the highly variable nature of the acoustic input signal. Nevertheless, people are generally able to recognize and understand spoken words without difficulty. A large body of research has investigated how a spoken word is identified from an acoustic speech stream and processed in the mental lexicon. Fundamental findings on this field of study will be presented below. Moreover, I will introduce three models of spoken word recognition and, subsequently, evaluate these models with reference to the reviewed empirical findings.

2.1.1 Fundamental findings on auditory word recognition

An overview of core findings on the processing of spoken words provides the necessary background for the discussion of established models of auditory word recognition in section 2.1.3. In addition, this review of fundamental findings presents the theoretical framework for the overall topic of this thesis, i.e. the activation of orthographic information during spoken word processing. The fundamentals to be discussed in the following will comprise a brief review of empirical studies on the incremental nature of spoken word processing, activations of multiple lexical candidates, the role of word frequency and phonological neighbourhood as well as the role of top-down processing.

To start with, auditory word recognition is incremental, i.e. the listener starts processing the auditory input before the end of the spoken word has been perceived. In other words, listeners do not need to hear the full word in order to match the input signal on one of the representations in the mental lexicon. Typical experimental paradigms used to investigate the early stages of spoken word processing are shadowing[1], monitoring[2] and gating[3] tasks where the listener responds immediately to the spoken words. For instance, in a series of shadowing experiments, Marslen-Wilson (1973, 1975, 1976) and Marslen-Wilson & Welsh (1978) demonstrated that, while hearing and repeating the incoming aurally presented words, the listeners instantaneously performed corrections of mispronounced words. Similarly, phoneme and rhyme monitoring tasks revealed that participants are able to respond instantaneously to a particular auditory property of a given word, such as a specific phoneme or rhyme, during presentation of the auditory stimuli (e.g. Marslen-Wilson, 1984; Marslen-Wilson & Tyler, 1975, 1980; Morton & Long, 1976). These findings are consistent with a number of studies that demonstrated that

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[1] In a shadowing task, participants are instructed to repeat a spoken word as quickly as possible. The participant's response requires only an analysis of the phonetic characteristics in order to build an articulatory plan of the stimulus. Hence, access to the full lexical representation is not necessary.

[2] In an auditory monitoring task, participants listen to a presented auditory stimulus in order to detect a pre-specified property of the word, such as a specific phoneme or rhyme. Similar to shadowing, full access to the lexical representation is not necessary since participants respond to a sublexical unit of the word.

[3] A gating task involves the presentation of increasingly longer auditory fragments of a word, usually ranging from 20 ms to 50 ms. At each increment, the participants are instructed to say the word they have heard (or guess what the word is going to become) and indicate how confident they are with their identification. Gating tasks provide detailed information about the amount of acoustic input which is necessary for lexical access (Marsen-Wilson, 1987).

participants are able to recognize an auditory word on the basis of a unique initial sound fragment[4] in a gating task (e.g. Cotton & Grosjean, 1984; Salasoo & Pisoni, 1985; Tyler & Wessels, 1983).

Having shown that auditory word recognition is incremental in nature, another fundamental finding on auditory word recognition refers to the assumption that the unfolding speech signal does not only activate the lexical representation of the target word but also activates a number of possible lexical candidates which compete for recognition. Evidence for the activation of lexical competitors has been presented, for instance, in an eye-tracking[5] study by Allopenna, Magnuson & Tanenhaus (1998). The authors measured the participants' eye movements to pictures on a computer screen while the participants listened to spoken instructions. The central finding was that participants fixated the pictures of words with phonological overlap more often than pictures of unrelated words during an early stage of auditory word recognition. This means, when participants heard the word *beaker*, they were more likely to look at the picture of the phonologically related competitors *beetle* or *speaker* than at the unrelated competitor *carriage*. Thus, lexical candidates that share a similar phonological form with the target word get activated at an early stage of processing and compete for recognition. During lexical competition, the frequency of the target word as well as the number and frequency of activated competitors have been shown to affect auditory word recognition. These factors will be reviewed in the following.

Word frequency is a key variable in auditory word recognition. Effects of word frequency have been found in a number of studies involving different auditory paradigms, such as lexical decision[6] (e.g. Luce, 1986; Luce & Pisoni, 1998; Marslen-Wilson, 1990; McCusker, Holley-Wilcox & Hillinger, 1979; Slowiaczek & Pisoni, 1986; Taft & Hambly, 1986), gating

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[4] The point at which the information of the input signal is sufficient to distinguish a spoken word uniquely from similar words is called the *uniqueness point* (Marslen-Wilson, 1987).

[5] Eye-tracking is a research tool used in psycholinguistic research to measure the participants' eye movements. Given that eye movements are linked to the current focus of attention, the collected data provide information about the underlying cognitive processes (for an overview, see e.g. Duchowski, 2003; Griffin & Davison, 2011).

[6] In a lexical decision task, participants are asked to decide whether a presented stimulus is a word or a nonword. Phonological, orthographic and semantic knowledge of the stimulus can be used to match the stimulus on lexical representations in the mental lexicon.

(Tyler, 1984) and speech-in-noise identification[7] (Luce & Pisoni, 1998). Collectively, the data indicated that high-frequency words produced faster response times and lower error rates than low-frequency words. Moreover, an eye-tracking study by Dahan, Magnuson & Tanenhaus (2001) showed that word frequency has a very early effect on auditory word recognition. While listening to a spoken word, participants tended to look at the picture of high-frequency competitors at a very early point of time compared to pictures of low-frequency words. For instance, participants heard the word *bench* and saw pictures of a bench (target word), a bed (high-frequency competitor) and a bell (low-frequency competitor). Although both competitors shared the same initial sounds with the target word, participants were more likely to fixate the high-frequency competitor *bed* relative to *bell*. In addition, participants fixated the high-frequency word before they fixated the low-frequency word, which indicated that the frequency effect occurred very early in the process of word recognition.

However, Luce (1986) argued that word frequency alone is not a sufficient predictor of recognition time for spoken words because it neglects interactions of activated competitors. Indeed, processing times for auditory words have been shown to be affected by the properties of a word's competitors, such as the number and frequency of lexical competitors that differ in only one phoneme to the target word (phonological neighbours). According to Luce & Pisoni (1998), phonological neighbourhood size has been defined as the number of words that can be generated from the target word by adding, deleting or substituting one phoneme. For example, the English word *speech* has three phonological neighbours, i.e. *speed*, *speak* and *peach*. Several studies (e.g. Goldinger, Luce & Pisoni, 1989; Luce & Pisoni, 1998; Luce, Pisoni & Goldinger, 1990; Vitevitch, Stamer & Sereno, 2008) have demonstrated that words with many phonological neighbours were responded to more slowly in lexical decision than words with only few neighbours. Similar competition effects were found in perceptual identification. This means, words with a large phonological neighbourhood size were identified less accurately compared to words with a small neighbourhood size. Moreover, the frequency of phonological neighbours has been demonstrated to affect auditory word recognition. For instance, Luce & Pisoni (1998) found that words in low-

[7] In a speech-in-noise identification task, participants are instructed to recognize spoken words that are masked by different levels of white noise.

frequency neighbourhoods were recognized more quickly and more accurately than words in high-frequency neighbourhoods.

Apart from the factors discussed so far, a fundamental question on this field of research is whether spoken word recognition is a strictly bottom-up process or whether it is affected by top-down influences of lexical, semantic, syntactic and pragmatic context. Evidence for top-down effects would support an interactive view of auditory word processing as suggested by interactive models (e.g. TRACE) whereas the absence of top-down effects would support a strictly bottom-up processing mechanism as proposed by autonomous models (e.g. Shortlist).

We have to distinguish between top-down effects on the prelexical processing stage, affecting the identification of sounds, and top-down effects on the lexical processing stage, affecting the identification of words. An example of the first type of context effects is the phoneme restoration effect (Obusek & Warren, 1973; Warren, 1970; Warren & Warren, 1970) that revealed that the perception of missing phonemes can be perceptually "restored" by means of semantic and syntactic contextual information. Top-down effects on identification of words have been shown, for instance, in a speech-in-noise identification task by Miller & Isard (1963). In this study, participants were instructed to identify a spoken word masked by white noise. The data revealed that performance accuracy was better in semantically and syntactically correct sentences than in semantically and/or syntactically anomalous sentences. Thus, sentential context affected the recognition of words. Similar effects of sentential context on word recognition have been obtained in gating tasks (e.g. Grosjean, 1980; Tyler, 1984; Tyler & Wessels, 1983; Salasoo & Pisoni, 1985). For example, in the original study by Grosjean (1980), participants needed to hear an average of 333 ms to identify a word in isolation but only 199 ms when it occurred in an appropriate sentential context. However, these studies also revealed that top-down feedback does not appear to have an early effect on word recognition. At the earliest stage, lexical competitors are activated that are compatible with the perceptual representation of the input signal. Top-down feedback does not affect the generation of these candidates but appears to be able to remove candidates from the set during a later stage of spoken word processing, as revealed by Zwitserlood (1989).

In a cross-modal priming paradigm[8], Zwitserlood (1989) demonstrated that semantic context induced by a prime word affects selection of appropriate candidates. When hearing initial fragments that occurred both in the Dutch equivalents of the word *captain* and *capital*, i.e. /k/, /kæ/ and /kæp/ in the present English example, response times in lexical decision were facilitated by the visual primes *ship* (semantically related to *captain*) and *money* (semantically related to *capital*). Furthermore, this study showed at which point of time during recognition sentential context affected the activation of lexical candidates. For this purpose, the initial fragments of the auditory target word were embedded in a spoken carrier sentence. Consistent with the first part of the study, a visual prime flashed before the presentation of the fragments of the target word. For example, the sentence "With dampened spirits the men stood around the grave. They mourned the loss of their /kæp-/" strongly favours the occurrence of the target word *captain* instead of *capital* even though the target word *captain* cannot be uniquely identified from the fragment /kæp/. Interestingly, priming effects were not only yielded for the plausible target *captain* but also for the implausible target *capital*. Hence, sentential context did *not* influence word recognition when only an initial fragment of the target was presented. However, when a longer fragment of the target word – which contained enough information to uniquely identify the word as *captain* – was embedded in the carrier sentence, the implausible target *capital* could no longer be primed by semantically related visual primes. In other words, after the word had been uniquely identified as *captain* on the basis of its initial sound fragments, i.e. after the word's uniqueness point, sentential context restricted the activation of lexical candidates. These data suggest that sentential context does not affect the initial activation of lexical candidates, which appears to be solely based on the acoustic input, but that it affects the activation of alternatives at a later stage of lexical processing.

In contrast to the assumption that auditory word recognition is, at least in part, an interactive process, a number of studies have provided evidence for a strictly bottom-up

[8] In a priming paradigm, participants are typically exposed to two stimuli in close succession, i.e. the prime and the target. Prime and target words are either related or unrelated, e.g. semantically, phonologically or orthographically. A priming effect is obtained when participants show shorter response times and reduced error rates for targets that were preceded by related in contrast to unrelated primes. The cross-modal priming paradigm is a specific type of priming paradigm. In cross-modal priming, the prime word is presented in the auditory modality while the target is presented visually.

view of speech processing without top-down feedback (e.g. Burton, Baum & Blumstein, 1989; Cutler, Mehler, Norris & Segui, 1987; Frauenfelder, Segui & Dijkstra, 1990; Marslen-Wilson & Warren, 1994; McQueen, 1991). For instance, this view was supported by the findings yielded in a phoneme monitoring task by Frauenfelder, Segui & Dijkstra (1990). In this study, participants were instructed to identify phonemes in three kinds of target stimuli. Stimuli were either French words that contained the target phoneme after the uniqueness point (e.g. /l/ in *vocabulaire*), nonwords that were derived from word stimuli by changing the target phoneme (e.g. /t/ in *vocabutaire*) or control nonwords (e.g. *socabutaire*). According to the interactive view of speech processing, monitoring times for the target phoneme in derived nonwords were expected to be slower than for control nonwords given that bottom-up processing of the derived nonwords was predicted to conflict with lexical top-down information. However, no difference was found between data of the derived and control nonwords. This finding has been interpreted as evidence for the absence of lexical top-down effects.

To summarize, the role of top-down feedback in spoken word recognition has been a hotly debated issue (for reviews, see McClelland, Mirman & Holt, 2006; Norris, McQueen & Cutler, 2000). Note that the debate is not about binary decisions in favour or against interactive or autonomous models. Instead, the distinction between interactive and autonomous models of spoken word recognition can be best illustrated "as the extreme ends of a continuum of possible models rather than as the two poles of a dichotomy" (Harley, 2008: 266). More research is needed to disentangle the degree of contextual interaction during auditory word recognition.

Taken together, the present section has provided a review of central findings on auditory word recognition. It has been shown that auditory word recognition is incremental and involves a competition of lexical candidates that match the input signal. Moreover, spoken word recognition has been shown to be affected by a number of factors, such as word frequency, phonological neighbourhood size and frequency as well as top-down effects. Different models have been developed to account for the reported findings. A selection of these models will be described in the following section.

2.1.2 Models of native auditory word recognition

Contemporary models of auditory word recognition differ in terms of the ways information flows between different levels of language processing. As mentioned earlier, interactive models allow information to flow from earlier to later levels of processing (bottom-up processing) but also in the other direction, i.e. from later to earlier processing stages (top-down processing) whereas autonomous models restrict the flow of information to bottom-up processing. In the following, I will present the three most influential models of native auditory word recognition, i.e. the cohort model, TRACE and Shortlist.

The cohort model

The central idea of the cohort model (Marslen-Wilson, 1984, 1987) is that the acoustic speech signal is recognized in a sequential manner, phoneme by phoneme from left to right, by eliminating alternative word candidates until only one candidate remains. The model consists of three stages of processing. At the first stage, the *access stage*, a set of word candidates (the cohort) is generated which matches the onset of the target word. For instance, for the recognition of the word *candle*, several word candidates are activated that match the first two phonemes /k/ and /kæ/ of the target word, such as *cattle*, *can*, *candy* and the target word *candle*, of course. Recognition of the first two phonemes eliminates all word candidates from the cohort which do not contain the relevant phonemes at the required position. This process of eliminating word candidates continues in a bottom-up manner until only one word candidate is left. For example, if the next phoneme is /n/, the cohort is reduced to the word candidates *can*, *candy* and *candle*. Consequently, an incoming /d/ and /l/ would limit the cohort still further to the target word *candle*. The stage when only one word is chosen from the possible word candidates is called *selection stage*. Finally, in the *integration stage*, syntactic and semantic characteristics of the word are utilized. We have to distinguish between an earlier version (Marslen-Wilson, 1984) and a later version of the cohort model (Marslen-Wilson, 1987). While cohort members were eliminated by a binary all-or-none selection process in the earlier version, the degree of activation is downgraded for non-matching word candidates in the later version of the model. This allows the later version to account for the recognition of mispronounced or misperceived words, whose lexical candidates would have been excluded from the cohort during the selection process if they had not matched the phonological structure of the target word. Moreover, the later version differs in terms of the role of contextual information. Both versions share the characteristic of bottom-up priority, however, the original version permits more interaction than the revised version. The later version assumes that word candidates cannot be eliminated from the cohort by context at an early stage. Finally, the two versions are based on different perceptual representations of the acoustic input signal. In the early version, the speech stream is segmented into phonemes whereas featural rather than phonemic information is being processed as input in the later version of the cohort model.

TRACE

TRACE (McClelland & Elman, 1986) is an interactive connectionist model of auditory word recognition which is based on the interactive activation model of visual word recognition (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). It consists of three hierarchically organized processing layers, i.e. features, phonemes and words. Word recognition occurs as the result of spreading activation between units of different layers which are connected in different ways. Connections between units of adjacent levels are excitatory in both directions, i.e. both bottom-up (feature-phoneme, phoneme-word) and top-down (word-phoneme) processing may occur whereas connections between units within the same level are inhibitory. Inhibitory connections within the feature, phoneme and word level have the effect that once a unit has been activated, all competitors of that level are inhibited. The incoming acoustic speech signal activates feature units, which in turn activate phonemes on the next hierarchical level. Phonemes increase the activation of words which contain the activated phonemes. For instance, the input /nɑɪt/ will not only activate words that begin with the phoneme /n/ but also words that begin with /ɑɪ/ or /t/, even though to a lesser extent. As activation accumulates these words compete and inhibit each other until only one word is left activated. Due to its highly interactive structure, lexical context can affect identification of phonemes whereas information above the word level, such as sentence context, can influence lexical processing.

Shortlist

Shortlist (Norris, 1994) is an autonomous model of auditory word recognition which involves two distinct processing stages. In the first stage, a limited set of word candidates, the “shortlist”, is generated from the incoming speech stream. Bottom-up information is used to determine the small number of words which are considered in the shortlist. An essential feature of the model is that only a limited number of word candidates is activated, usually between 3 and 30 (hence the name shortlist). If too many word candidates share a given segment, the candidates with the lowest activation will be excluded from the list. During the second stage, the best fitting lexical candidates enter an interactive activation network which is similar to TRACE. In the network, the candidates compete for recognition via lateral inhibition. Only those candidates that best match the input win the competition by inhibiting their competitors most effectively. Recently, the Shortlist model has been further developed into Shortlist B (Norris & McQueen, 2008). Shortlist B shares the basic architecture and the central assumptions of its predecessor with two exceptions. First, the new model is based on probabilities and not on absolute activations as the original Shortlist model. Secondly, the input is not a string of phonemes but the probability of being a phoneme. Thus, the input to the model consists of the probability values of phonemes which are compared to the lexical entries.

2.1.3 Evaluation of models of auditory word recognition

All models of spoken word recognition described above regard spoken word recognition as a competition between the target word and multiple lexical candidates which share specific phonological properties with the target. The time needed until the target word has been uniquely recognized depends on its frequency and the number (and frequency) of activated competitors. The models differ, though, with respect to the number and type of activated competitors. For instance, in the cohort model, the set of activated candidates all share the initial phoneme sequence. However, eye-tracking data which demonstrated activation of rhyme competitors (e.g. fixating the picture of a *speaker* when hearing the target word *beaker*) challenge the assumption of the cohort model (Allopenna, Magnuson & Tanenhaus, 1998). The reported rhyme effect would be more consistent with the predictions of TRACE and Shortlist because the latter models incorporate a bottom-up recognition network which allows activation of competitors that share phonemes with the target word at any position.

Furthermore, the three models make different predictions about the role of top-down processing in auditory word recognition. The cohort model is able to account for the limited role of top-down effects as proposed, for instance, by Zwitserlood (1989). However, the highly interactive TRACE model predicts top-down effects on all processing levels whereas Shortlist is based on the assumption that top-down feedback is never necessary in spoken word recognition. Therefore, both TRACE and Shortlist are not fully able to account for the limited feedback effects. While TRACE appears to overestimate feedback effects from higher processing levels, Shortlist appears to underestimate the role of context. There has been a long-lasting debate about whether spoken language is processed in an interactive or solely in a bottom-up manner. Arguments and counter-arguments against and in favour of interactive and autonomous models have been found on both sides (e.g. see Norris, McQueen & Cutler (2000) and McClelland, Mirman & Holt (2006) for two contrary views). A detailed outline of this debate is beyond the scope of the present thesis, though. With respect to the present study, I assume that auditory word recognition is, at least in part, an interactive process.

Finally, I would like to point out that all models presented in this section are exclusively based on auditory input. However, it has been shown that spoken language recognition is not a unimodal process but can be influenced by speech cues that are not auditory in nature, such as visual information. A classic finding by McGurk & MacDonald (1976) demonstrated that auditory and visual information of facial gestures interact during speech perception. By presenting conflicting auditory and visual speech stimuli, i.e. participants saw a video of a person saying /ga/ but the soundtrack was taken from a recording of a person saying /ba/, the participants' perception was affected in such a way that they did not perceive /ba/ or /ga/ but both speech cues were apparently fused into the perception of a completely different sound, i.e. participants reported hearing a /da/ sound. This classic finding, later referred to as the *McGurk effect*, challenges models of auditory word recognition because it demonstrates that spoken language processing is not solely based on auditory input but is rather the result of integrating multiple sources of information.

Visual information of facial gestures, however, is not the only type of non-auditory information which affects spoken language processing. As will be shown in the present thesis, auditory word recognition is also influenced by orthographic knowledge. Given that models of auditory word recognition are solely based on auditory input and are not capable of integrating orthographic information, processing orthographic information during auditory word recognition is another challenge for the models presented above. But before I turn to orthographic effects in spoken language processing in section 2.3, I will first take a closer look at the way orthographic information is processed and stored in the mental lexicon during visual word recognition.

2.2 Visual word recognition in L1

As noted by Lupker, "the topic of 'visual word recognition' may have the largest literature in Cognitive Psychology and, therefore, a chapter on this topic must be selective" (2005: 39). It is far beyond the scope of this chapter to provide a comprehensive review of models and empirical findings on visual word recognition. As mentioned earlier, I will rather present a brief overview of those aspects of visual word recognition which are considered relevant with respect to the development of my working model and the theoretical foundation of my empirical investigation. This overview starts with a review of fundamental findings on visual word recognition. Then, I will present two models of visual word recognition and subsequently review empirical studies which investigated the role of phonology and orthographic consistency during visual word recognition. The role of orthographic consistency will be discussed with particular focus on consistency effects across different alphabetic writing systems. For this reason, an overview of writing systems and cross-linguistic theories of orthographic processing will be provided before I present evidence for consistency effects across orthographies. Finally, the reviewed empirical findings will be discussed in light of the presented models and theories.

2.2.1 Fundamentals on visual word recognition

Visual word recognition differs from auditory word recognition in two important ways. First, while the listener hears spoken words usually only once and for a very short period of time, the reader can go back and reanalyze a printed word as many times as necessary. Second, spoken words are presented as a continuous speech stream without word boundaries and with sounds slurred into another due to coarticulation. By contrast, word boundaries and single letters can be identified much more easily for visually presented words.

In spite of these modality-specific differences, the processing mechanism for spoken and written words is characterized by a number of similarities. For instance, both the spoken and written input signal has to be recognized and matched against the corresponding lexical representation in the mental lexicon. Hence, several fundamental findings on auditory word recognition correspond to related findings on the processing of printed words. In the present section, I will present fundamental findings on visual word recognition, i.e. activation of multiple lexical candidates, the role of word frequency and orthographic neighbourhood as well as the role of top-down feedback.

First of all, visual word recognition is characterized by lexical competition. Similar to lexical competition in spoken word recognition, the input signal does not only activate the lexical representation of the printed target word but also activates a number of lexical competitors. A large body of data has shown that similarly spelled words become activated and compete for recognition during visual word recognition (e.g. Andrews, 1997). Consistent with auditory word recognition, this lexical competition is affected by the frequency of the target word and the number and frequency of the competitors.

There is general agreement that word frequency is the most powerful determinant of lexical access time in visual word recognition (e.g. Balota, Cortese, Sergent-Marshall, Spieler & Yap, 2004; Keuleers, Diependaele & Brysbaert, 2010; Murray & Forster, 2004). In general, high-frequency words are processed faster than low-frequency words. An abundant number of studies has provided evidence for the existence of word frequency effects in different tasks on visual word processing, such as lexical decision and word naming[9] (e.g. Besner & McCann, 1987; Forster & Chambers, 1973; Norris, 1984; Whaley, 1978), semantic categorization[10] (Forster & Shen, 1996; Monsell, Doyle & Haggard, 1989) and eye-tracking (e.g. Inhoff & Rayner, 1986; Rayner & Raney, 1996; Rayner, Sereno & Raney, 1996).

Moreover, number and frequency of similarly spelled words (referred to as orthographic neighbours) have been shown to affect visual word recognition. Orthographic neighbourhood size (also termed orthographic neighbourhood density) has been defined as the number of existing words of the same length that can be obtained by changing one letter of the target word (Coltheart, Davelaar, Jonasson & Besner, 1977). For example, the words *gong*, *long*, *pong*, *sing*, *sung* and *tong* are all orthographic neighbours of the English word *song*. Influences of orthographic neighbourhood size on language processing have been demonstrated in various visual tasks, such as lexical

[9] In a word naming task, participants are asked to say a printed word as quickly as possible.

[10] A semantic categorization task requires access to the semantic representation of a word. Participants are given a semantic category (e.g. flower) and are instructed to decide whether a presented word is a member of this semantic category or not.

decision, naming or semantic categorization (see Andrews, 1997; Perea & Rosa, 2000, for reviews). The majority of studies demonstrated facilitatory effects of orthographic neighbourhood density. This means, words from large orthographic neighbourhoods were associated with more accurate and faster performance than words with few orthographic neighbours. However, the impact of neighbourhood frequency, i.e. the frequency of orthographic neighbours of a target word, on task performance is not clear. Mixed results have been found for the influence of orthographic neighbourhood frequency on visual word recognition (see Andrews, 1997, for a discussion).

With respect to the role of top-down effects in visual word recognition, there is converging evidence that flow of information during processing of printed stimuli is bidirectional, i.e. comprising bottom-up and top-down processing. Top-down feedback influences processing both on the prelexical stage, i.e. identification of letters, and the lexical stage, i.e. identification of words. Concerning the prelexical stage, several studies have demonstrated that lexical information affects letter identification. For instance, Reicher (1969) and Wheeler (1970) demonstrated that letters can be recognized more easily in words than in isolation or in nonwords, respectively (word superiority effect). Furthermore, letters in pronounceable nonwords (pseudowords), such as the letter K in the nonword TARK, are identified more easily than in unpronounceable nonwords, such as K in ATRK, (e.g. Aderman & Smith, 1971), or when presented in isolation (e.g. McClelland & Johnston, 1977).[11] The latter phenomenon is known as the pseudoword superiority effect.

Top-down effects on the lexical level were first demonstrated by Schuberth & Eimas (1977). In their study, participants were instructed to make lexical decisions to words and nonwords that were either presented in isolation or preceded by an incomplete sentence. The results demonstrated that identification of nonwords and congruent words were facilitated by sentence context. Similar facilitatory context effects were found for word naming (West & Stanovich, 1978). However, later studies slightly revised these findings**.** For instance, a study by Stanovich & West (1983) indicated that sentence context only facilitates word recognition when a highly predictable semantic context is

[11] Consistent with the notation by Ota, Hartsuiker & Haywood (2010), I put orthographic words used in experimental work in the letter-case in which they were presented in the experiment (e.g. WORD or *word*). When referring to orthographic words outside such methodological contexts, I use lowercase italics.

presented. This means, the target word *apple* is only recognized faster than control words in a highly predictable semantic context, such as “She took a bite of the fresh green …”, but not in a neutral context like “The final word in this sentence is …”.

Effects of sentential context have been also found in various electrophysiological studies measuring event-related potentials (ERPs)[12] to semantic anomalous sentences (e.g. Kutas & Hillyard, 1980). Words that are semantically anomalous in the preceding context (e.g. the word *socks* in the sentence “He spread the warm bread with…”) produced a large negativity wave peaking at 400 ms after the stimulus onset (hence called “N400 effect”). In contrast, highly predictable words (e.g. the word *butter* in the aforementioned context) elicited positive waveforms in this time range. The N400 effect has been proved a very robust effect which is also sensitive to several lexical factors (e.g. word frequency, orthographic neighbourhood) in addition to semantic context (see Van Petten & Luka, 2006, for more details).

Taken together, the findings of the word and pseudoword superiority effects and the facilitatory effects of sentential context in various tasks clearly suggest that visual word recognition is influenced by top-down feedback. Although some researchers argue that the word superiority effect can also be explained without top-down feedback (e.g. Massaro, 1978), there is general agreement that visual word recognition is an interactive process, involving both bottom-up and top-down processing.

In sum, the reviewed findings indicate that visual word recognition is characterized by activation of lexical candidates that compete for selection. This competition is affected by the word frequency and the orthographic neighbourhood of the candidates. Moreover, top-down effects of sentential and lexical context have been shown to influence identification of words and letters, respectively. Based on these fundamental findings, different models of visual word recognition have been developed. Two of these models will be presented in the following section.

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12 Event related potentials (ERPs) are calculated on the basis of electrical brain activity measured via electrodes on the scalp (for an overview, see e.g. Kaan, 2007; Stemmer & Connolly, 2011).

2.2.2 Models of native visual word recognition

Several models of visual word recognition have been developed since the early 1970s (for an overview, see e.g. Belke, 2004; Jacobs & Grainger, 1994; Lupker, 2005). These models can be subdivided into two different groups: localist connectionist models, which are based on the existence of a mental lexicon (Coltheart, Curtis, Atkins & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001; Zorzi, Houghton & Butterworth, 1998), and distributed connectionist models (Harm & Seidenberg, 1999, 2004; Plaut, McClelland, Seidenberg & Patterson, 1996; Seidenberg & McClelland, 1989), which deny the existence of a mental lexicon but suggest that words are represented in highly-connected, distributed sublexical representations. There has been a long-lasting debate about the existence of a mental lexicon in connectionist models of visual word recognition (e.g. see Besner, Twilley, McCann & Seergobin, 1990; Coltheart, 2004, 2005; Seidenberg & Plaut, 2006). One of the central arguments in this debate is that distributed connectionist models cannot accurately account for lexical decisions due to their lack of local representations. For this reason, I will neglect the role of distributed connectionist models in my thesis.

Instead, I will describe two localist connectionist models, i.e. the dual-route cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) and the bimodal interactive activation model (BIAM) (Grainger & Ferrand, 1994, 1996; Grainger, Muneaux, Farioli & Ziegler, 2005; Grainger & Ziegler, 2011). The DRC model has been selected from a number of models since it provides the “most comprehensive theory of visual word recognition *and* reading aloud described to date” (Rastle, 2007: 80). In addition, it has been tested extensively in an abundant number of studies. By contrast, the BIAM has only been tested in a few studies but has been selected from the range of models as it offers a promising mechanism for orthographic and phonological interactions in language processing.

The dual-route cascaded (DRC) model

The dual-route cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) is a localist computational model of visual word recognition and reading aloud which accounts for processing of English monosyllabic words. The overall architecture of the model is illustrated in Figure 2.1.

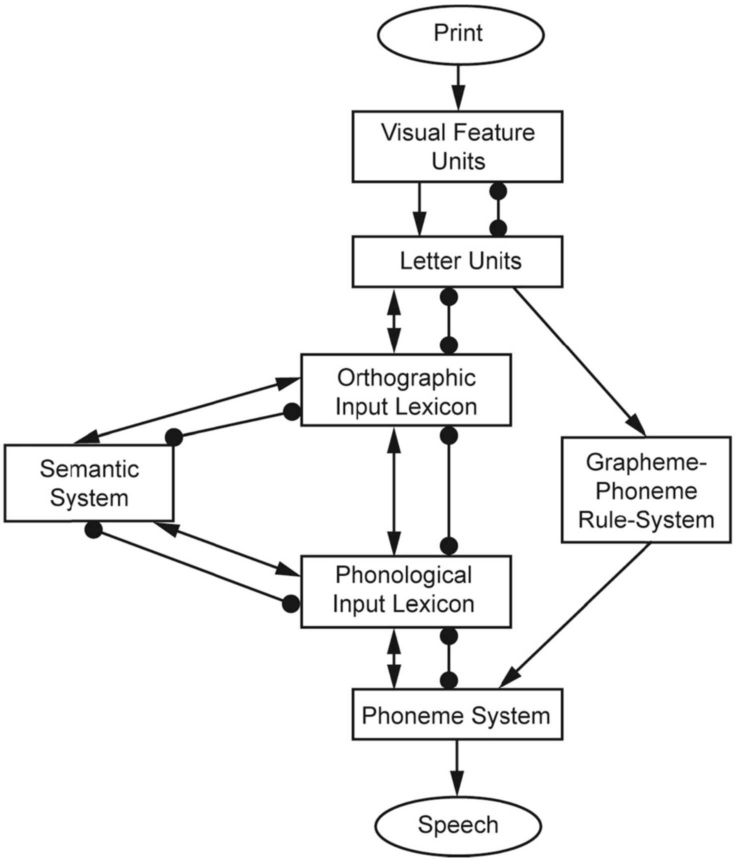

Figure 2.1. The dual-route cascaded (DRC) model of visual word recognition and reading aloud (adapted from Coltheart, Rastle, Perry, Langdon & Ziegler, 2001).

Basically, the DRC model consists of two processing routes, the lexical and the non-lexical route. Each route comprises several interacting layers which contain different sets of units, for example, letters in the letter unit layer or words in the orthographic lexicon. The lexical route involves a spread of activation from activated representations in the orthographic lexicon to corresponding phonological units in the phonological lexicon, either with or without access to the semantic lexicon. In contrast, the non-lexical route does not involve access to the mental lexicon at all. This pathway proposes a direct mapping from letters to phonemes via the grapheme-phoneme conversion system – a process which has been referred to as phonological recoding.

The lexical route can be used for irregular or regular English words, i.e. words which are consistent with grapheme-to-phoneme correspondence (GPC) rules of English, such as *cave* or *maid*, and irregular words, i.e. words which do not obey to the GPC rules of English, like *said* or *have*, whose entries have already been established in the orthographic and phonological lexicon. Words whose orthographic or phonological representations have not been established are processed via the non-lexical route, for example nonwords or regular English words which are still unknown to beginning readers. This route applies GPC rules to convert the input letter strings to the corresponding phonemes.

As mentioned above, the DRC model was developed solely for the reading of English monosyllabic words. Visual word recognition in other languages whose writing systems differ structurally from English, such as Chinese or Japanese, cannot be accounted for by the DRC model. However, the model has been successfully applied to the reading of German, whose orthographic system consists of more regular letter-sound correspondences than English (Ziegler, Perry & Coltheart, 2000).

The bimodal interactive model (BIAM)

The bimodal interactive model (Grainger & Ferrand, 1994, 1996; Grainger, Muneaux, Farioli & Ziegler, 2005; Grainger & Ziegler, 2011) is a localist connectionist model of visual word recognition which has been developed to account for the increasing evidence of phonological effects in visual word recognition (as will be discussed in section 2.2.3). Basically, it incorporates a bimodal version of the interactive activation model by McClelland & Rumelhart (1981).

In the BIAM, phonology and orthography are connected both at sublexical (O-units, P-units) and lexical (O-words, P-words) processing levels (for an illustration, see Figure 2.2). Activation between sublexical and lexical levels flows either directly between the sublexical orthographic input lexicon and phonological representations at the word level or via the central interface between orthography and phonology. Note that these two processing routes would correspond to the lexical and non-lexical routes in the DRC model. The central interface contains correspondences between sublexical orthographic and phonological representations (similar to the GPC rules in the DRC model). However, the central interface does not only consist of bidirectional correspondences between grapheme- and phoneme-sized units but also comprises mappings between larger sublexical units, such as syllables or rhymes (Ziegler, Muneaux & Grainger, 2003). Differences in orthographic consistencies across languages would be located within the central interface, i.e. refer to the correspondences between orthography and phonology, and vice versa.

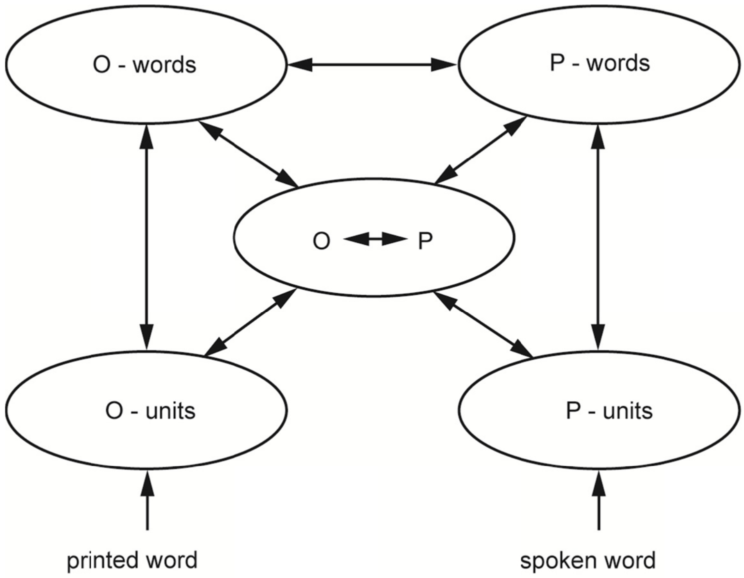

Figure 2.2. The bimodal interactive activation model (BIAM) of visual word recognition (adapted from Grainger, Muneaux, Farioli & Ziegler, 2005).

Although the model shares its basic processing routes with the DRC model, there is an essential difference to the aforementioned model. The key characteristic of the BIAM refers to its bimodal input lexicon. Stimulus input is not restricted to orthographic input but both visual and spoken input can be processed by this model by mutually activating each other. Bidirectional connections between orthographic and phonological units allow the model to account for phonological influences in processing of printed words and also account for orthographic influences in processing of spoken words. Thus, the BIAM is a highly interactive model, allowing bidirectional flow of activation at any orthographic and phonological processing level with and without access to the central interface.

2.2.3 The role of phonology

Early models of visual word recognition were solely based on orthographic information (Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald & Schwaneveldt, 1982) and neglected the role of phonology. However, at present, it is well established that the phonological code plays a crucial role in visual word recognition. Extensive research on phonological influences on visual word recognition has demonstrated that phonology is not only activated in reading aloud but also in tasks which do not explicitly require the pronunciation of printed words.

Early evidence for the existence of phonological effects in visual word recognition was demonstrated in a study by Rubenstein, Lewis & Rubenstein (1971). Rubenstein and colleagues found that response times in a visual lexical decision task were slower for pseudohomophonic nonwords (e.g. JALE, which is homophonic to JAIL) than for non-pseudohomophonic controls (e.g. JARL). Similarly, responses to homophonic words (e.g. MAID, which is homophonic to MADE) were slower than to non-homophonic words (e.g. MESS). Both the homophone effect and pseudo-homophone effect in lexical decision have been replicated in several studies (homophone effect: Ferrand & Grainger, 2003; Pexman, Lupker & Jared, 2001; pseudo-homophone effect: Besner & Davelaar, 1983; McCann, Besner & Davelaar, 1988; Vanhoy & van Orden, 2001; Ziegler, Jacobs & Klüppel, 2001). The homophone effect was, though, not restricted to lexical decision tasks but has been also yielded in other tasks. For instance, van Orden (1987) demonstrated that participants produced more errors in a semantic categorization task when asked to decide whether ROWS (homophonic to ROSE) is a flower compared to the orthographic control word ROBS. These effects were taken as evidence for the activation of the phonological code on the basis of word representations in the orthographic lexicon.

With reference to the DRC model, Pexman, Lupker & Jared (2001) proposed that the reported homophone effect arises due to a feedback from nodes in the phonological lexicon to nodes in the orthographic lexicon. To be more precise, the stimulus ROWS activates the phonological representation /rəʊz/ in the phonological lexicon which, in turn, activates the orthographic representations for both ROWS and ROSE in the orthographic lexicon. Similarly, the pseudohomophone effect can be also explained with reference to the architecture of the DRC model. For instance, the pseudohomophonic nonword JALE is mapped via GPC rules onto the phonemic representation /dʒeɪl/ which will activate the phonological node in the phonological lexicon. Subsequently, activation of /dʒeɪl/ feeds back to the orthographic lexicon where the orthographic representation JAIL is activated. On the whole, these results support the interactive structure as well as the dual route architecture of the DRC model.

The impressive number of studies on phonological effects in visual word recognition raised the question of how quickly phonology is activated in the course of processing visual words, even when explicit pronunciation is not required. Evidence for the fast activation of phonology in early stages of processing comes from studies which investigated masked phonological priming.[13] A number of studies demonstrated that the very short presentation (usually 15-50 ms) of a masked pseudohomophonic prime (e.g. BRAIK, which is homophonic to the target BRAKE) produced faster response times to the target compared to orthographically similar (BRACK - BRAKE) or unrelated controls (GONT - BRAKE) in lexical decision (Grainger & Ferrand, 1994; Lukatela, Frost, Turvey, 1998; Lukatela & Turvey, 1994; 2000) and reading aloud (Lukatela & Turvey, 1994; 2000). A facilitatory effect of pseudohomophones was also observed in other tasks, such as masked perceptual identification (Booth, Perfetti & MacWhinney, 1999; Perfetti, Bell & Delaney, 1988; Perfetti & Bell, 1991; Xu & Perfetti, 1999; see Rastle & Brysbaert, 2006, for a review). Taken together, the results of these studies revealed that the primes influenced the recognition of the printed stimuli although they were not consciously perceived. This early and fast influence of phonology on the time course of visual word recognition has led some researchers to suggest that phonology plays a dominant and obligatory part in processing of printed words (see Frost, 1998, for review and discussion of the *strong phonological theory*).

The increasing evidence for phonological influences during masked priming, which have been referred to as “fast phonology” effects, provides a challenge to the DRC model. As mentioned earlier, the DRC model is primarily based on processing orthographic forms

[13] Two different types of masked priming paradigms have been used in psycholinguistic research. In the forward masking paradigm (Forster & Davis, 1984), a pattern mask (e.g. #####) is followed by a very short presentation of a word or nonword prime stimulus, which is then replaced by the target stimulus and the pattern mask. In backward masking (Perfetti, Bell & Delaney, 1988), a pattern mask (e.g. #####) is followed by a briefly presented target word. The target word is followed by a very short presentation of a verbal mask (e.g. a nonword) and a pattern mask.

via the lexical route and explains phonological effects solely by means of feedback nodes from orthographic to phonological representations. Given that the role of phonological recoding is not central in the DRC model, Rastle & Brysbaert (2006) tested whether the DRC model is able to simulate the reported fast phonological effects. The results of numerous simulations demonstrated that the DRC model was *not* able to simulate both masked phonological priming effects while also accounting for accurate reading of irregular words, such as *have* or *said*. Given that the DRC model is based on a balanced dual-route mechanism between the lexical and non-lexical route, it cannot simulate both effects at the same time.

Recently, Diependaele, Ziegler & Grainger (2010) tested the bimodal interactive activation model (BIAM) for fast phonological effects in lexical decision and reading aloud.[14] Although it is based on a similar dual-route mechanism as the DRC model, it was able to successfully simulate effects of masked phonological priming while maintaining its ability to account for accurate reading of exception words. Diependaele and colleagues suggested that the failure of the DRC model is not due to its parallel dual-route mechanism but rather due to the missing input phoneme representations. Unlike the BIAM, the DRC model does not contain input phoneme representations but only output phoneme representations. Consequently, effects of sublexical phonology on lexical processing can be only mediated via feedback from the output phoneme representations in the DRC model. In contrast, the BIAM contains feedforward connections from input phoneme representations to the phonological lexicon. It has been argued that this characteristic is fundamental for simulations of sublexical fast phonological effects in visual word recognition.

To conclude, the literature reviewed in the present section provides compelling evidence for the role of phonology in visual word recognition. It has been shown that phonology plays an important part in lexical processing of printed words even when explicit pronunciation of words is not required. It remains to be seen whether the computation of phonological information is an obligatory process, as argued by some

[14] Note that the BIAM is primarily a model of visual word recognition (i.e. silent reading) and does not contain a production component (i.e. an output phoneme layer). In order to test the model's ability to simulate accurate reading aloud of exception words, the phonological output buffer of the CPD+ model of reading aloud (Perry, Ziegler & Zorzi, 2007) was added to the BIAM.

researchers (e.g. Frost, 1998), or whether it is rather nonessential and secondary (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). Both models of visual word recognition introduced earlier contain phonological representations and are able to account for a number of reported findings. However, the DRC model fails to account for effects of masked phonological priming. By contrast, a recent simulation of the BIAM demonstrated that its dual-route architecture contains an appropriate mechanism for simulations of such effects.

2.2.4 The role of orthographic consistency

Having discussed the relevance of phonology in visual word recognition in the preceding section, I will now introduce the concept of orthographic consistency. Orthographic consistency characterizes the transparency of mappings between orthographic and phonological units. Such mappings are regarded as consistent when orthographic and phonological units are in a one-to-one correspondence, as exemplified by the grapheme <f> that is always pronounced as /f/ in English. By contrast, inconsistent spelling-to-sound correspondences are characterized by different pronunciations of a grapheme. For instance, the grapheme <a> is pronounced as /a:/ in *arm* but as /æ/ in *ash*. Note that inconsistencies are not restricted to the level of grapheme-phoneme correspondences but can occur at levels of different grain sizes, i.e. sizes of orthographic and phonological units, such as syllables or rimes[15]. Moreover, as will be detailed below, inconsistencies can occur in both directions, i.e. comprise mappings from orthography to phonology (feedforward consistency) as well as mappings from phonology to orthography (feedback consistency). Also note that the concept of consistency is usually distinguished from the concept of regularity:

> An irregular word is one that violates grapheme-phoneme rules (e.g. *yacht*). To define an irregular or exception word, one obviously has to know what the 'rules' are. For the concept of consistency, it does not matter what the rules are. The pure existence of a word that is spelt similarly to other words but yet pronounced differently renders the neighborhood of that word inconsistent. (Frost & Ziegler, 2007: 110)

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[15] In line with Ziegler & Goswami, I will distinguish between the terms *rhyme* and *rime*. "The term *rhyme* is used to refer to judgments about phonology (e.g., as in *rhyme* judgments) and to the phonological unit of any word following the onset (e.g. r-abbit, t-opic). The term *rime* is used when this phonological unit refers specifically to the division of a single syllable (e.g. s-eam, str-eam)." (2005: 4).

Effects of orthographic consistency on visual word recognition have been found in a number of studies. First evidence was provided by Glushko (1979). In a naming experiment, the author found that inconsistent words, i.e. words with bodies[16] that could be pronounced in multiple ways, such as <int> pronounced as /ɪnt/ in *mint* but /aɪnt/ in *pint*, were named more slowly than consistent words whose spelling bodies could be pronounced in only one way, such as <ade> is always pronounced as /eɪd/ in words like *blade* or *shade*. This finding, which has been replicated in other studies (e.g. Jared, 1997, 2002), demonstrated that a word's pronunciation is affected by the knowledge of words with similar spellings. With reference to models of visual word recognition, it has been suggested that inconsistent words activate several phonological representations for a given orthographic input, which slows down language processing. By contrast, consistently spelled words activate only one corresponding pronunciation.

Most studies on consistency effects in visual word processing have investigated correspondences from orthography to phonology (termed as feedforward consistency). However, consistency effects were also found in the other direction (termed as feedback consistency), i.e. involving mappings from phonology to orthography (Perry, 2003; Stone, Vanhoy & van Orden, 1997). For instance, the rime /iːp/ is considered feedback inconsistent as it has more than one possible spelling, i.e. <eep> in *deep* or <eap> in *heap*, whereas rimes in feedback consistent words have only one possible spelling, such as /ʌk/ is always spelled <uck> in the words *duck* or *luck*. Although feedback consistency effects in visual word recognition were found in a few studies (e.g. Perry, 2003; Stone, Vanhoy & van Orden, 1997), the existence of such effects was questioned in other studies (Kessler, Treiman, Mullennix, 2007; Peereman, Content & Bonin, 1998; Ziegler, Petrova & Ferrand, 2008). To date, the widely held belief is that feedforward consistency effects are clearly present in visual word recognition while the existence of feedback consistency effects on printed word processing remains highly disputable. Thus, in the remainder of this section, I will primarily focus on the effects of feedforward consistencies during visual word processing, i.e. mappings from spelling to sounds.[17]

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[16] The *body* refers to the orthographic representation of the phonological rime.

[17] Correspondences in the other direction, i.e. from phonology to orthography (feedback consistency), will be discussed once again with respect to orthographic effects on auditory speech processing (see section 2.3).

So far, the reported studies on consistency effects were exclusively conducted in English or French because these languages are characterized by highly inconsistent correspondences between orthography and phonology. However, alphabetic orthographies vary with respect to the transparency of correspondences between orthography and phonology. In the following, I will first provide an overview of the consistency of alphabetic writing systems and subsequently describe two cross-linguistic theories of orthographic processing. Finally, I will present a review of studies that investigated how differences in orthographic consistency across languages affect visual word recognition of skilled and beginning readers.

2.2.4.1 Overview of orthographic systems

Writing systems are human inventions to represent spoken forms of language. Different orthographic systems were invented over the centuries which differ in the way how linguistic units are mapped onto orthographic representations. In this thesis, I will primarily focus on alphabetic orthographies. Nevertheless, I will briefly provide a general overview of writing systems before I turn to the consistency of alphabetic orthographies.

Three different categories of orthographic systems have been identified with reference to the size of the units that are transcribed by orthographic symbols (e.g. Frost, 2004). Orthographic units can either transcribe phonemes (e.g. in English), syllables (e.g. in the Japanese syllabic kana orthography) or morphosyllables (e.g. in Chinese). Hence, orthographic systems are divided into alphabetic, syllabic and logographic systems. In contrast to alphabetic and syllabic writing systems, where the orthographic units refer to phonological units such as phonemes and syllables, respectively, the orthographic units represent meaningful morphemes in logographic systems. Thus, the pronunciation of a logographic word, such as in Chinese, is recalled from memory and cannot be inferred from the orthographic code (Patterson & Coltheart, 1987). Having introduced a general classification of writing systems, I will now focus on the characteristics of alphabetic orthographies.

Alphabetic orthographies vary across the transparency of their spelling-to-phonology mappings. This complexity of grapheme-phoneme correspondence (GPC) is usually referred to as *orthographic depth* (Klima, 1972; Lukatela, Popadic, Ognjenovic, Turvey, 1980; Liberman, Liberman, Mattingly & Shankweiler, 1980; Katz & Feldman, 1981; Katz & Frost, 1992). In a shallow or transparent orthography, graphemes and phonemes are in a one-to-one correspondence. In contrast, in a deep or opaque orthography, the relationship between orthography and phonology is more inconsistent. Orthographic depth is often conceptualized as a continuum between two ends, one end representing a shallow orthography, the other end featuring a deep orthography. According to this view, languages can be compared to each other in terms of their orthographic depth, e.g. the orthography of a language can be considered deeper or shallower than the orthographic code of another language.

As noted earlier, inconsistencies between orthography and phonology are not restricted to the level of grapheme-phoneme correspondences but can be described at various levels of grain sizes, such as body-rime correspondences. Deep orthographic systems that are characterized by inconsistent grapheme-to-phoneme mappings are usually also characterized by inconsistent relations between the spelling body and the phonological rime (e.g. Ziegler, Jacobs & Stone, 1996; Ziegler, Stone & Jacobs, 1997). However, statistical analyses of the deep orthographies of English and French demonstrated that orthography-to-phonology mappings of the rime unit are slightly more transparent than the consistency of individual phonemes (Peereman & Content, 1998; Treiman, Mullennix, Bijeljac-Babic & Richmond-Welty, 1995). Nevertheless, these correspondences of larger grain sizes are still characterized by a high degree of inconsistency in deep orthographies.

Recall that inconsistencies can occur in both directions. In deep orthographies, such as English, both spelling-to-sound and sound-to-spelling correspondences are usually highly inconsistent. However, orthographies do not necessarily have the same degree of consistency in both directions. For instance, some orthographies that are characterized by highly consistent correspondences from orthography to phonology, such as Spanish, Greek, German, Dutch or Swedish, are less consistent in the opposite direction (Landerl, 2006).

In order to compare alphabetic writing systems in terms of their degree of orthographic consistency, comprehensive computational analyses of bidirectional mappings between orthography and phonology are necessary. At present, though, computational calculations have only been conducted for French (Peereman & Content, 1997, 1999;

van den Bosch, Content, Daelemans & de Gelder, 1994; Ziegler, Jacobs & Stone, 1996), English (Berndt, Reggia & Mitchum, 1987; Treiman, Mullennix, Bijeljac-Babic & Richmond-Welty, 1995; Spencer, 2009; van den Bosch, Content, Daelemans & de Gelder, 1994; Ziegler, Stone & Jacobs, 1997), Dutch (van den Bosch, Content, Daelemans & de Gelder, 1994), German (Neef, 2005; Neef & Balestra, 2011) and Italian (Neef & Balestra, 2011). Although objective measures of transparency are lacking for most languages, there is overall agreement that some European languages contain relatively shallow orthographies (e.g. Finnish, Italian, Spanish and German) while others are rather deep (e.g. French, Danish and English). Therefore, Seymour, Aro & Erskine (2003) suggested a hypothetical classification of European languages with regard to orthographic depth and syllabic complexity[18] (see Figure 2.3).

		orthographic depth **shallow** →				**deep**
	simple	Finnish	Greek Italian Spanish	Portuguese	French	
syllabic structure						
	complex		German Norwegian Icelandic	Dutch Swedish	Danish	English

Figure 2.3. Hypothetical classification of European languages with reference to their orthographic depth (continuum from shallow to deep orthography) and syllabic structure (simple vs. complex) (adapted from Seymour, Aro & Erskine, 2003).

Given that alphabetic writing systems vary widely in terms of orthographic consistency, it is likely that these cross-linguistic differences affect the processing mechanism of visual word recognition. For this reason, two different theories of cross-linguistic word recognition have been developed that explicitly focus on the role of orthographic consistency in cross-linguistic investigations of visual word recognition.

[18] Syllabic complexity is used to distinguish languages that predominantly contain simple syllabic structures, e.g. open syllables (CV) with few initial or final consonant clusters, such as in Spanish and Italian, from languages with complex syllables, e.g. closed syllables (CVC) and complex consonant clusters in onset and coda position, such as in German, Danish and English (Seymour, Aro & Erskine, 2003).

2.2.4.2 Cross-linguistic theories of orthographic processing

The DRC model and the BIAM have been developed to primarily account for visual word recognition in one specific language but not for differences across various orthographies. Hence, I will now introduce two cross-linguistic theories of orthographic processing, i.e. the orthographic depth hypothesis (ODH) and the psycholinguistic grain size theory (PGST) that both emphasize the role of orthographic consistency in visual word recognition across alphabetic writing systems.

The orthographic depth hypothesis (ODH)

The orthographic depth hypothesis (ODH) proposes that readers adapt their processing strategies to the characteristics of the orthographic system they are confronted with (e.g. Frost & Katz, 1989; Frost, Katz & Bentin, 1987; Katz & Feldman, 1983; Katz & Frost, 1992). Based on the dual-route framework of visual word recognition, it assumes that readers of shallow orthographies are encouraged to use the non-lexical or phonological route due to the highly consistent links between spelling and pronunciation. In contrast, readers of deep orthographies rely less on the non-lexical route, given that the spelling-sound relations are highly inconsistent, but rely to a greater extent on the lexical or orthographic route. Thus, according to the ODH, the transparency of the writing system determines the processing routes in reading.

The psycholinguistic grain size theory (PGST)

Similar to the ODH, the psycholinguistic grain size theory (PGST) developed by Ziegler & Goswami (2005, 2006) suggests that fundamental differences in reading mechanisms develop as a response to the orthographic system. However, the PGST does not focus on a dichotomous concept of lexical and non-lexical processing; it rather focuses on the grain size of processing units that are recoded onto phonological structures. According to the PGST, the preliterate child across all languages is sensitive to larger units of phonological grain size, i.e. whole words and syllables. Awareness to phonological units of smaller grain sizes develops during literacy acquisition as a response to the transparency of the orthographic system. Children learning transparent writing systems, such as Spanish, Greek or German, primarily develop recoding strategies based on grapheme-phoneme correspondences. Hence, they develop an awareness of phonemes, i.e. phonological units of small grain size. In contrast, beginning readers of inconsistent orthographies, such as English, cannot focus on simple grapheme-to-phoneme correspondences but have to focus on units of multiple grain size, e.g. mapping phonological rimes on strings of letters, using whole-word recognition or even grapheme-phoneme correspondences, though to a limited extent. Consequently, beginning readers of inconsistent writing systems develop awareness of units of both small and larger grain size whereas beginning readers of transparent orthographies are primarily sensitive to small-unit processing. In this way, the orthographic consistency of a language appears to shape the reader's nature of phonological recoding and reading strategies. Interestingly, this does not only apply to beginning readers but also accounts for "the long-term organization and dynamics of the skilled adult reading system" (Ziegler & Goswami, 2005: 23). Consequently, the PGST provides a cross-linguistic theory of reading acquisition as well as skilled reading and appears to be an "improved and modern alternative to the Orthographic depth hypothesis" (Frost, 2006: 439).

2.2.4.3 Consistency effects across orthographies

Having outlined relevant models and theories of visual word recognition, I will now provide evidence for cross-linguistic effects in visual word recognition. As I will illustrate below, different degrees of an orthography's consistency have been shown to affect processing of written words in cross-linguistic comparisons. This field of research can be subdivided into two areas. On the one hand, word recognition of proficient readers, i.e. adults who have fully acquired reading skills, and, on the other hand, word recognition of beginning readers, i.e. children who are in the process of reading acquisition. For both fields of research, a selected review of studies comparing performance of participants from different orthographic backgrounds will be presented. Finally, I will discuss the studies with reference to the ODH and PGST.

A number of cross-linguistic studies of visual word recognition have been conducted with skilled readers from different alphabetic orthographies. These studies demonstrated that orthographic depth affects word-recognition processes.

First evidence for cross-linguistic effects of orthographic transparency was provided in studies which examined the performance of English and Serbo-Croatian[19] participants in lexical decision and word naming tasks. Katz & Feldman (1983) found that lexical decision but not naming was facilitated by semantic priming in Serbo-Croatian while semantic facilitation effects of similar strength were obtained in English for both tasks. This effect was explained with reference to different processing routes for English and Serbo-Croatian stimuli. Note that lexical decision requires access to the lexicon whereas naming can be achieved without access to the semantic system by phonological recoding. Thus, the absence of semantic facilitation in naming for Serbo-Croatian compared to English suggests that word-recognition processes in Serbo-Croatian are more dependent on phonological recoding than English. This means, the shallow orthography of Serbo-Croatian is processed via the non-lexical (phonological) route without accessing semantic representations whereas the phonological code of English is established via the lexical route by accessing the semantic system and, as a consequence, being affected by semantic priming. A follow-up study confirmed the absence of semantic facilitation in word naming of Serbo-Croatian compared to more inconsistent orthographies (English, Hebrew) (Frost, Katz & Bentin, 1987).

The assumption of the ODH that readers of opaque orthographies predominantly use the lexical (orthographic) route postulates that phonological effects should be reduced in deep orthographic systems, such as English. However, as outlined in section 2.2.3, phonological effects have been found in word recognition in deep orthographies, such as English or French, which are inconsistent with the predictions of the ODH. In contrast to the ODH, the psycholinguistic grain size theory is not based on the relative contribution of phonology in cross-linguistic reading but suggests that the very nature of the phonological processes varies across orthographies depending on the language's consistency. As a consequence, readers raised in deep and shallow orthographies develop distinct processing strategies based on phonological and orthographic units of different grain sizes.

This view was supported, for instance, by a word naming experiment which revealed that German skilled readers demonstrated a preference for phonological units of small

[19] Serbo-Croatian is an example of an extremely shallow orthography whereas English represents a deep orthography.

grain size during reading whereas English participants preferred large-unit processing (Ziegler, Perry, Jacobs & Braun, 2001). In this study, German and English skilled readers read aloud words which had similar orthographic, phonological and semantic forms in both languages (i.e. cognates, such as the English word *hand* and the German word *Hand*). Word length effects were used as an indicator of small-unit processing. Hence, if units of small grain sizes are processed, more chunks need to be processed, which would increase response times in word naming. By contrast, effects of body neighbourhood size (body-*N*)[20] were taken as indicators of large-unit processing. This means, if manipulations of body-*N* affect response times, participants apparently prefer large-unit processing. The authors expected that German readers would demonstrate stronger word length effects than English participants whereas the English participants would show stronger body-*N* effects. The results confirmed this hypothesis. German readers preferred more small-unit processing than English participants while English participants demonstrated more large-unit processing relative to the German group. Therefore, the results supported the assumptions of the PGST by revealing that identical stimuli are processed differently by readers of shallow and deep orthographies. It has been argued that these preferences in small- and large-unit processing have been established during reading acquisition (Goswami, Gombert & de Barrera, 1998).

Having provided evidence for cross-linguistic differences in word processing of skilled readers, I will now turn to the field of literacy acquisition and reading development. An increasing number of studies investigated to what extent differences in orthographic transparency affect reading acquisition across languages. Traditionally, most studies on literacy acquisition focused on reading development of English. Given that English is an alphabetic language with a highly inconsistent spelling-to-sound correspondence, it has been argued that the findings obtained for literacy acquisition of English can, most probably, not be transferred to the process of reading development in languages with more transparent orthographies. For this reason, a number of studies has investigated to what extent differences in orthographic transparency affect reading acquisition across languages.

[20] Size of body neighbourhood (body-*N*) comprises the number of words that share the same orthographic rime (e.g. *late*, *date*, *fate* are body neighbours of *hate*).

Several studies have compared the performance of beginning readers of English with beginning readers of German (e.g. Frith, Wimmer & Landerl, 1998; Mann & Wimmer, 2002; Wimmer & Goswami, 1994; see Landerl, 2006, for a review), French (e.g. Bruck, Genesee & Caravolas, 1997) Spanish (e.g. Goswami, Gombert & de Barrera, 1998) or Greek (Goswami, Porpodas & Wheelwright, 1997). Taken together, these studies revealed that reading acquisition in the inconsistent English writing system progresses more slowly than in transparent orthographies.

The most comprehensive comparison of reading acquisition in different languages, to date, has been reported by Seymour, Aro & Erskine (2003). Seymour and colleagues investigated the development of basic word and nonword reading skills across 13 different European orthographies (Danish, Dutch, English, Finnish, French, German, Greek, Icelandic, Italian, Norwegian, Portuguese, Spanish and Swedish). The results demonstrated that the time needed to develop basic literacy skills varies between European languages. However, neither the method of reading instruction nor age of onset of formal schooling or cultural background could fully account for these differences. Instead, it was assumed that the delay in literacy acquisition for some languages could be explained with reference to the characteristics of the languages' orthographic consistency. Especially the low performance of the English and Danish participants, whose orthographies were considered to be located at the very deep end of the continuum of orthographic transparency, performed very poorly and demonstrated reduced levels of phonological recoding accuracy. Thus, it appears that grapheme-phoneme recoding skills develop more slowly in deep than in shallow writing systems. The authors attempted to explain their findings with reference to the ODH. It was suggested that the difference in orthographic depth established two different cognitive mechanisms for reading acquisition, i.e. a dual process (lexical and non-lexical route) for deep orthographies and a single process (non-lexical route) for transparent orthographies. Ziegler & Goswami (2005) discussed the low performance of Danish and English children in light of the PGST. According to the PGST, the speed of reading acquisition is slowed down for English and Danish beginning readers because the opaque orthography requires development of small as well as large unit-processing whereas beginning readers in shallow orthographies only develop awareness of smaller grain sizes. Overall, it appears that the transparency of a language's orthography predicts the speed of reading development.

Another predictor of reading development, which has been frequently discussed in literature, is phonological awareness (Ziegler et al. 2010; for reviews, see Catts, 1991; Goswami & Bryant, 1990; Pennington, 1991; Scarborough, 1998). Phonological awareness, also referred to as phonological sensitivity or metaphonological awareness, comprises the ability to recognize and manipulate phonological units within a word, such as syllables, rimes or phonemes (e.g. Goswami & Ziegler, 2005). It is measured by phonological awareness tasks, such as phoneme deletion[21] or phoneme counting[22].

Phonological awareness plays an important role in the general process of reading and spelling development. There is overall agreement that phonological awareness and literacy acquisition are in a reciprocal relationship. This means, higher phonological skills at the pre-reading stage accelerate reading development and, vice versa, successful reading development enhances metaphonological skills (e.g. Perfetti, Beck, Bell & Hughes, 1987).

However, development of phonological awareness appears to be influenced by the transparency of the writing system. Goswami (2006) compared performance levels for beginning readers (during their first year of literacy instruction) across different orthographies in phoneme counting tasks, as reported in several single-language studies. This comparison demonstrated that children learning to read transparent orthographies reached higher accuracy scores in phoneme counting (e.g. Greek: 100% (Harris & Giannoulis, 1999; Porpodas, 1999); Italian: 97% (Cossu, Shankweiler, Liberman, Katz & Tola, 1988); Turkish: 94% (Durgunoglu & Oney, 1999); German: 92% (Wimmer, Landerl, Linortner & Hummer, 1991)) than children learning the inconsistent orthography of English (accuracy score of 70% reported in Liberman, Shankweiler, Fischer & Carter (1974) and 71% in Tunmer & Nesdale (1985), respectively).

The poor performance of beginning readers of English in phoneme counting is quite understandable given that the English orthography is characterized by highly inconsistent correspondences between graphemes and phonemes. In contrast to transparent orthographies, inconsistent one-to-many correspondences between letters

[21] In a phoneme deletion task, participants are instructed to delete a particular phoneme of a word.

[22] In a phoneme counting task, participants are instructed to count the number of phonemes of a word.

and sounds in inconsistent writing systems do not boost awareness of phoneme-sized representations (Goswami, Ziegler & Richardson, 2005). Thus, according to the PGST, beginning readers of inconsistent orthographies subsequently develop an awareness of phonological units of larger grain sizes (e.g. syllables or rimes), which are less inconsistent than small units, in addition to the less effective spelling-to-sound mappings of small units. The development of awareness of units of larger grain size in addition to smaller units, though, takes some extra time and, hence, slows down the process of reading acquisition in inconsistent orthographies.

2.2.5 Evaluation of models and theories

Both the DRC model and the BIAM provide a dual-route mechanism which accounts for a number of reported findings on visual word recognition. In both models, printed words can be either processed via the lexical (orthographic) route or non-lexical (phonological) route. By providing a processing route for irregular words, i.e. words whose phonological code cannot be established by regular mappings between sublexical orthographic and phonological units, the models are well suited for inconsistencies of the English language. The DRC model is generally regarded as the most comprehensive and extensively-tested model of printed-word processing. Nevertheless, the BIAM appears to provide a more conclusive approach to certain phenomena of visual word recognition. For instance, its fully interactive structure and its interface between orthography and phonology as an integral component of the model provide the appropriate mechanism to account for fast phonological effects as well as for effects of spelling-to-sound consistencies observed in English or French. Due to its fully interactive structure, it accounts for bidirectional consistencies, i.e. correspondences between spelling and phonology (feedforward consistency) and, vice versa, between phonology and spelling (feedback consistency). The DRC model, in contrast, is primarily based on a lexical route and neglects the compelling role of phonology in orthographically inconsistent languages. Moreover, due to its unidirectional links from graphemes to phonemes, it fails to explain feedback consistency effects.

Given that the consistency between orthography and phonology differs widely across alphabetic writing systems, models of visual word recognition should be able to adapt to the consistency of the language. Consequently, they should not only account for visual word recognition of inconsistent orthographies but also for consistent orthographies. Simulation work by Ziegler, Perry & Coltheart (2000) demonstrated that the DRC model can be successfully applied to word recognition of the shallow German orthography. In the BIAM, a central interface between orthography and phonology can be adjusted according to the transparency of the language's writing system. Therefore, both models are considered to explain word processing of shallow and deep orthographies. Nevertheless, it might be questioned whether shallow orthographies require both a lexical and a non-lexical route at all when the pronunciation of almost all words can be generated by a limited set of grapheme-to-phoneme correspondence rules (Ziegler, Perry & Coltheart, 2000). However, an answer to this critical question is beyond the scope of this thesis and will not be discussed further here. For the purpose of the present study, it is more important to evaluate to what extent differences in visual word recognition across orthographies can be accounted for by the presented models and theories.

For this reason, cross-linguistic theories of visual word recognition have been developed which attempt to illustrate differences in language processing across orthographies. The orthographic depth hypothesis (ODH) and the psycholinguistic grain size theory (PGST) provide two different explanations for cross-linguistic differences that have been observed in printed word-processing between readers from deep and shallow orthographies.

Based on a dual-route architecture, the ODH attempts to explain differences observed for skilled readers from consistent and inconsistent orthographies in terms of reliance on the lexical and non-lexical route as a response to the consistency of the writing system. Given that both DRC model and BIAM contain distinct processing routes for lexical and non-lexical processing, assumptions of the ODH are consistent with the architecture of these models. However, this explanation has been questioned by the existence of strong phonological effects in deep orthographies.

An alternative approach to cross-linguistic differences in reading has been proposed by the PGST. In contrast to the ODH, strong phonological effects in visual word recognition of deep orthographies do not pose a problem for the PGST. On the contrary, phonology is a fundamental ingredient of this theory. Being able to account for cross-linguistic differences both in skilled reading and reading acquisition, the PGST provides a more comprehensive theory of orthographic processing across orthographies than the ODH.

Note that the PGST challenges the assumptions of the DRC model. Initial simulations of the DRC model on processing units larger than phonemes and graphemes failed to predict sensitivity to rime units for English skilled readers. Given that the sublexical route is explicitly based on grapheme-phoneme correspondences, it has been argued that the recent version of the DRC model is not sensitive to orthographic and phonological processing of units of larger grain sizes, such as rimes (Ziegler & Perry, 1998). The BIAM, though, does not explicitly focus its sublexical connections on correspondences between graphemes and phonemes but proposes a mapping of orthographic and phonological sublexical units of different grain sizes, including rimes (Ziegler, Muneaux & Grainger, 2003). For this reason, the BIAM appears to be able to account for effects of inconsistencies which are located at units of different grain sizes. It has to be noted, though, that effects of large-unit processing have not been tested in simulations of the BIAM, yet. Nevertheless, it can be concluded that the BIAM and the PGST provide more convincing explanations for the reported effects of phonology and consistency than the DRC model and the ODH.

2.3 Orthographic effects on L1 auditory word processing

Having provided relevant findings on monolingual processing of spoken and written words in the previous sections, I will now turn to the interaction of both fields, i.e. the effects of spelling on spoken word recognition. Over the last 30 years, a large number of studies has demonstrated that information about a word's spelling influences auditory speech processing in literate participants. At first sight, this finding is surprising given that there appears to be no evident benefit in activating orthographic information during auditory speech processing. Spoken word recognition works perfectly well without orthographic information, for instance for illiterate people. Moreover, given that some languages are characterized by considerable inconsistencies between spelling and pronunciation, activation of conflicting information might even hinder auditory speech processing. However, if we assume that spoken and written words are processed in a highly interactive manner (as proposed by the BIAM), it would be less surprising that orthography influences spoken word processing in a similar way as phonology has been demonstrated to influence visual word recognition in section 2.2.3.

In the following, I will first review studies that provided evidence for the existence of orthographic effects on auditory word recognition. This evidence stems from two different groups of studies, i.e. studies that involved metaphonological tasks and studies involving tasks that were not metaphonological in nature. Moreover, I will review previous studies which investigated the role of different orthographic systems for the obtained orthographic effects. Finally, the presented evidence will be discussed in light of models of auditory word recognition.

2.3.1 Evidence from different metaphonological tasks

Metaphonological tasks involve an explicit awareness and analysis of the sound structure of spoken words, e.g. phonemes, rhymes and syllables, independent of the meaning of the presented words. For example, rhyme judgement tasks, in which participants have to decide whether presented stimuli rhyme or not, require explicit analysis of the phonological rhyme while other metaphonological tasks, such as phoneme deletion tasks, focus on the level of single phonemes.

Until the late 1990s, orthographic effects on auditory word recognition were almost exclusively investigated in metaphonological tasks. One reason for the predominance of metaphonological tasks is the simplicity of the basic design and procedure. Furthermore, as Pattamadilok, Perre & Ziegler (2011) pointed out, metaphonological tasks involve an analysis of units smaller than a word (sublexical units) and are hence appropriate to investigate sublexical stages of spoken word recognition. Interactions of orthography and speech processing have been investigated in various metaphonological tasks over the last decades, such as phoneme detection (Cutler, Treiman & van Ooijen, 1998, 2010; Dijkstra, Roelofs & Fieuws, 1995; Frauenfelder, Segui & Dijkstra, 1990), phoneme counting (e.g. Ehri & Wilce, 1980) syllable monitoring (e.g. Taft & Hambly, 1985), syllable blending[23] (Ventura, Kolinsky, Brito-Mendes & Morais, 2001) and tone judgement[24] (Pattamadilok, Kolinsky, Luksaneeyanawin & Morais, 2008). Apart from those tasks, orthographic effects on auditory word processing have been most extensively investigated in rhyme judgement and phoneme manipulation tasks. A review of studies using the latter paradigms will be below.

2.3.1.1 Auditory rhyme judgement tasks

A study by Seidenberg & Tanenhaus (1979) on auditory rhyme judgements is considered the pioneering study on orthographic influences during spoken word recognition. In this study, participants were instructed to decide whether an aurally presented pair of words rhymed or not by pressing the "Yes" or "No" button. Both rhyming and non-rhyming pairs consisted of either orthographically similar words (rhyme: *turn* - *burn*; non-rhyme: *bomb* - *tomb*) or orthographically different words (rhyme: *turn* - *learn*; non-rhyme: *bomb* - *room*). Although no orthographic information was needed to perform the rhyming judgements, response times were, on average, 99 ms faster for orthographically similar rhymes than for orthographically different rhymes, whereas orthographically similar non-rhymes were judged 58 ms more slowly than orthographically different non-rhymes. In sum, the results revealed that orthographic

[23] In a syllable blending task, participants hear two auditory words and are instructed to pronounce a new word or nonword that consists of the initial syllable of the first word and the final syllable of the second word.

[24] In a tone judgement task, participants are instructed to decide whether two auditory stimuli from a tonal language (e.g. Mandarin Chinese, Thai, etc.) contain the same tone or not.

and phonological congruency facilitated response times whereas incongruent orthographic and phonological information slowed down spoken word recognition. This finding was interpreted as evidence for the *automatic* activation of orthography during auditory language processing. However, as I will illustrate below, the automaticity of orthographic activation in metaphonological tasks was questioned in a replication of this study.

Given that a production frequency bias in favour of orthographically similar rhymes was noticed in the original study, Donnenwerth-Nolan, Tanenhaus & Seidenberg (1981) argued that correct predictions of the target word for orthographically similar rhymes might have resulted in faster response times in this condition. For this reason, they repeated the rhyme-monitoring task with stimuli that were equated for production frequency. Nonetheless, orthographically similar rhymes were still detected faster than orthographically different rhymes.

Due to its surprising results and its simple and straightforward method, the study by Seidenberg & Tanenhaus (1979) deeply influenced research on orthographic effects during spoken word recognition. However, a recent replication of this study by Damian & Bowers (2009b) challenged the interpretation of the original findings. By using exactly the same materials and procedure as in the original study, the authors basically replicated the classic finding that orthographic similarity facilitated response times for rhyming pairs but inhibited latencies for non-rhyming pairs. But when a large number of filler trials was added to obscure the orthographic and phonological characteristics of the critical stimuli, the orthographic effect disappeared. This finding suggests that the activation of orthography in rhyme judgement, as observed by Seidenberg & Tanenhaus (1979), does not occur automatically during speech processing but is the result of a specific response strategy. Consequently, orthographic effects in rhyme judgement tasks cannot be treated as general and automatic effects of spoken word recognition but appear to be elicited by the salience of orthographic and phonological properties in the stimulus materials.

Nevertheless, auditory rhyme judgement tasks have provided interesting insights into different aspects of orthographic processing during spoken word recognition. For example, Zecker, Tanenhaus, Alderman & Siqueland (1986) investigated the lateralization of the orthographic effect in order to determine whether the phonological and orthographic codes were presented differently in the left and right hemispheres of the brain. Other studies investigated the orthographic effect in rhyme judgement as an indicator of orthographic processing with dyslexic participants or beginning readers (Cone, Burman, Bitan, Bolger & Booth, 2008; Desroches, Cone, Bolger, Bitan, Burman & Booth, 2010; McPherson, Ackerman & Dykman, 1997; Rack, 1985; Zecker, 1991). Most recently, Pattamadilok, Perre & Ziegler (2011) explored the neurophysiological nature of the orthographic effect in rhyme judgement. The results of their ERP study indicated that the characteristics of orthographic effects in metaphonological tasks, such as rhyme judgement, are different from those discovered in tasks which do not involve metaphonological components (see section 2.3.2).

2.3.1.2 Phoneme manipulation tasks

Apart from the classic finding by Seidenberg & Tanenhaus (1979), another study provided early evidence for orthographic influences on spoken word recognition in metaphonological tasks. Morais, Cary, Alegria & Bertelson (1979) examined Portuguese literate and illiterate adults performing auditory phoneme manipulation tasks, such as phoneme deletion and addition, i.e. participants were instructed to delete the first sound of a word or add a sound to a presented word. Whereas literate participants performed the tasks easily, illiterates were unable to delete or add a phoneme at the beginning of a nonword. Morais and colleagues concluded that awareness of phonological units in speech develops as a consequence of learning to read. This finding has been replicated in several studies with illiterate adults (e.g. Adrián, Alegria & Morais, 1995; Lukatela, Carello, Shankweiler & Liberman, 1995).

A large number of studies used phoneme manipulation tasks in addition to other tasks to investigate the relation between phonological awareness and reading proficiency (for reviews, see section 2.2.4.3). Other studies implemented phoneme manipulations to answer the question of whether literate participants perform a phoneme manipulation task by using a phonological or an orthographic strategy. Once children have learned that certain letters or groups of letters correspond to certain sounds, they can perform a phoneme deletion task by using either a phonological or an orthographic strategy. The phonological strategy would imply that they segment the spoken word into single sounds and remove the required phoneme. In an orthographic strategy, on the other hand, they remove the letter or string of letters that typically correspond to the target phoneme. The three most relevant studies in this field of research will be briefly outlined.

To start with, Stuart (1990) demonstrated that 9-year-old children used both phonological and orthographic strategies in order to delete the penultimate sound of aurally presented words. Stimuli consisted of words and nonwords that resulted into real English words when either the penultimate phoneme or letter was removed. For example, for the stimulus /raɪnd/ (*rind*) the response based on a phonological strategy would be /raɪd/ (*ride*) while an orthographic strategy would lead to the response *rid* /rɪd/.

This finding is in line with a study by Castles, Holmes, Neath & Kinoshita (2003) who investigated the involvement of orthographic and phonological strategies in two speeded phoneme manipulation tasks, i.e. phoneme reversal and phoneme deletion. In the phoneme deletion task, half of the items were congruent, i.e. there was a one-to-one relationship between the to-be-deleted sound and the corresponding letter (e.g. "remove /d/ from *dentist*"). The other stimuli consisted of incongruent items, which did not contain a one-to-one-correspondence between the sound to-be-removed from the word and the letters representing that sound (e. g. "remove /n/ from *knuckle*" or "remove /s/ from *fox*"). Results showed significantly higher error rates and slower response times in the incongruent than in the congruent condition. Similar results were found in the phoneme reversal task where participants had to say the sounds of congruent and incongruent stimuli in reversed order. Thus, it was suggested that the participants' performance was affected by an explicit orthographic component.

Further evidence for orthographic activation during auditory phoneme manipulation tasks was provided by Tyler & Burnham (2006). In their study, stimuli consisted of words which resulted into a new real English word after the initial letter had been deleted. Half of the stimuli were congruent items, i.e. phonemic as well as orthographic knowledge would lead to the correct response (e.g. /weɪdʒ/ (*wage*) minus /w/ = /eɪdʒ/ (*age*)). The other half consisted of incongruent items. If an orthographic instead of a phonemic strategy was used for incongruent items, the deletion of the first letter resulted in an incorrect spelling of the response word (e.g. phonological strategy: /fəʊk/ (*folk*) minus /f/ = /əʊk/ (*oak*); orthographic strategy: <folk> minus <f> = <olk> /əʊk/). Analyses of response times yielded significantly longer response times for incongruent stimuli than for congruent stimuli, even when participants were instructed not to use the spelling of a word. Qualitative analyses of the error rates provided further evidence for the use of orthographic strategies in the spoken responses. For some items, participants were affected by the spelling in such way that they did not delete the first sound but the first letter of the word, e.g. *chart* resulted in the incorrect response /ha:t/ or *phone* to /həʊn/.

2.3.1.3 Concluding summary

Taken together, the studies reviewed above demonstrated that phonological decisions in auditory metaphonological tasks were clearly influenced by orthographic information. Consequently, these findings have been interpreted as evidence for orthographic influences on auditory speech processing.

Studies which tested phoneme manipulation skills with illiterate and literate participants showed that awareness of letters facilitates manipulations of individual sounds. However, this finding does not suggest that literate people have a direct awareness of individual sounds. It rather appears that their knowledge of corresponding orthographic units helps them to get access to the phonemic structure of words. In other words, orthographic knowledge is recruited strategically. Being aware of the correspondences between sounds and letters, it is highly likely that participants use this information in tasks that require explicit awareness and manipulation of phonological units, such as rhyme judgements or phoneme manipulation tasks.

Morais & Kolinsky (1995) suggested that, alternatively, orthography is activated in metaphonological tasks automatically, similar to a kind of Stroop effect[25]. They argued

[25] The Stroop effect is a psychological phenomenon regarding the processing of mental conflicting information. The effect shows that naming the colour of a word produces longer reaction times and more errors when the colour of the ink does not match the name of the colour (e.g. the word *red* is written in green instead of red ink) than when both colour of the ink and name of the colour match (Stroop, 1935; see MacLeod, 1991, for a review).

that orthographic information interferes with corresponding phonological representations at a decision stage. This means, participants based their decisions in rhyme judgement or phoneme manipulation tasks on phonological units but were confused by conflicting orthographic information. If we assume that strong links between orthographic and phonological units have been established during literacy acquisition, these links co-activate corresponding orthographic units during phonological processing (in a similar way as phonological units are activated during visual word recognition).

Both explanations would support the assumption of a bidirectional coupling between orthography and phonology as proposed in highly interactive models of language processing. Nevertheless, it should be noted that the reported findings were yielded in tasks that explicitly focused the participants' attention on the analysis and manipulation of phonological units. These tasks did not resemble natural language processing. Therefore, the results cannot be interpreted in a way indicating that orthography is always and automatically activated in spoken word processing. The reported evidence rather suggests that orthography is activated strategically in metaphonological tasks "because orthography may provide useful cues both for segmentation and decision processes" (Pattamadilok, Perre & Ziegler, 2011: 121). In order to evaluate whether orthographic activation can be regarded as a general effect during auditory speech processing, I will now review studies which investigated interactions of orthography and phonology in various auditory tasks that were *not* metaphonological in nature.

2.3.2 Evidence from tasks without metaphonological components

As shown above, orthographic information affects auditory speech processing in metaphonological tasks. On second thought, the finding that a word's spelling influences performance in auditory metaphonological tasks is probably not surprising given that literacy acquisition goes along with an increasing awareness of correspondences between orthography and phonology (Ehri & Wilce, 1980; Morais, Cary, Alegria & Bertelson, 1979; Olson, 1996; Treiman & Cassar, 1997). However, orthographic influences have been also demonstrated in auditory tasks that do not involve metaphonological components. In the following, two different types of paradigms will be outlined. On the one hand, studies which investigated orthographic overlap in phonological priming and, on the other hand, studies which employed manipulations of orthographic consistency without primes. The latter type of studies investigated an effect often referred to as the *orthographic consistency effect*.

2.3.2.1 Orthographic effects in priming

In contrast to metaphonological tasks, priming paradigms do not require an explicit analysis of the phonological structure and its orthographic correspondences. For this reason, priming paradigms have been used to investigate whether orthographic effects during spoken word recognition are general effects of auditory speech processing.

Orthographic effects were investigated by manipulating the orthographic and phonological overlap between primes and targets. For example, Jakimik, Cole & Rudnicky (1985) conducted an auditory lexical decision task with primes and targets that either included initial phonological overlap (e.g. *chocolate* - *chalk*), initial orthographic overlap (e.g. *fighter* - *fig*), both phonological and orthographic overlap (e.g. *napkin* - *nap*) or no overlap (e.g. *insect* - *spy*). Facilitatory priming effects for primes and targets were found for stimuli that were orthographically and phonologically related, i.e. *napkin* - *nap*. This finding, which has been repeated in other studies (e.g. Burton, Jongman & Sereno, 1996; Chéreau, Gaskell & Dumay, 2007; Miller & Swick, 2003; Slowiaczek, Soltano, Wieting & Bishop, 2003), illustrates that the orthographic code is activated during spoken word recognition.

Although these studies did not involve an explicit analysis of the phonological or orthographic structure of the stimuli, which is in contrast to metaphonological tasks discussed earlier, it has been argued that phonological and orthographic overlap might induce task-specific response strategies (Goldinger, 1999; Pitt & Shoaf, 2002). Therefore, lexical processing might have been biased by expectancies and response strategies rather than by priming effects in the reported studies. Note that the degree of strategic influences in priming paradigms can be varied by adding filler trials, increasing time pressure (e.g. by reducing the interstimulus interval) or masked priming. Recent studies by Chéreau, Gaskell & Dumay (2007), Perre, Midgley & Ziegler (2009) and Taft, Castles, Davis, Lazendic & Nguyen-Hoan (2008) attempted to reduce the possibility of strategic orthographic influences by presenting a very low number of related trials. For instance, only 5% of the trials consisted of related primes and targets in the study by Chéreau, Gaskell & Dumay (2007). Thus, it was extremely difficult for participants to detect an orthographic relation between prime and target, which minimized the option that participants developed an orthographic strategy while performing this task. Furthermore, a very short interstimulus interval was used to induce very quick responses, which would again minimize the use of strategic biases. Nevertheless, orthographic effects were found in priming, even when the auditory primes were masked by meaningless syllables (Taft, Castles, Davis, Lazendic & Nguyen-Hoan, 2008). To conclude, priming paradigms have provided strong evidence for the activation of orthography during auditory speech processing in situations where strategic influences are minimized.

2.3.2.2 Manipulations of orthographic consistency

Another method to investigate orthographic influences in tasks without metaphonological components is by manipulating a word's consistency with which phonology is mapped onto orthography. While in priming paradigms the target's pronunciation or spelling has to be introduced before or at the same time as the target word, an orthographic or phonologically related competitor is not required when orthographic consistency is manipulated.

First evidence for the influences of consistency manipulations on auditory speech processing was provided by Ziegler & Ferrand (1998) who manipulated the orthographic (feedback) consistency of spoken words in an auditory lexical decision task. Half of the stimuli were inconsistent, i.e. their phonological rimes could be spelled in multiple ways (e.g. /i:p/ can be spelled <eap> or <eep>), the other half was consistent, i.e. their rimes can be spelled in only one way (e.g. /ʌk/ may only be spelled <uck>). The results revealed that inconsistent words produced longer auditory lexical decision latencies and more errors than consistent stimuli. This finding has become known as the *orthographic consistency effect*. The study by Ziegler & Ferrand (1998) attracted much attention because it demonstrated in a clear and straightforward manner that orthographic effects in spoken word recognition are not restricted to metaphonological tasks but can be regarded as general effects in auditory speech processing.

Since its discovery, the orthographic consistency effect has been proved a very robust finding, which has been obtained in different languages, such as French (Pattamadilok, Morais, de Vylder, Ventura & Kolinsky, 2009; Pattamadilok, Morais & Kolinsky, 2011; Pattamadilok, Perre, Dufau & Ziegler, 2009; Peereman, Dufour & Burt, 2009; Perre, Pattamadilok, Montant, Ziegler, 2009; Perre & Ziegler, 2008; Ziegler, Ferrand & Montant, 2004) English (Dich, 2011; Pattamadilok, Knierim, Kawabata Duncan & Devlin, 2010; Ziegler, Petrova & Ferrand, 2008) and Portuguese (Ventura, Kolinsky, Pattamadilok & Morais, 2008; Ventura, Morais & Kolinsky, 2007; Ventura, Morais, Pattamadilok & Kolinsky, 2004). Thus, it is noteworthy that the orthographic consistency effect has not only been observed in languages characterized as deep orthographies, such as English or French, but also in languages with transparent orthographic systems, such as Portuguese.

Given that a lexical decision task is a particularly unnatural task, the orthographic consistency effect has been also tested in semantic categorization tasks, which are considered more natural tasks as participants listen to auditory speech to extract meaning. When the orthographic consistency effect was observed in semantic categorization (Pattamadilok, Perre, Dufau & Ziegler, 2009; Peereman, Dufour & Burt, 2009), this has been considered “the strongest evidence available thus far for the claim that orthography influences spoken language processing in a nonstrategic way” (Pattamadilok, Perre, Dufau & Ziegler, 2009: 175).

Other studies demonstrated that the orthographic consistency effect is directly linked to a person’s reading ability. Ventura, Morais & Kolinsky (2007) showed that even second-, third- and fourth-grade Portuguese children showed an orthographic consistency effect in lexical decision while no effect was obtained for a group of pre-readers from kindergarten school. These results are in line with a study by Pattamadilok, Morais, de Vylder, Ventura & Kolinsky (2009) who found a consistency effect in French-speaking second- to fourth-grade children and adults. A very recent study by Dich (2011) investigated whether orthographic proficiency influenced the size of the orthographic consistency effect in adults. The study included an auditory lexical decision task with orthographically consistent and inconsistent words and a spelling test. Results suggested that individual differences in the participants' size of the orthographic consistency effect could be partially explained by their spelling skills.

On the whole, studies on the orthographic consistency effect provided strong evidence for the claim that orthographic representations of spoken words are activated during auditory word recognition. Therefore, orthography does not only interact with spoken word recognition during metaphonological tasks (as discussed in section 2.3.1) but also during auditory tasks which do not require a metaphonological analysis of the provided stimuli. As we will see below, the latter findings have important implications for models of auditory word recognition.

2.3.2.3 Concluding summary

While early research on orthographic influences on phonological processing was restricted to metaphonological tasks (as outlined in section 2.3.1), more recent studies found orthographic effects in tasks that did not contain metaphonological components. The latter type of studies provided important evidence for the role of orthography in spoken word recognition since they demonstrated that information about a word's spelling gets activated in situations which do not necessarily require access to the orthographic form, such as in lexical decision or semantic categorization tasks. Moreover, priming paradigms demonstrated that orthography affects auditory speech processing in a subliminal way, which has been treated as strong evidence for the *automatic* activation of orthography in phonological processing. Taken together, priming studies and manipulations of orthographic consistency provided clear evidence for the nonstrategic but automatic recruitment of orthography in auditory word recognition.

Note that this conclusion is inconsistent with the interpretation of orthographic biases in metaphonological tasks discussed earlier. However, a recent study by Pattamadilok, Perre & Ziegler (2011) indicated that the characteristics of the orthographic effect observed in metaphonological tasks differs from those obtained in tasks that did not focus on metaphonological skills. This means, in online speech recognition tasks, such as lexical decision or semantic categorization, "orthographic knowledge seems to contribute to lexical access, whereas in tasks that require explicit phonological analyses, it seems to affect more peripheral processes, such as segmentation and decision"

(Pattamadilok, Perre & Ziegler, 2011: 121). Hence, it appears that we have to distinguish between two different kinds of orthographic effects in auditory word recognition. Depending on the metaphonological nature of the task, orthography might be activated strategically (in rhyme judgement, phoneme manipulation etc.) or automatically (in online spoken word recognition tasks).

The assumption that orthographic and phonological representations are connected by strong bidirectional links is reinforced by studies demonstrating that orthographic effects during speech processing are not restricted to metaphonological tasks but can be regarded as general effects of spoken word recognition. For instance, the orthographic consistency effect can be explained by activation of multiple spellings for a given phonological unit, which slows down processing of orthographically inconsistent words. Hence, permanent links between orthographic and phonological units allow the rapid flow of activation from the phonological input to corresponding orthographic representations. In contrast to evidence from metaphonological tasks, these links are not only (strategically) accessed during explicit awareness of phonological units (and their corresponding orthographic representations), but are regarded as permanent connections which activate orthographic units automatically during auditory speech processing. This way, orthographic representations get activated in situations which do not necessarily involve orthographic information, such as lexical decision or semantic categorization.

2.3.3 The role of different orthographic systems

Research on orthographic influences on spoken language processing has primarily focused on alphabetic orthographies, especially English or French. In section 2.2.4, it has been shown that differences in orthographic consistency across languages affect visual word recognition. Similarly, it can be assumed that the transparency of the orthographic system affects orthographic influences during auditory word recognition. In the following, I will therefore review studies which investigated cross-linguistic effects of orthographic recruitment during phonological processing.

Before I discuss the role of cross-linguistic differences of orthographic transparency on the reported orthographic effects during spoken word recognition, I will briefly summarize the role of logographic orthographies on this field of research. A very limited number of studies tested the performance of participants from logographic orthographies in auditory metaphonological tasks, such as phoneme deletion. The results showed that participants who were literate in both alphabetic and logographic script outperformed those who had only learned a logographic notation (Cheung, Chen, Lai, Wong & Hills, 2001; de Gelder, Vroomen & Bertelson, 1993; Read, Zhang, Nie & Ding, 1986). This finding suggests that alphabetic orthographies promote the development of phonological awareness.

As already discussed in the section on cross-linguistic differences in visual word recognition, phonological awareness appears to be influenced by the transparency of the orthographic system (see section 2.2.4.3). Recall that participants from transparent orthographies (Greek, Italian, Turkish, German) reached higher accuracy scores in phoneme counting tasks than English participants. This finding demonstrates that inconsistent correspondences between orthography and phonology result in less accurate performance in metaphonological tasks. Hence, participants from deep orthographies are more strongly affected by orthographic influences than participants from shallow orthographies. It should be noted, though, that the reported studies were conducted with beginning readers. Interactions of phonological and orthographic processing might be different for literate adults because skilled readers of inconsistent orthographies might have become used to the inconsistencies of the writing system and are, consequently, less affected by the inconsistencies.

In contrast to studies that examined the effects of different orthographic systems in auditory metaphonological tasks, only very little research has been carried out on this topic involving tasks without metaphonological components. Orthographic effects in priming studies have been exclusively investigated with English stimuli. Research on the orthographic consistency effect, though, has been carried out in English, French and Portuguese. Thus, research on the orthographic consistency effect has not been restricted to deep orthographies (e.g. English, French) but has been also carried out in transparent orthographies, such as Portuguese.

Of particular interest for the present study is a cross-linguistic analysis of the orthographic consistency effect in French and Portuguese. Pattamadilok, Morais, Ventura & Kolinsky (2007) investigated whether the consistency of the language's writing system affected the magnitude of the orthographic consistency effect. The study involved an auditory lexical decision task, with French and Portuguese stimuli of a similar consistency and L1 participants of the respective languages. Given that the authors considered Portuguese a rather shallow orthography compared to French, they expected that Portuguese participants would be more affected by orthographic manipulations than French participants. Contrary to their assumptions, they found a smaller orthographic consistency effect in auditory lexical decision with Portuguese stimuli and participants (52 ms) compared to French stimuli and participants (69 ms). It was suggested that the consistent phoneme-to-grapheme correspondences in Portuguese made the participants less susceptible to orthographic inconsistencies than the French participants, whose inconsistent phoneme-to-grapheme mappings might have established stronger connections between phonological and orthographic representations, which made them more sensitive to orthographic inconsistencies in the auditory modality.

It is noteworthy that orthographic consistency was manipulated on the rime level. According to the psycholinguistic grain size theory, the French participants should be more familiar with the processing of units of larger grain size, such as rime units, than the Portuguese participants. This should have resulted in a smaller consistency effect for the French participants compared to the effect of the Portuguese group. However, the finding of a smaller consistency effect for the Portuguese participants, who were less used to the processing of (inconsistent) rime units than the French participants, does not agree with the assumptions of the PGST. Further cross-linguistic comparisons are necessary to disentangle the exact mechanism of orthographic-phonological interactions during auditory speech processing.

2.3.4 Orthographic effects in models of auditory word recognition

Traditionally, auditory speech processing was considered a purely phonological process, independent of orthographic knowledge (see section 2.1). As the reported orthographic effects have been proved to be reliable and robust effects in speech processing, such effects have to be implemented into current models of auditory word recognition or, alternatively, new models have to be developed which incorporate the role of orthography during auditory word recognition.

In order to understand how orthography interacts with the acoustic input signal in models of auditory word recognition, I will first discuss reported findings with reference to the locus of the orthographic effect. Subsequently, the role of orthography will be discussed in light of established models of auditory word recognition, such as TRACE, the cohort model and Shortlist. Finally, the bimodal interactive model (BIAM), which has been introduced as a model of visual word recognition in section 2.2.2, will be included in the discussion of the reported effects.

With reference to models of spoken word recognition, it is important to localize the effect of orthographic information during speech processing. In other words, it has to be determined whether orthographic information affects lexical and/or sublexical representations and, moreover, at which point of time during word recognition the orthographic influence arises.

To date, no clear picture has emerged as to whether orthographic interactions occur at lexical or sublexical processing levels.[26] Some data support the view that orthographic information interacts with phonological units at sublexical processing levels. The majority of data supporting this view stems from metaphonological tasks that involved orthographic manipulations of sublexical units (see section 2.3.1). However, this view has also been supported by the finding of an orthographic consistency effect in a task without metaphonological components. Pattamadilok, Morais, Ventura & Kolinsky (2007) found that lexical decision times on pseudowords were affected by orthographic consistency. This means, pseudowords that contained orthographically inconsistent rimes yielded longer response times than orthographically consistent pseudowords. Given that pseudowords do not correspond to lexical representations in the mental

[26] Note that the terms *lexical* and *sublexical* are used to refer to the grain size of the processing units. This means, *lexical* refers to representations of whole words while *sublexical* comprises units smaller than a word, such as phonemes and rimes. Also note that the term *sublexical* has to be distinguished from the term *prelexical*, which refers to the chronological order of processing. *Prelexical* refers to all processes that occur before lexical access whereas *postlexical* describes processes that occur after lexical access. As noted by Pattamadilok, Ventura, Morais & Kolinsky, “prelexical processing necessarily takes place before lexical access, while sublexical representations may be activated before or after lexical activation” (2005, p. 91).

lexicon, it was assumed that the orthographic interaction could not occur at the lexical level but affected sublexical representations. In contrast, other findings suggest that orthographic influences are limited to the lexical processing level. Contrary to the observed consistency effect for pseudowords discussed above, no consistency effect emerged for pseudowords in a study by Ventura, Morais, Pattamdilok & Kolinsky (2004). In addition, Ventura and colleagues did not find a consistency effect in a shadowing task, neither for words nor for pseudowords. It is widely accepted that a shadowing task involves less lexical processing than a lexical decision task. Therefore, the absence of an orthographic consistency effect in shadowing was interpreted as evidence for a lexically-rooted orthographic influence during spoken word recognition. In sum, the reviewed findings suggest that orthographic interactions during auditory word processing affect both sublexical and lexical representations.

With respect to the locus of the orthographic effect during the time course of spoken word recognition, i.e. whether it occurs prelexically, lexically or postlexically, collected findings suggest a prelexical and lexical view. Strong evidence for the prelexical and lexical locus of the orthographic effect during spoken word recognition has been provided by Perre & Ziegler (2008). In an auditory lexical decision task, participants listened to orthographically consistent and inconsistent words. Inconsistent words consisted of "early inconsistent" words, i.e. words whose initial consonant-vowel cluster had multiple spellings, and "late inconsistent" words, i.e. words whose final consonant-vowel cluster could be spelled in multiple ways. In order to investigate the time course of orthographic interaction during spoken word recognition, event-related brain potentials (ERPs) were measured. Interestingly, the ERP differences between orthographically consistent and inconsistent words were "time-locked to the 'arrival' of the orthographic inconsistency in a spoken word" (p. 135). That is, the activation of orthographic information occurred prelexically (for "early inconsistent" words) and lexically (for "late inconsistent" words).

Moreover, as mentioned earlier, a recent ERP study by Pattamadilok, Perre & Ziegler (2011) found different loci of the orthographic effect in a metaphonological task compared to a task without metaphonological components. While the orthographic consistency effect seemed to occur at the lexical processing stage, orthographic effects in a metaphonological task, i.e. rhyme judgement, affected the prelexical and postlexical processing stages. However, more electrophysiological data are needed to support the assumption that the locus of the orthographic effect is task-dependent.

On the whole, it appears that orthographic information affects sublexical and lexical representations at prelexical, lexical and postlexical stages of spoken word processing. These assumptions can be best captured by an interactive model of speech processing that allows interactions of orthographic and phonological units of sublexical and lexical grain size.

The finding that orthography interacts with auditory speech signals during spoken word processing challenges well established models of auditory word recognition, such as TRACE, the cohort model or Shortlist (see section 2.1). These models, which were specifically developed for auditory word recognition and have been tested in multitudinous studies on speech perception, are solely based on phonological input and are not capable of integrating information derived from the orthographic code. However, the abundant evidence for literacy effects in language comprehension demonstrates that current models of auditory word recognition can no longer ignore the role of orthography. Cutler & Davis (2008) claimed that orthographic effects in auditory tasks have to be interpreted in the framework of a detailed and well established model of spoken word recognition. In addition, Peereman, Dufour & Burt (2009) pointed out that these models are likely to process orthographic information if their architectures incorporated links between orthographic and phonological representations.

Nonetheless, I will neglect the role of TRACE, the cohort model and Shortlist in the present discussion and rather discuss the observed literacy effects on spoken language processing in light of the bimodal interactive model (BIAM). The BIAM was originally developed to explain phonological effects in visual word recognition but offers a promising architecture that accounts for processing both visual and auditory words. Due to its highly interactive links between orthographic and phonological representations, it is the only model of word processing which, at present, is able to explain the role of orthographic interactions during spoken word recognition.

I will illustrate the special status of the BIAM with respect to visual word recognition. In the section on visual word recognition (section 2.2), it has been demonstrated that the processing of printed words is *not* solely based on orthographic representations.

Instead, phonology has been shown to affect visual word recognition. As a consequence, correspondences between orthographic and phonological representations at sublexical and lexical processing levels are central components of models of visual word recognition. In contrast to other models of visual word recognition, the BIAM contains a bimodal input mechanism and a bidirectional framework of orthographic and phonological representations that accounts for effects of feedforward consistencies, i.e. spelling-to-sound correspondences, as well as correspondences from sounds to spellings (feedback consistency). It is the latter direction of mappings, i.e. from phonology to orthography, which is involved in the observed orthographic influences on auditory speech processing. Therefore, the same mechanism that explains phonological effects in visual word recognition is able to account for orthographic effects in auditory word recognition.

For instance, in metaphonological tasks which require manipulations of phonological units (see section 2.3.1), participants use these links because access to the corresponding orthographic units might help them to analyze the phonological structure of the auditory input. Alternatively, as discussed earlier, the orthographic code is activated automatically in metaphonological tasks as a kind of Stroop effect.

The BIAM is also able to explain the existence of orthographic consistency effects in auditory word recognition. According to the BIAM, inconsistent mappings between orthography and phonology induce a slowdown of auditory processing. To be more precise, if the phonological input activates several corresponding orthographic representations and not only one, more time is needed to resolve this conflict than if only one spelling is activated. As a consequence, phonological rimes that can be spelled in multiple ways generate longer processing times than rimes with only one possible spelling, as has been demonstrated over the last decade in a large body of data.

Furthermore, the BIAM seems to be able to account for cross-linguistic differences of orthographic activation during spoken word recognition, as demonstrated by Pattamadilok, Morais, Ventura & Kolinsky (2007). Similar to cross-linguistic differences in visual word recognition, the BIAM's central interface appears to be sensitive to the orthographic depth of a language, which results in different degrees of the orthographic consistency effect for participants from shallow and deep orthographies. However, more cross-linguistic research is needed to assess the role of orthographic depth in spoken word processing.

To conclude, given that the reported orthographic effects have been demonstrated to be reliable and robust effects in auditory word processing, orthographic representations have to be incorporated into models of spoken word recognition. While established models, such as TRACE, the cohort model and Shortlist, still neglect the role of orthography during spoken word processing, I have discussed the reviewed findings of orthographic activations with reference to the bimodal interactive activation model (BIAM). I have demonstrated that the BIAM's highly interactive mechanism of orthographic and phonological units, which has been primarily applied to account for effects in visual word recognition, provides an appropriate framework for explaining the reported literacy effects in the auditory modality.

3 Word processing in L2

Today, the majority of people are able to speak two or even more languages (more or less fluently). However, as noted by Grosjean (1989), bilinguals are not two monolinguals in one person. Instead, complex processes are at work in the bilinguals' mind. A central question on bilingual language processing is to what extent information from the first language (L1) interacts during processing of the second language (L2) or vice versa. Furthermore, it is of interest whether L1 and L2 words are stored in a language-specific lexicon or a shared lexicon of both languages.

As we will see below, similar lexical entries that exist in both languages, such as cognates[27], interlingual homographs[28] or interlingual homophones[29], have contributed to a large extent to our present understanding of the way native and non-native languages are processed and stored in the bilingual or multilingual lexicon. Research on cognates, interlingual homographs and homophones was motivated by the question of whether both lexical entries from different languages were activated when an identical or similar orthographic and/or phonological form was presented. For instance, differences in response times between words which are part of both languages, such as the Dutch-English cognate *film*, and words which exist in only one language of the bilingual's mental lexicon would suggest that both languages become activated in parallel (language non-selective access). In contrast, equivalent response times for cognates and monolingual control words would support a language selective view. Besides, simultaneous activation of cross-linguistic competitors, such as whether an L2 word activates lexical competitors in the L1, would provide evidence in favour of a shared or independent lexicon.

[27] Cognates are defined as words that share a similar form and an identical meaning in two languages, such as the Dutch-English example of *film* having the same form and an identical meaning in both languages.

[28] Interlingual homographs have an identical orthographic form but a different meaning, such as the English-French homograph *pain* (meaning bread in French).

[29] Interlingual homophones are words with similar (but not identical) phonological forms in two languages. For example, the Dutch word *lief* (meaning nice) and the English word *leaf* are interlingual homophones.

In the present chapter, I will outline relevant empirical findings and models on auditory and visual word recognition of non-native stimuli. Moreover, the interaction of orthographic information during non-native spoken word recognition will be discussed.

3.1 Auditory word recognition in L2

The traditional view of bilingual language processing proposes that languages are processed independently by activating one language and deactivating the other. This position is associated with a language switching mechanism (Macnamara, 1967; Macnamara & Kushnir, 1971). Intuitively, this input switch provides a conclusive explanation for a mechanism that maps the input of a specific language onto the representation in the corresponding lexicon by deactivating the lexicon of the irrelevant language. Especially with respect to bilingual recognition of spoken words, it seems reasonable to expect a language-selective access of the bilingual lexicon, i.e. only the relevant target language gets activated whereas the irrelevant language is turned off. This assumption is based on the fact that the acoustic speech signal contains language-specific cues which enable the listener to identify the sublexical unit as belonging to one language or the other. For instance, some phonemes only occur in English but not in German (e.g. /θ/) or vice versa (e.g. /ʏ/). Moreover, some phonemes that occur in both languages (e.g. /r/) sound different as a result of allophonic variation. Due to these phonemic and subphonemic cues, the listener is able to determine the language membership of a spoken input and map the input onto the appropriate lexicon by deactivating the lexicon of the irrelevant language.

While this position was favoured in the early studies on bilingual language processing, more recent empirical work has challenged this view. However, research on bilingual language processing is not only governed by the fundamental question of whether words of both languages are activated in parallel (language non-selective access) or only words belonging to the target language (language selective access). In addition, researchers investigate whether two languages are stored in two separate independent mental lexicons or in a shared integrated lexicon of both languages. These fundamental questions on bilingual auditory word recognition will be discussed in the following.

Thereafter, models of non-native auditory word recognition will be introduced and evaluated.

3.1.1 Fundamentals on non-native auditory word recognition

Several fundamental findings on monolingual auditory word recognition have been also found in the bilingual domain. For instance, L2 auditory word recognition is incremental in nature (Grosjean, 1988), involves lexical competition (e.g. Marian & Spivey, 2003) and is affected by word frequency and neighbourhood density (e.g. Imai, Walley & Flege, 2005). Besides, fundamental findings on spoken word processing of bilinguals refer to the question of how words from both languages are stored and processed in the bilingual lexicon. This central question on recognition of auditory L2 words will be addressed below in more detail.

As mentioned above, researchers have proposed a language selective view of spoken word processing in the bilingual mind. The language selective view is consistent with a study by Grosjean (1988), who demonstrated that bilingual listeners were able to identify the language membership of spoken "guest words", i.e. words that are pronounced as either code-switches or borrowings, exclusively on the basis of the initial phonemes. This selective view of bilingual processing has been challenged, though, by a number of later studies.

For instance, a study by Schulpen, Dijkstra, Schriefers & Hasper (2003) investigated the role of language-specific information in cross-modal priming. Dutch-English bilinguals were instructed to make lexical decisions to visually presented targets that were accompanied by auditory primes that were either interlingual homophones or monolingual control words. The results demonstrated that response times to words preceded by an auditory interlingual homophone (e.g. /liːf/ - LEAF) were faster than to targets preceded by an unrelated control word (e.g. /baɪk/ - LEAF). This pattern of results was observed for the English and Dutch pronunciation of interlingual homophones. Thus, the finding suggests that both the Dutch and the English representations of the interlingual homophones were activated. The simultaneous and parallel activation of words from two languages supports the non-selective view of bilingual language processing.

Further evidence for the non-selective view was provided by several eye-tracking experiments carried out by Marian and colleagues (Marian, Blumenfeld & Boukrina, 2008; Marian & Spivey, 2003; Marian, Spivey & Hirsch, 2003; Spivey & Marian, 1999). In a series of experiments, Russian-English bilinguals were instructed to identify a particular object from a set of objects (e.g. "Pick up the marker"). The choice of provided objects was varied systematically with respect to the object names' phonological overlap and language membership. For instance, the set of objects consisted of a within-language competitor, e.g. the English word *marbles*, a between-language competitor, e.g. the Russian word *marka* (meaning stamp) and unrelated filler items. The pattern of eye movements showed that on hearing the English word *marker*, participants fixated the between-language competitor *marka* more often than unrelated distractor items. Moreover, participants made more eye movements to the within-language competitor *marbles* relative to unrelated objects. The results showed that bilinguals both activate competitors from their non-target language (between-language competitors) and their target language (within-language competitors) during auditory word recognition. Taken together, these findings provided strong evidence for a parallel and language non-selective activation of both languages. Even in purely monolingual situations, bilinguals do *not* appear to deactivate the irrelevant lexicon. These results have been replicated in eye-tracking paradigms with Dutch-English bilinguals (Weber & Cutler, 2004), Spanish-English bilinguals (Ju & Luce, 2004), Japanese-English bilinguals (Cutler, Weber & Otake, 2006) and German-English bilinguals (Blumenfeld & Marian, 2007).

A very recent study by Lagrou, Hartsuiker & Duyck (2011) provided additional evidence for non-selective lexical access in bilingual auditory word recognition. By investigating the homophone interference effect from L2 to L1 (and vice versa), they found that Dutch-English bilinguals responded more slowly to homophones than to control words in an English and Dutch (monolingual) auditory lexical decision task. English and Dutch stimuli were spoken by a native speaker of English or Dutch in order to examine whether subphonemic differences between the pronunciation of stimuli by native or foreign-accented speech affected the size of the homophone effect. Interestingly, the size of the homophone effect was equivalent in both conditions. This means that bilinguals did not use subphonemic cues (such as information about a speaker's accent) to restrict lexical access to a single language. Hence, the results indicated that lexical access in bilingual auditory speech processing is language-independent both in L1 and L2.

Taken together, studies that investigated bilingual word recognition in the auditory modality have provided strong evidence for the counter-intuitive view that bilinguals activate both languages. Subphonemic cues that reveal information about the language membership of the word are not utilized by the bilingual listener to deactivate the irrelevant lexicon. Therefore, researchers suggest a language non-selective view of lexical access in the auditory modality. In addition, the reviewed eye-tracking studies by Marian and colleagues have provided evidence for cross-linguistic competition, i.e. lexical competition was not restricted to competitors from the target language (within-language competitors). Rather, competitors from the non-target language (between-language competitors) were also activated and contributed to lexical processing. The latter type of interaction has been typically interpreted as evidence for an integrated lexicon of both languages (van Heuven, Dijkstra & Grainger, 1998). Consequently, the reported findings of between-language competition in eye-tracking challenge the assumption of two separate lexicons in the auditory modality. To conclude, the reviewed studies on bilingual auditory word recognition provide strong evidence for a language non-selective access to an integrated lexicon of both languages.

3.1.2 Models of non-native auditory word recognition

While a large number of models have been developed to account for L1 auditory word recognition, the choice of comprehensive models which account for non-native speech processing is very limited. At present, the Bilingual Model of Lexical Access (BIMOLA) (Grosjean, 1988, 1997; Léwy & Grosjean, 1996; Léwy, Grosjean, Grosjean, Racine & Versin, 2005) is the only model which has been developed to explain bilingual auditory word recognition. Other contemporary models of bilingual processing, such as the Bilingual Interactive Activation (BIA) Model and its successor BIA+, have been developed and computationally implemented for visual word recognition (see section 3.2.2). However, according to Dijkstra & van Heuven, the BIA+ model is believed to also account for bilingual word recognition in the auditory modality "even though modality specific processing characteristics are to be expected" (2002, p. 194). Given that this formulation is a very vague one and that the "modality specific processing characteristics" have not been specified yet, the BIA+ model and its predecessor, the BIA model, are primarily considered as bilingual models of visual word recognition and, hence, will be further described in the section on bilingual word recognition of visual stimuli. For this reason, the description of bilingual models of auditory word recognition will be limited to the BIMOLA.

The Bilingual Interactive Model of Lexical Access (BIMOLA)

The Bilingual Interactive Model of Lexical Access (BIMOLA) (Grosjean, 1988, 1997; Léwy, Grosjean, 1996; Léwy, Grosjean, Grosjean, Racine & Versin, 2005) is a localist connectionist model which is based on the TRACE model of monolingual auditory word recognition (McClelland & Elman, 1986). This model was developed to account for monolingual and bilingual language modes. A monolingual language mode refers to a situation in which only one language is relevant although the bilingual knows two languages, whereas a situation of a bilingual language mode refers to the mixing of both languages. Similar to TRACE, the BIMOLA consists of an interactive structure of three different auditory layers, i.e. features, phonemes and words (see Figure 3.1). Words of both languages are processed in parallel (language non-selective access) but the processing mechanisms differ across the auditory layers. While the feature level is shared by both languages, the phoneme and word levels are organized in language-specific subsets, i.e. two separate lexicons for each language combined in a larger set. Connections between the auditory layers are unidirectional between the features and phonemes and bidirectional between phonemes and words. Furthermore, the model incorporates top-down connections by which external information about language mode and linguistic context can activate words of a specific lexicon which, in turn, can activate phonemes. First attempts have been made to test this model by computational simulations (Léwy, Grosjean, Grosjean, Racine & Versin, 2005). More computational tests are in preparation (Grosjean, 2008).

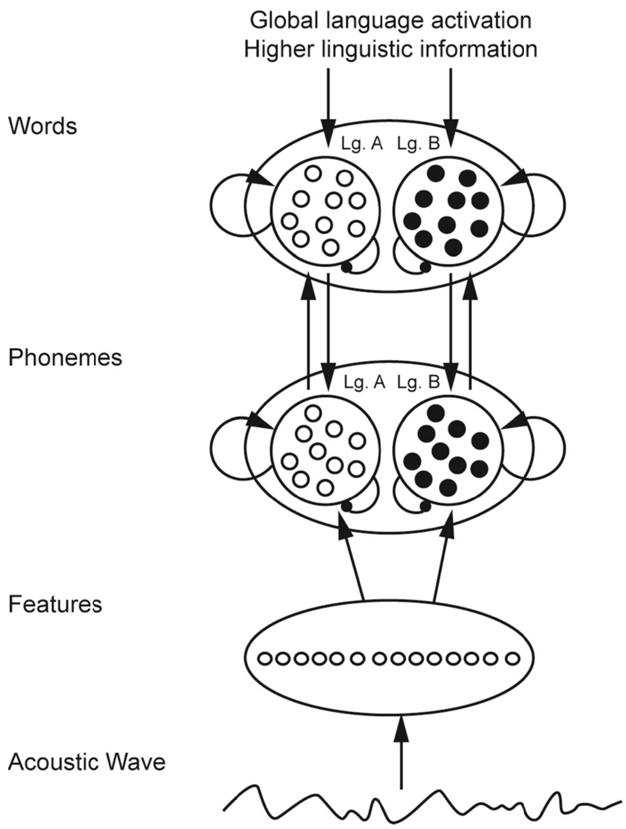

Figure 3.1. The Bilingual Model of Lexical Access (BIMOLA) (adapted from Grosjean, 1997).

3.1.3 Evaluation of models

To date, the BIMOLA is the only model which has been developed to account for spoken word recognition of bilinguals. As noted earlier, it shares a number of characteristics with TRACE, such as the interactive flow of information between different auditory layers. Like TRACE, it is solely based on auditory input and does not allow interactions of auditory and visual information, such as facial gestures or orthographic knowledge.

According to the BIMOLA, there is a parallel non-selective activation of words in both languages. This view is consistent with the studies reviewed in the previous section. Moreover, it consists of two separate lexicons for each language connected in a larger set. The architecture of independent and interconnected lexicons for both languages was driven by theoretical considerations on the abilities of a bilingual speaker. According to Grosjean (1997), a bilingual speaker with a high proficiency in both languages is able to speak only one language, which suggests that this language is processed independently of the other language. Both languages are interconnected because the bilingual speaker can code-switch quite easily between the two languages. However, the assumption of two separate lexicons has been questioned by empirical investigations. As reviewed above, studies that demonstrated interactions between lexical presentations from both languages (e.g. Marian & Spivey, 2003) provide evidence for an integrated lexicon (at the word level).

More research is needed to understand the exact mechanism of how bilingual speakers store and process spoken words in their mental lexicon(s). In addition, models of bilingual auditory word processing, such as the BIMOLA, have to be tested in computational simulations. First simulations with the implemented BIMOLA have demonstrated that the model is able to account for general aspects of spoken language processing, such as the frequency effect. A more comprehensive computational implementation of the BIMOLA is still in development (Grosjean, 2008). It remains to be seen if the BIMOLA is able to account for future results found in experimental investigations of bilinguals.

To conclude, the BIMOLA presents a good starting point for modeling bilingual spoken word recognition although its architecture of two separate lexicons is inconsistent with latest findings on this field of research. Given that there is no comprehensive alternative to the BIMOLA, the development of a new model of bilingual auditory word recognition which incorporates a parallel processing mechanism of both languages and an integrated lexicon is eligible.

3.2 Visual word recognition in L2

Similar to research on bilingual language processing in the auditory modality, there is a long-lasting debate on cross-language activation during lexical processing and storage of printed stimuli. This issue will be addressed below in the section on fundamentals on L2 visual word recognition. Based on these fundamental findings, I will then present two current models of non-native visual word recognition and subsequently review empirical studies which investigated the role of phonology and different orthographies during bilingual visual word recognition. Finally, the reviewed empirical findings will be discussed in light of the presented models of bilingual visual word recognition.

3.2.1 Fundamentals on non-native visual word recognition

Fundamental principles on monolingual visual word recognition, which have been discussed in section 2.2.1, can be also applied to the bilingual domain. That is, bilingual word recognition is an interactive process that involves lexical competition and is affected, for instance, by factors like L2 word frequency (e.g. Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger & Zwitserlood, 2008) and orthographic neighbourhood density (e.g. van Heuven, Dijkstra & Grainger, 1998). However, in contrast to monolingual word recognition, one might ask whether lexical competition arises in bilingual word recognition between candidates from both languages or from one language only. For this reason, most research on visual word recognition has addressed the fundamental questions of whether lexical access in bilinguals is language selective or language non-selective and, moreover, whether languages are stored in two independent lexicons or a shared lexicon for both languages. As noted earlier, these distinctions are an essential ingredient of models of bilingual word recognition. In the present section, I will review fundamental findings that contributed to the discussion of a selective or non-selective access to an integrated or independent bilingual lexicon.

Note that empirical investigations on bilingual processing in the auditory modality have been also driven by these fundamental questions (see section 3.1). Nevertheless, research on printed L2 word recognition differs from the aforementioned studies in one important aspect. While the bilingual listener may rely on language-specific cues in the acoustic speech signal to identify a spoken word as belonging to one language or the other, there are usually no cues about a word's language membership available in the printed alphabetic word used for bilingual word recognition.[30]

As detailed earlier, studies on bilingual word processing make use of stimuli with different types of cross-linguistic overlapping, such as interlingual homographs or cognates. Recall that research is motivated by the assumption that these stimuli are assumed to be processed differently in the bilingual mind compared to monolingual stimuli that exist in only one language.

Although several studies found no clear differences in response times for cognates or interlingual homographs relative to monolingual control words (e.g. Dijkstra, van Jaarsveld & ten Brinke, 1998; Gerard & Scarborough, 1989; see Dijkstra, 2005, for a review), the majority of later studies supported a language non-selective view of bilingual processing in the visual modality. This view was motivated by an increasing number of studies that showed activation of the non-target language during processing of interlingual homographs (e.g. Beauvillain & Grainger, 1987; de Groot, Delmaar & Lupker, 2000; Dijkstra, Grainger & van Heuven, 1999; Dijkstra, Timmermans & Schriefers, 2000; Jared & Szucs, 2002) and cognates (e.g. de Groot, Borgwaldt, Bos & van den Eijnden, 2002; de Groot & Nas, 1991; Dijkstra, Grainger & van Heuven, 1999; Lemhöfer, Dijkstra & Michel, 2004; van Hell & de Groot, 1998; van Hell & Dijkstra, 2002). Furthermore, while most studies demonstrated effects of the first language on word recognition in L2, cross-linguistic effects have been also demonstrated in the other direction (e.g. Duyck, 2005; van Hell & Dijkstra, 2002; van Heuven, Dijkstra & Grainger, 1998; van Wijnendaele & Brysbaert, 2002).

In addition to the collection of behavioural research outlined so far, an increasing number of electrophysiological and neuroimaging[31] studies have been conducted over

[30] Of course, some cross-linguistic differences concerning graphemic representations exist between alphabetic orthographies. For instance, the letters *ä* and *ü* only occur in the German but not in the English orthographic system. Therefore, in research on bilingual visual word recognition, words containing graphemic representations which are not part of both languages are typically avoided. Besides, differences in capitalization between interlingual homographs or cognates, such as the German word *Gold* and the English word *gold*, are avoided by presenting all items in capital letters (GOLD).

[31] Neuroimaging involves the use of various recent technologies, such as functional magnetic resonance imaging (fMRI), that are used to image and model the structure and function of the brain (see Binder & Price, 2001; Brown & Hagoort, 1999, for an overview).

the last couple of years, which provided new and promising insights into the mechanisms of non-native visual word recognition and largely supported the non-selective view of visual word recognition (e.g. Kerkhofs, Dijkstra, Chwilla & de Bruijn, 2006; van Heuven, Schriefers, Dijkstra & Hagoort, 2008; for reviews, see Abutalebi, Cappa & Perani, 2005; Moreno, Rodríguez-Fornells & Laine, 2008; van Heuven & Dijkstra, 2010).

The studies reported so far investigated to what extent bilinguals activated orthographically and/or semantically identical word candidates from their L1 while performing single-word reading tasks in their L2. Strong evidence in favour of an activation of both languages during visual word processing has been also demonstrated by manipulating the number of interlingual orthographic neighbours, i.e. the number of orthographically similar words in the non-target language. While there is general agreement that orthographic neighbourhood influences visual word recognition in a monolingual context (see section 2.2.1), van Heuven, Dijkstra & Grainger (1998) demonstrated that this concept can be also applied to bilingual word recognition. Dutch-English bilinguals showed slower response times to English words in progressive demasking (PDM)[32] and lexical decision when the number of orthographic neighbours was increased in Dutch. By contrast, an increase of English neighbourhood size produced facilitatory effects for English and inhibitory effects for Dutch target words. This cross-language effect of orthographic neighbourhood was supported by a more recent electrophysiological investigation of interlingual neighbourhood in bilingual language processing (Midgley, Holcomb, van Heuven, Grainger, 2008). Taken together, these findings have been interpreted as strong evidence for an interaction of lexical competitors from both languages (within-language and between-language competitors). Therefore, parallel activation and interaction of word candidates from both languages suggest an integrated lexicon for both languages.

In sum, the increasing number of research on bilingual language processing in the visual modality has provided strong evidence for a language-independent access to language-specific representations in the mental lexicon. Moreover, the finding of clear

[32] In a progressive demasking task (PDM), participants are instructed to identify a visually presented stimulus which slowly emerges from a pattern mask. Participants are asked to press a button as soon as they have identified the word and to type in the word in a response prompt (Grainger & Segui, 1990).

interactions in lexical competition between candidates from both languages has been interpreted as evidence in favour of an integrated lexicon of bilinguals. In the following section, I will introduce two models of bilingual visual word recognition which incorporate the assumption of a language non-selective access to an integrated lexicon.

3.2.2 Models of non-native visual word recognition

The number of models that are able to account for bilingual visual word processing is rather limited. In fact, only two models have been explicitly developed for visual word recognition of bilingual speakers, i.e. the bilingual activation (BIA) model (Dijkstra & van Heuven, 1998; van Heuven, 2000; van Heuven, Dijkstra & Grainger, 1998) and its successor the BIA+ model (Dijkstra & van Heuven, 2002). Both models propose language non-selective activation of words in a shared lexicon of both languages. Furthermore, these two models are of particular interest since they are believed to be extendable to the domain of auditory word recognition.

The Bilingual Interactive Activation (BIA) Model

The Bilingual Interactive Activation (BIA) Model (Dijkstra & van Heuven, 1998; van Heuven, Dijkstra & Grainger, 1998; van Heuven, 2000) is a localist connectionist model of bilingual visual word recognition, which proposes two main assumptions. First, the bilingual lexicon is integrated across languages, and second, access to the lexicon occurs in a language non-selective way. The model shares the basic architecture of the monolingual interactive activation model (McClelland & Rumelhart, 1981), however, in addition to the feature, letter and word levels, a fourth layer contains language nodes, which represent the language the activated words belong to (see Figure 3.2).

When a sequence of letters is presented to the model, a complex process of activation and inhibition starts until only one lexical entry, which is related to one of the two languages, is left as the most active word unit. The BIA model has been computationally implemented and has been shown to account for a number of effects in bilingual visual word recognition. However, the model has been criticized for some shortcomings, such as the lack of semantic or phonological representations. For this reason, a revised version, i.e. the BIA+ model, has been developed which will be presented below.

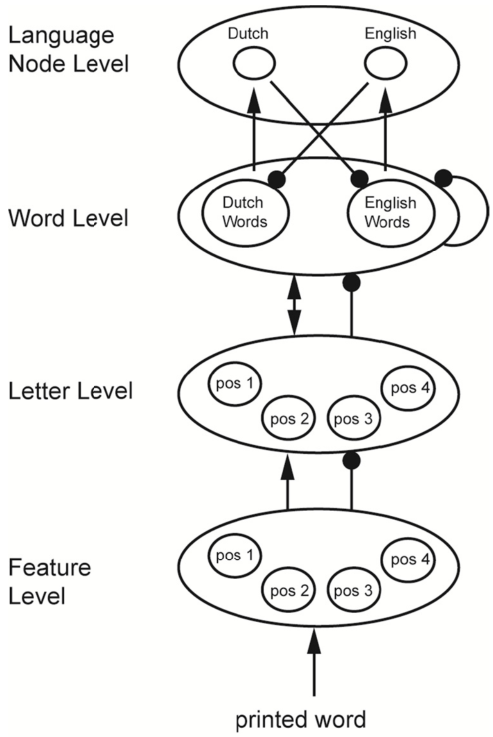

Figure 3.2. The BIA Model (adapted from Dijkstra & van Heuven, 1998).

The BIA+ Model

The BIA+ model (Dijkstra & van Heuven, 2002) is a modification and extension of the BIA model outlined above. In contrast to its predecessor, the BIA+ model contains phonological and semantic representations. Thus, the model consists of a highly interactive network of orthographic, phonological and semantic representations (see Figure 3.3).

It incorporates an integrated lexicon and a language non-selective view of lexical access. A visual input letter string activates sublexical orthographic representations of both languages which activate orthographic word candidates as well as sublexical phonological representations. In this way, sublexical orthographic units can activate lexical phonological representations either directly via activation of lexical orthographic representations or via the activation of corresponding sublexical phonological units, which then activate the entries in the phonological lexicon. In a next step, orthographic and phonological word candidates activate the corresponding semantic representations and the language nodes. The model assumes that linguistic context, such as sentence context, is able to affect the word identification system whereas non-linguistic context, i.e. effects that arise from participant expectancies, influences the task/decision system. The BIA+ model has been successfully implemented for computational simulations of visual word recognition.

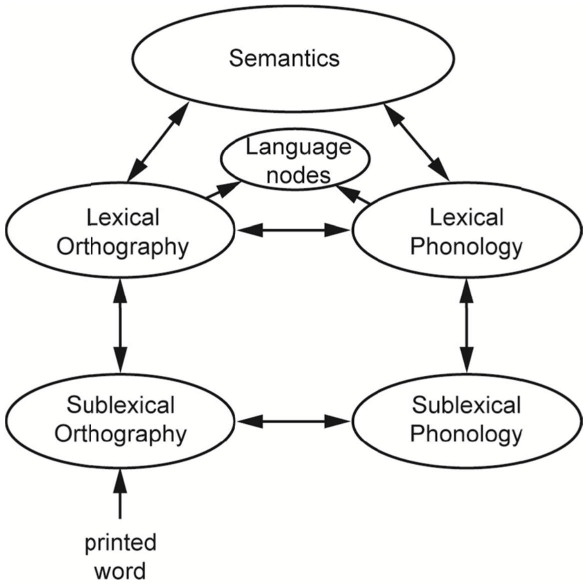

Figure 3.3. The BIA+ Model (adapted from Dijkstra & van Heuven, 2002).

3.2.3 The role of phonology

As discussed in section 2.2.3, findings from the monolingual domain indicated that phonology plays a crucial role during visual word recognition in L1. While an abundant number of studies have investigated phonological effects in monolingual processing of printed stimuli, bilingual research on this topic is much scarcer. This section will provide a review of the few studies that examined activations of phonological representations in bilinguals.

First evidence for the activation of phonology during visual word recognition of bilinguals was demonstrated by Dijkstra, Grainger & van Heuven (1999). They showed that response times in lexical decision and progressive demasking were longer for L2 words that were phonologically similar to L1 words, such as the English word *leaf* /liːf/ and the Dutch word *lief* /liːf/ (meaning nice), compared to control words. Interestingly, phonology was activated although it was not useful for the performance of this task. This finding is consistent with the results of a study by Kim & Davis (2003) who tested Korean-English bilinguals in a naming and lexical decision task. Even though the Korean and English language have different alphabets, the results indicated that L2 target words were primed by L1 homophones.[33] Recently, this effect has been also found with Chinese-English bilinguals independent of priming direction (Chinese to English or English to Chinese) and proficiency level of English (Zhou, Chen, Yang & Dunlap, 2010).

While the studies outlined so far investigated whether phonological similarity between L2 and L1 stimuli influenced processing of L2 targets, other studies addressed a related question. Given that orthographic units are mapped onto phonological units by sound-to-spelling correspondence rules, the following studies tested whether rules about grapheme-to-phoneme correspondences of the non-target language are applied to visual word recognition of the target language.

In a masked priming paradigm, Brysbaert, van Dyck & van de Poel (1999) observed that it was easier for Dutch-French bilinguals to identify visually masked words of their L2, e.g. the French word *nez* (meaning nose), which were preceded by homophonic L1 prime words, e.g. the Dutch word *nee* (meaning no), than those which were preceded by an L1 orthographic control prime, e.g. the Dutch word *nek* (meaning neck). Interestingly, homophonic prime effects were found for Dutch-French bilinguals but not for French monolinguals because the L1 primes were only homophones of the French target words when Dutch grapheme-to-phoneme correspondence (GPC) rules were applied (although participants were not informed about the existence of such stimuli). Thus, the data demonstrated that Dutch-French bilinguals used L1 GPC rules when performing a task in their L2 (French). This cross-linguistic homophone effect was later replicated by Duyck, Diependaele, Drieghe & Brysbaert (2004). Moreover, van Wijnendaele & Brysbaert (2002) showed that the cross-linguistic homophone effect can be also obtained in the

[33] As noted by Duyck (2005), the priming effect in lexical decision only reached significance in a one-tailed t-test and was not acknowledged by Kim & Davis (2003).

other direction, i.e. stimuli that were homophones of L1 targets (according to GPC rules of the L2) facilitated L1 word recognition.

Although the studies discussed above suggest strong evidence for the activation of spelling-to-sound rules of the non-target language (either L1 or L2) during word recognition in the target language (L2 or L1), Jared & Kroll (2001) observed differentiating data. By testing French-English and English-French bilinguals in a word naming experiment, they found that spelling-to-sound correspondences from both languages can be activated. However, their activation depended on the position of the target stimuli during the experiment, i.e. whether the critical stimuli occurred before or after a block of filler items from the non-target language. In addition, activation of spelling-to-sound correspondences was affected by the participants' language proficiency and experience of the less dominant language.

To conclude, the studies reviewed above provide further evidence for a language non-selective activation of both languages in bilinguals. Consistent with findings that demonstrated the early and obligatory activation of phonology in L1, the results obtained in research on bilingual language processing support a mandatory, prelexical and language-independent activation of phonological representations in bilinguals. These findings are compatible with the BIA+ model. Due to its lack of phonological representations, the BIA model cannot account for the observed phonological effects.

3.2.3 The role of different orthographies

During non-native language processing, L2 participants are in many instances not only challenged by different phonological systems of two languages but also by different orthographic systems. For example, German-English bilinguals are confronted with two alphabetic orthographies which differ in terms of orthographic consistency whereas Chinese-English bilinguals are exposed to two orthographies which differ even more fundamentally (logography vs. alphabet). Throughout the present section, the role of different orthographic systems during bilingual processing of visual stimuli will be illustrated. Although the present research project addresses orthographic effects induced by alphabetic (and not logographic) writing systems, I will also provide a brief overview of studies that tested bilingual visual word recognition in alphabetic and logographic writing systems.

Early research on non-native visual word recognition focused on L1-L2 orthographic distance, i.e. the extent to which writing systems of L1 and L2 differ in terms of correspondences between linguistic units and orthographic representations (Koda, 1996). As described in section 2.2.4.1, writing systems can be classified as alphabetic, syllabic and logographic. First studies on non-native word recognition predominantly examined performance of non-alphabetic learners of English in visual word recognition tasks with English stimuli. These studies demonstrated that L2 speakers of English from non-alphabetic backgrounds (e.g. Japanese, Chinese) are less efficient in processing written stimuli of English than L2 participants who were raised in an alphabetic L1 background. (e.g. Akamatsu, 1999; Brown & Haynes 1985; Koda, 1988, 1990; Muljani, Koda & Moates, 1998). Thus, the observed findings suggest that L1-L2 orthographic similarity facilitates reading proficiency in a non-native language whereas the opposite applies to L1-L2 orthographic distance. Consequently, orthographic features of L1 have impacts on L2 word recognition. A possible explanation for this conclusion is that L2 speakers develop their word recognition skills on the basis of the cognitive mechanisms of their L1. Usually, this mechanism has already been established before the language learner is exposed to word recognition in the second language[34]. Hence, it was proposed that this mechanism cannot be changed or modified for word recognition in L2 (Akamatsu, 1998).

Apart from studies which investigated processing differences between bilingual participants from alphabetic and non-alphabetic writing systems, only a few studies have investigated the influence of orthographic transparency on non-native visual word recognition.

A study by Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger & Zwitserlood (2008) examined in how far L2 visual language processing is influenced by specific L1-L2 language combinations. They compared the performance of German, Dutch and French proficient non-native speakers of English and a group of English native speakers in a progressive demasking task with English stimuli. Note that German, Dutch and French

[34] For example, in the study by Akamatsu (1999), the Japanese participants started to learn English at the age of 12 years when they had already acquired literacy skills in their L1.

represent different stages on the continuum of orthographic depth outlined in section 2.2.4.1. The results demonstrated that the non-native participants from different L1 backgrounds processed the English words basically in the same way with only small cross-linguistic differences. Orthographic depth of the L1 did not have the expected effect on L2 language processing. However, L2 word recognition was determined by characteristics of L2 target items, such as written and spoken word frequency, word length and frequency and number of L2 orthographic neighbours. Overall, it was suggested that proficient non-native speakers were able to adapt to the characteristics of the target language even though these characteristics differed from the native language, for example with respect to orthographic depth.

In contrast to the finding that L2 visual word processing is unaffected by cross-linguistic differences in orthographic depth, other studies have observed the opposite. De Groot, Borgwaldt, Bos & van den Eijnden (2002) demonstrated that lexical decision and word naming of Dutch-English bilinguals was affected by the consistency of the language. Faster response times (and less semantic facilitation) for Dutch stimuli compared to English stimuli were explained with respect to the different degrees of orthographic consistencies. It was suggested that the processing of inconsistent words comes at a cost of speed. Consequently, English words produced longer response times than Dutch words. The reduced effect of semantic facilitation for Dutch words was explained with reference to the orthographic depth hypothesis. As outlined in section 2.2.4.2, the ODH proposes that readers of consistent orthographies are likely to perform naming tasks by means of phonological recoding without accessing the semantic system whereas inconsistent orthographies require access to the semantic system. Hence, the reduced effect of semantic variables for Dutch compared to English stimuli was interpreted as a reliance on the non-lexical route of orthographic processing.

Moreover, a neuroimaging study by Meschyan & Hernandez (2006) demonstrated that orthographic transparency affects bilingual word reading. Their study revealed that different brain regions were activated in Spanish-English bilinguals during silent word reading of Spanish words compared to English words. Orthographically transparent Spanish words produced greater activity in a region that is usually associated with phonological processing whereas orthographically opaque English words demonstrated greater activity in regions that are involved in word recoding and visual processing.

Consequently, this study suggests that orthographically transparent and opaque stimuli are processed differently in the bilingual mind.

Recently, first attempts have been made to apply the psycholinguistic grain size theory (PGST) to L2 reading acquisition. Kim (2009) investigated to what extent two groups of Korean-English bilinguals differed with respect to phonological processing in L2 reading development. Note that Korean has a relatively shallow alphabetic writing system which is in contrast to the inconsistent orthography of English. Participants consisted of English-Korean beginning readers who differed in terms of their English experience and proficiency. One group was born in the USA and exposed to English from birth on whereas the other group had been in contact with English for two or less than two years. Results of phonological awareness tests in both languages demonstrated that children with a low level of English proficiency used a phonological recoding strategy that focused on L1 characteristics, i.e. they made use of small-unit processing based on the transparent orthography of Korean. On the contrary, those bilinguals characterized by a higher level of English proficiency showed a processing pattern that reflected characteristics of both languages, i.e. recoding strategies based on units of small (phoneme) and large (onset-rime) grain size. The results are in line with the assumption of the PGST that the consistency of the orthographic system shapes the sensitivity to the preferred grain size unit in phonological and orthographic processing. In this study, participants developed specific recoding strategies for L2 with increasing proficiency of that language. Hence, this result suggests that beginning readers are able to develop L2 processing strategies as a response to characteristics of the L2 orthography. However, it is important to note that this study investigated an example of biliteracy acquisition, i.e. simultaneous literacy acquisition in two languages. Therefore, the relevance of this finding with regard to late L2 literacy acquisition, which started after participants achieved full literacy in their L1, may be rather limited.

Altogether, the studies that investigated the role of different orthographies in L2 visual word recognition have provided evidence for three theoretical positions. First, the processing of printed words in L2 is unaffected by orthographic differences between the L1 and L2 writing system (Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger & Zwitserlood, 2008). Second, the processing mechanism developed during literacy acquisition in L1 is applied to L2 (e.g. Akamatsu, 1998). Third, (proficient) bilingual readers are able to develop a processing mechanism which is based on the characteristics of the L2 writing system (de Groot, Borgwaldt, Bos & van den Eijnden, 2002; Kim, 2009; Meschyan & Hernandez, 2006).

As shown, the studies reviewed above have provided inconsistent results. Furthermore, it is important to note that the studies investigated different types of bilinguals. This means, some studies investigated late bilinguals who acquired literacy in their L2 after having acquired full literacy in their L1 (e.g. Akamatsu, 1998; de Groot, Borgwaldt, Bos & van den Eijnden, 2002; Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger & Zwitserlood, 2008) whereas other studies investigated early bilinguals with and without simultaneous literacy acquisition in both languages (e.g. Kim, 2009; Meschyan & Hernandez, 2006, respectively). Concerning late bilinguals (which are investigated in the empirical part of this thesis), the reported findings are in line with all three theoretical positions. Without doubt, more research is needed to specify the role of different orthographies in bilingual visual word recognition.

3.2.4 Evaluation of models

The basic structure of the BIA and BIA+ models, such as the division in lexical and sublexical units and the interactivity of information processing, are based on fundamental findings that have been discussed with reference to monolingual visual word recognition in section 3.2.1. The models' specifics on bilingual processing of printed words have been tested in a large number of empirical findings on bilingual word recognition and will be evaluated below.

First of all, both models propose a language non-selective access to an integrated lexicon of both languages which is in line with the vast majority of empirical findings on this field of research. It should be noted that parallel activation of orthographic representations from both languages is limited to languages that share a similar orthography. Obviously, languages that do not share a similar orthography at all, such as English and Chinese, have no orthographically similar word candidates in common that can be activated across languages. Nevertheless, cross-language effects of phonology may occur for such language pairs. As demonstrated, similar phonological representations can be activated in parallel for language pairs that do not share a similar orthography (Kim & Davis, 2003; Zhou, Chen, Yang & Dunlap, 2010). However, strictly speaking, the assumptions of the BIA and BIA+ model primarily refer to bilingual processing of languages with similar alphabetic orthographies.

An important drawback of the BIA model, compared to the BIA+ model, refers to the lack of phonological representations. Consistent with research on monolingual visual word recognition, several studies have provided clear evidence for phonological effects in bilingual processing of printed words. Therefore, a model of bilingual visual word recognition requires orthographic and phonological representations. The BIA+ model incorporates phonological representations that are linked to corresponding orthographic representations by interactive connections. In this way, the BIA+ model is able to account for the reported mandatory and cross-linguistic phonological effects.

It is not specified in the BIA+ model, though, how orthographic units are mapped on the corresponding phonological units (and vice versa). In contrast to the bimodal interactive activation model (BIAM) of monolingual word processing, the BIA+ does not contain a central interface that contains all (bidirectional) correspondences between orthographic and phonological units of both languages. Given that (bilingual) visual word recognition appears to be a highly interactive process that involves activations of grapheme-to-phoneme correspondence rules of both languages, the existence of a central interface can be seen as a plausible feature for modeling bilingual word processing.

Moreover, it has not been specified in the BIA+ model to what extent alphabetic language pairs that differ with respect to orthographic depth are processed differently. Empirical data have revealed inconsistent results concerning the role of different orthographies in bilingual word processing. In this regard, a first attempt has been made to transfer the psycholinguistic grain size theory to the field of bilingual reading acquisition and skilled reading. Recall from section 2.2 that the PGST is considered a promising theory of cross-linguistic reading acquisition and skilled reading in the monolingual domain. It remains to be seen whether bilingual readers develop different processing strategies, such as sensitivity to small or large orthographic and phonological representations, as a response to characteristics of the L1's and/or L2's orthographies. This issue has to be addressed in future research.

To conclude, the architecture of the BIA+ model appears to be in line with the reviewed findings on bilingual visual word recognition whereas its predecessor, the BIA model, lacks required phonological (and semantic) representations. Due to its interactive links between orthography and phonology, the BIA+ model is able to explain phonological effects during bilingual visual word recognition. However, In contrast to the bimodal interactive activation model (BIAM) of monolingual processing, the BIA+ contains no input for auditory speech signals. For this reason, it cannot account for orthographic effects in auditory word recognition that will be discussed in the next section.

3.3 Orthographic effects on L2 auditory word processing

In the previous sections, I have discussed relevant findings on bilingual processing of auditory and visual words. The present section deals with the interactions of both fields, i.e. the effects of phonological and orthographic information on non-native auditory word recognition. First, I will present general evidence for orthographic influences on L2 spoken word recognition. Second, I will discuss studies that investigated this issue with reference to the role of different orthographies. Finally, the observed findings will be discussed with respect to a model of bilingual word recognition.

3.3.1 Evidence for orthographic interactions in L2 word processing

While numerous studies have investigated orthographic interactions during *monolingual* spoken word recognition (as outlined in section 2.3), a very limited set of studies has addressed orthographic effects in non-native speech processing.

For instance, Weber & Cutler (2004) showed in an eye-tracking experiment that Dutch-English bilinguals looked longer and more frequently on pictures of distractor words that were phonologically similar (e.g. *pencil*) to the target item (e.g. *panda*) than dissimilar distractor words (e.g. *dice*). Interestingly, participants had problems distinguishing the words *pencil* and *panda* on the first syllable although they differ in the vowel sound, i.e. /ɛ/ in *pencil* but /æ/ in *panda*. For instance, when hearing the first syllable of the word *panda*, participants activated both the words *panda* and *pencil*. In reverse, though, the target word *pencil* did not activate the distractor *panda*. This asymmetric pattern was explained with respect to the orthographic representations of the contrastive sounds. It was suggested that Dutch listeners associate the phoneme /ɛ/ only with lexical representations that contain the grapheme <e> but not <a> given that both sounds are pronounced similarly in Dutch and English but the Dutch pronunciation of <a> differs from that in English.

This conclusion was supported in a follow-up study by Escudero, Hayes-Harb & Mitterer (2008). They found that only the group of Dutch-English bilinguals that learned the phonological and orthographic form of novel words containing the /ɛ/ - /æ/ vowel contrast demonstrated the reported asymmetric pattern. The control group, which learned the novel words solely by matching the phonological form to the corresponding pictures, did not show this pattern. Therefore, the results suggest that orthographic knowledge affects non-native speech processing.

In addition, Escudero & Wanrooij (2010) demonstrated that the orthographic code is not only activated during the processing of spoken L2 words but also during the perception of L2 sounds. By conducting a sound categorization task with Spanish learners of Dutch, the authors found that the categorization of vowel sounds was affected by orthographic representations of the presented vowels. That is, orthographic representations both helped and hindered the correct categorization of L2 vowels depending on the vowel contrast.

3.3.2 The role of different orthographies

As outlined in section 2.3.3, different orthographic systems have been shown to influence the degree of orthographic activations in monolingual auditory word recognition. Moreover, different orthographic systems have been also demonstrated to affect L2 visual word recognition (see section 3.2.4). In the present section, I will now provide a review of the very few studies that investigated the role of orthographic systems on orthographic effects in L2 spoken word recognition.

Consistent with research on non-native visual word recognition, first studies on orthographic influences on L2 spoken word recognition focused on L1-L2 orthographic distance, i.e. the degree of similarity between L1 and L2 orthographic systems with reference to the correspondences between linguistic units and orthographic representations. Holm & Dodd (1996) investigated the performance of learners of English as a second language from China, Vietnam and Hong Kong as well as a control group of native speakers of English in auditory phoneme counting and auditory rhyme judgement of English stimuli. The groups of non-native participants differed in terms of their orthographic background. That is, participants from the People's Republic of China were raised both in an alphabetic and logographic writing system whereas the non-native groups from Hong Kong and Vietnam came from an orthographic background that was solely logographic or alphabetic, respectively. The results demonstrated that the Hong Kong group, which was raised in a solely logographic orthography, showed the highest error rates in both metaphonological tasks.

This finding is consistent with the performance of Chinese-Dutch bilinguals in a phoneme deletion task with Dutch spoken pseudowords (de Gelder, Vroomen & Bertelson, 1993). In this study, Chinese-Dutch bilinguals who were raised in a logographic writing system but also acquired reading skills in Dutch outperformed a group of Chinese-Dutch bilinguals who were only familiar with the logographic writing system of Chinese.

Taken together, these two studies indicate that a logographic orthographic background clearly impairs performance in auditory metaphonological tasks with stimuli from an alphabetic L2. Consequently, orthographic features of L1 affect L2 auditory word recognition.

The research outlined so far focused on the contrast between logographic and alphabetic orthographies on L2 spoken word recognition. However, concerning the empirical part of this thesis, it is of greater interest to what extent participants from L1 alphabetic orthographies that differ in terms of orthographic depth demonstrate different orthographic influences on L2 auditory word recognition. This question has been partially addressed in a study by Erdener & Burnham (2005). They explored the role of orthographic information in an auditory shadowing task with participants from a shallow (Turkish) and deep (English) alphabetic background. Both language groups were tested on non-native stimuli from a shallow (Spanish) and deep (Irish) orthography. The results showed that Turkish participants produced lower error rates than the English group for both Spanish and Irish stimuli. When the presentation of the auditory stimuli was simultaneously accompanied by the spelling, the error rate decreased for both groups. However, the Turkish participants made fewer errors than the English group for Spanish stimuli but more errors than the English group for Irish stimuli. The authors concluded that “the facilitative effect of orthographic information in nonnative tasks is a function of the degree of native language and nonnative orthographic depth” (Erdener & Burnham, 2005: 220). Thus, different degrees of orthographic depth in L1 have influence on the performance in speech processing tasks with non-native stimuli. It is noteworthy, though, that all participants of this study had no knowledge of the target languages Spanish and Irish. Strictly speaking, the participants were no learners of a foreign language. Moreover, the study compared the participants' performance in two conditions, i.e. auditory only vs. auditory with (visual) orthographic information. For this reason, the study did not solely test auditory but rather audiovisual speech processing. However, this study is the only investigation, to date, that attempted to address the influence of orthographic depth on orthographic processing during non-native spoken word recognition.

On the whole, research on orthographic impacts on non-native auditory speech processing is very rare. Especially, possible interactions between the transparency of the first language and the degree of orthographic activations during L2 spoken word recognition have not been explicitly explored. Having shown in section 3.2.4 that the processing of printed L2 stimuli is affected by the participants' transparency of the L1 writing system, it can be assumed that similar cross-linguistic effects of orthographic transparency may be found in spoken word recognition of L2 stimuli. This research question will be explored in the empirical part of this thesis. However, before I turn to the empirical investigation, I will first discuss the reviewed findings of orthographic activations with reference to models of L2 auditory word processing.

3.3.3 Orthographic interactions in models of L2 auditory word recognition

As noted earlier, the BIMOLA is the only model, to date, which has been explicitly developed to account for bilingual auditory word processing. While it accounts for a number of reported findings on L2 spoken word recognition, it ignores the role of orthographic representations completely and cannot simulate the reported findings of orthographic interactions in L2 auditory word recognition.

The processing levels at which the orthographic effects occur in the presented studies suggest that orthographic representations have to be added both at the lexical and sublexical processing levels. For instance, the eye-tracking data by Weber & Cutler (2004) have been interpreted as activation of the wrong lexical competitor, i.e. participants encoded the sound contrast lexically by looking at the inappropriate picture of the lexical competitor. In addition, Escudero & Wanrooij (2010) demonstrated orthographic activation of sublexical representations.

These findings indicate that a bilingual model of auditory word recognition has to be extended by orthographic representations on lexical and sublexical processing levels. Hence, the processing mechanism is considered to be similar to the architecture of the BIA+ model, which has been developed for visual word recognition of L2 stimuli, though. Moreover, in order to account for cross-linguistic activations of orthographic units, sublexical and lexical processing levels should contain orthographic representations of both languages. Specific details of a bilingual model of auditory word recognition that is assumed to account for orthographic interactions will be provided in the next chapter.

4 A working model of bilingual word recognition

In the preceding chapters, essential findings on monolingual and bilingual word processing have been reviewed and discussed with reference to current models and theories of word processing. I have argued that the processing of auditory stimuli cannot be treated independently of the processing of printed stimuli and vice versa. While there is general agreement that phonological knowledge is activated during visual word recognition, an increasing number of studies has demonstrated that the opposite is also true. This means, orthographic knowledge influences spoken word recognition. However, well established models of monolingual auditory word recognition have been shown to neglect the role of orthographic presentations. For this reason, I have argued that the bimodal interactive model (BIAM) (Grainger & Ferrand, 1994, 1996; Grainger, Muneaux, Farioli & Ziegler, 2005; Grainger & Ziegler, 2011) provides the best account for the reported orthographic effects on *monolingual* auditory word recognition. Concerning *bilingual* auditory word recognition, no model exists at present which is able to explain first findings of orthographic activations during bilingual processing of spoken words. As a consequence, I will now introduce a working model of bilingual auditory word recognition which is able to account for the existing findings on orthographic influences on non-native spoken word processing.

The working model is a bilingual version of the bimodal interactive activation model (BIAM). It is grounded on the assumption that the fundamental architecture of language processing, which has been acquired in the first language, is not changed when a second language is learned. Thus, the original architecture of the BIAM has been extended by the addition of a processing mechanism for two languages. Based on the review of studies on bilingual word recognition, the working model assumes a language non-selective access to an integrated lexicon of both languages. An outline of the working model is presented in Figure 4.1.

As shown, orthographic and phonological representations are connected at sublexical (O-units, P-units) and lexical (O-words, P-words) levels by bidirectional links. At both levels, orthographic and phonological representations, respectively, are stored and accessed in a shared lexicon of L1 and L2. This allows interactions of L1 and L2 units during word processing. Due to its bidirectional links between orthographic and phonological units, the working model accounts for phonological interactions during visual word recognition as well as orthographic interactions during auditory word recognition. However, for the purpose of the present thesis, I will focus on the latter type of interaction, i.e. orthographic activation during spoken word processing.

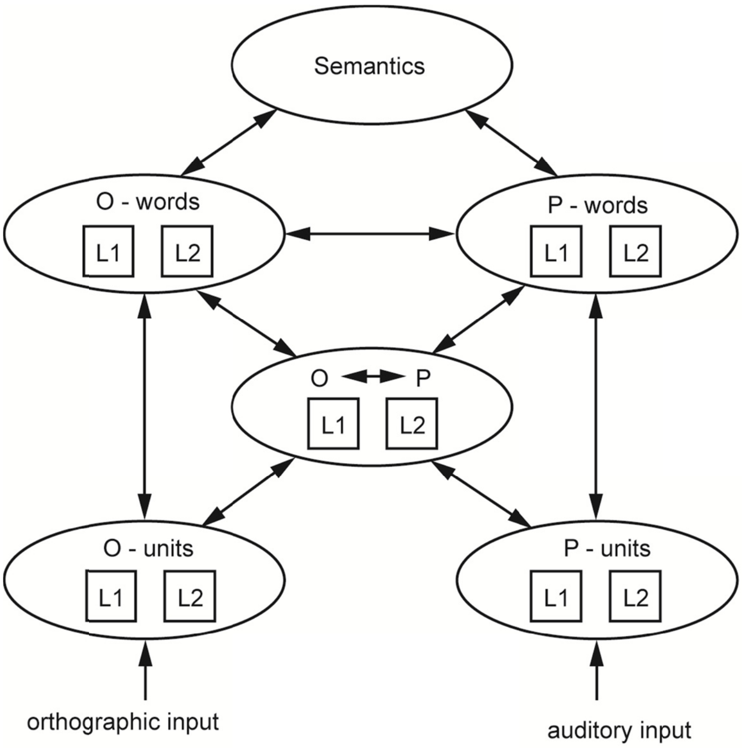

Figure 4.1. Schematic representation of the working model of bilingual word recognition.

An integral constituent of the model is the central interface which consists of bidirectional mappings between orthographic and phonological units. Note that the central interface contains L1 and L2 bidirectional correspondences between orthography and phonology. The assumption that both L1 and L2 correspondences between orthography and phonology are included in the central interface is based on experimental data that provided evidence for the activation of spelling-to-sound rules of the non-target language (either L1 or L2) during word recognition in the target language (L2 or L1) (see section 3.2.3). For instance, the German vowel /ɑɪ/ corresponds to the orthographic units <ei> or <ai> in the German words *Blei* [lead] or *Mai* [May], whereas the English vowel /ɑɪ/ corresponds to a number of English orthographic units, such as <y> (in *dry*), <ie> (in *tie*) or <uy> (in *buy*), to mention just a few. In addition, the central interface is sensitive to correspondences of phonological and orthographic units of various grain sizes. It contains rules about grapheme-phoneme correspondences as well as rules about correspondences at larger grain sizes, such as syllables or rimes. Thus, it incorporates the psycholinguistic grain size theory (introduced in section 2.2.4.2).

How is a spoken L2 word processed in this model? The spoken input activates relevant phonological representations of L2 (and L1) at the sublexical level, which activate the phonological entry of the target word (and a number of competitors of L2 and L1) at the lexical level. Finally, the semantic representation of the L2 word is accessed. Due to its interactive structure, activation may also occur in a top-down manner, i.e. lexical units may activate sublexical units. The critical question concerning the contribution of orthography in this process is whether L2 spoken word recognition is a purely phonological process, solely based on activations of phonological representations at sublexical and lexical processing levels, or whether corresponding orthographic representations are co-activated. The working model allows both. That is, it is able to account for a purely phonological process (as described above) and co-activation of orthographic units. Phonological units can activate sublexical and lexical orthographic representations via the central interface which contains bidirectional correspondences between orthographic and phonological units for L1 and L2. In addition, phonological representations of lexical units can directly activate corresponding orthographic representations at the lexical level without accessing the central interface.

As outlined in section 3.3, first studies have shown that orthography is activated during L2 spoken word recognition. But how does the activation of orthography during spoken word recognition differ between native and non-native speakers? Moreover, to what extent does the L1 affect the contribution of orthography during auditory processing in L2? Given that L1 and L2 are stored together and have been shown to interact during bilingual word recognition of visual and auditory stimuli, it is highly likely that orthographic characteristics of the L1 (e.g. the consistency of spelling-to-sound mappings) affect the activation of orthography during L2 auditory word processing. Hence, different degrees of orthographic consistency of the L1 writing system might affect the degree of orthographic activation in L2 spoken word recognition. These questions will be addressed in the empirical part of this thesis.

5 Empirical investigation

Having developed a model of bilingual word recognition that is assumed to account for interactions of orthographic and phonological processing in the auditory modality, I will now test this model in the empirical part of this thesis. In the present chapter, I will first describe the motivation and objectives of the empirical investigation and explain methodical aspects. Subsequently, the collected data will be presented and discussed.

5.1 Motivation and objectives of the present study

As shown in section 2.3, results from auditory word recognition tasks with and without metaphonological components clearly suggest that the orthographic code is activated during monolingual spoken language processing. This finding challenges established models of auditory word recognition, such as TRACE, the cohort model or Shortlist, which assume that phonological input is processed without reference to its orthographic representations during auditory word recognition. In the present thesis, I have therefore discussed the observed orthographic effects in terms of the bimodal interactive activation model (BIAM) – a less established model in the field of auditory speech processing. Given that the architecture of the BIAM was able to account for the reported effects, I have developed a working model of bilingual word recognition, which is based on the BIAM.

A central assumption of the working model is that the fundamental cognitive structures of language processing that have been established during first language acquisition are not changed when a second language is acquired. In other words, I suggest that the whole processing mechanism and the bidirectional links between orthographic and phonological representations, which have been developed during literacy acquisition in the L1, do not adapt to L2 word recognition. Broadly speaking, it is rather a new bundle of L2 graphemes and corresponding phonemes that is added to the mental lexicon whereas the overall processing mechanism does not change.

However, first language acquisition differs from second language acquisition in one important aspect concerning the acquisition of spoken and written language. During first language acquisition, a child learns to speak many years before it learns to read and write. Thus, it is highly familiar with the phonological forms of words before it establishes links to the corresponding orthographic forms. By contrast, when bilinguals learn their second language at school after they have become literate in their first language – usually not before the age of 10 years – they learn both the spoken and written form of L2 words at the same time. Consequently, the simultaneous acquisition of spoken and written forms of L2 words are likely to establish stronger links between phonological and orthographic representations in the mental lexicon of non-native speakers compared to native speakers. This assumption suggests stronger links between the orthographic and the phonological system of L2 units in the working model of bilingual word recognition.

Moreover, the empirical research was motivated by the consideration that L2 learners usually acquire their second language after they have achieved full literacy in their first language. Hence, the fundamental mechanism of language processing has been developed as a response to the characteristics of the first language. Recall that languages differ with respect to the consistency of their writing systems. It has been shown in the first part of this thesis that the transparency of a writing system affects the way printed words are processed in monolingual visual word recognition (see section 2.2.4). Moreover, an effect of the language's transparency has also been yielded in research on orthographic activation during monolingual spoken word recognition (see section 2.3.3). With respect to bilingual language processing, some studies have demonstrated that bilinguals transfer their strategies of orthographic processing from L1 to L2 visual word recognition (see section 3.2.3). However, it remains to be seen whether the transparency of the L1 writing system affects the degree of orthographic activation in L2 auditory word recognition. An effect of the transparency of the L1's orthography on orthographic recruitment during L2 word recognition would suggest that socialisation in a transparent or opaque L1 writing system affects strategies of orthographic processing in a second language. As a consequence, such language-specific strategies of orthographic processing need to be integrated into the working model.

Based on these considerations, the empirical investigation attempts to answer the following questions:

1) *Is L2 spoken word recognition affected by the co-activation of orthographic information?*

While there is general agreement that orthographic information is activated during auditory word processing in the monolingual domain, only very few studies have tested for orthographic effects in non-native auditory word processing. For this purpose, the present study was conducted to provide further evidence for the contribution of orthographic information to non-native spoken word recognition by testing two groups of non-native speakers of English in three different auditory tasks with English stimuli. Based on previous findings and the assumptions of the working model, it was hypothesized that both groups of non-native speakers should show an orthographic influence. This result would indicate that L2 spoken word recognition – similar to L1 spoken word recognition – is not solely based on a phonological route but interacts with the orthographic system. With respect to the working model, this finding would support the existence of connections from the phonological system to the orthographic system.

2) *What differences exist between orthographic activation in native and non-native speech processing?*

The results of the non-native groups were compared to a control group of native speakers of English, which was tested on the same auditory tasks. It was hypothesized that non-native speakers should show a stronger orthographic activation than the English control group because they acquired spelling and pronunciation of English words at the same time and were likely to have established stronger links between orthographic and phonological representations. In contrast, for native English speakers, the orthographic form of words was secondary to the phonological form during language acquisition which is likely to have resulted in weaker connections between spoken and written representations. In terms of the working model, this result would suggest that stronger connections between phonological and orthographic representations exist for non-native speakers compared to native speakers.

3) *What differences in orthographic activation exist between two non-native groups with deep and shallow orthographies in their first language?*

As argued above, the transparency of a writing system appears to affect strategies of orthographic processing in visual word recognition of native and non-native stimuli, such as sensitivity to orthographic and phonological units of different grain sizes (Ziegler & Goswami, 2005). The empirical investigation tested whether the transparency of the first language has an effect on orthographic activation during L2 auditory word recognition. Given that participants who were raised in a shallow L1 orthography are less familiar with inconsistent mappings between orthographic and phonological representations, it was hypothesized that participants with a shallow L1 orthographic background should demonstrate a stronger orthographic influence on spoken English words than participants with a deep L1 orthographic background. This result would suggest that the orthographic background of the first language, i.e. whether participants were raised with a shallow or deep orthography, is relevant for the individual recruitment of orthographic knowledge in L2. With reference to the working model, this finding would suggest that the processing mechanism of the model has to be sensitive to a language's transparency of mappings between phonological and orthographic units. This means, a processing mechanism that has been developed as a response to the transparency of the L1 orthographic system is transferred to the second language although the specific transparency of the L2 may require a more efficient processing strategy.

5.2 Methodical aspects

The present investigation was based on a number of methodical considerations on experimental psycholinguistic research that will be outlined in the present section. I will point out why I selected specific experimental tasks and languages for the investigation of the research questions outlined above. Moreover, I will discuss relevant linguistic and non-linguistic confounding variables that were controlled for in the experiments. Finally, the overall design of the empirical investigation will be introduced.

5.2.1 Choice of tasks

The research questions outlined in the previous section were investigated by conducting three behavioural experiments which have been used in the landmark studies in monolingual research on this topic. These paradigms comprised rhyme judgement

(Seidenberg & Tanenhaus, 1979), phoneme deletion (originally by Morais, Cary, Alegria & Bertelson (1979), adapted by Tyler & Burnham (2006)) and lexical decision with orthographically consistent and inconsistent stimuli (Ziegler & Ferrand, 1998). Before I explain in more detail why I chose these behavioural tasks for the present investigation, I will briefly outline some general aspects on measurements of response times and accuracy in behavioural paradigms.

Accuracy is usually measured in terms of error rates, defined as the number of incorrect responses divided by the number of all responses. Accuracy measures represent the end product of cognitive processes that occurred on the way to the participants' response. Hence, a high error rate for particular stimuli suggests that the underlying processes for these items have been more complex and challenging than for stimuli with a lower error rate. However, as we will see below, this interpretation has to be treated with some caution.

The other behavioural measure which is traditionally analyzed in psycholinguistic research refers to response times or response latencies. Response times are usually defined as the time span between the onset of a presented stimulus and the participants' response, for instance by pressing a response button in a lexical decision task or saying the word in a naming task. Longer response times for specific stimuli suggest a more complex and inhibitory process of language processing than shorter response latencies.

It is noteworthy that accuracy measures and response times are not independent measures of the same event but are usually highly correlated. Very fast response times can produce high error rates because improved speed might come at cost of accuracy. This phenomenon has been known in psychology as the *speed-accuracy trade-off* (Pachella, 1974). Therefore, both accuracy and response times have to be included in the analysis and interpretation of behavioural data.

For the present investigation, error rates and response times were the appropriate measures to replicate and extend previous findings on orthographic activation during spoken word processing. More up-to-date research tools, such as electrophysiological or neuroimaging techniques, were not necessary to investigate the research questions of the present project. The project required a simple and transportable experimental setup that allowed fast and reliable collection of data which could, above all, be easily compared to the predecessor studies. Consequently, the relatively simple and straightforward behavioural measurements of error rates and response times were the appropriate research tools for this research project.

Having outlined some general aspects on behavioural research tools used in psycholinguistic research, I will now discuss the three selected behavioural experiments in more detail.

First of all, the selected tasks have yielded robust and straightforward effects of orthographic activation in research on monolingual spoken word processing. For this reason, these paradigms were considered appropriate to be extendable to research on bilingual language processing. The fundamental design and procedure of the experiments reported in the present study were based on the original experiments, which have been reviewed in section 2.3. However, some important adaptations were made in order to extend the findings to non-native word recognition. These adaptations will be described in the methods sections of the respective experiments.

Second, the chosen tasks differed with respect to their metaphonological nature. Two of the selected paradigms (rhyme judgement, phoneme deletion) were metaphonological tasks which involved an explicit awareness of sublexical phonological units. For instance, a decision on whether two stimuli rhyme or not can be solely based on the phonological structure of the stimuli without consulting the semantic or orthographic representations of the stimuli in the mental lexicon. However, as argued in section 2.3, strong links between the phonological and orthographic code have been developed during literacy acquisition when beginning readers became aware of the correspondences between sounds and spellings. For this reason, participants are likely to activate the spellings of words strategically when the (auditory) stimulus materials contain salient orthographic information, such as presenting a rhyme pair where the phonological rime is spelled differently. By contrast, a task which is not metaphonological in nature, such as a standard auditory lexical decision (Goldinger, 1996), does not explicitly highlight the orthographic or phonological properties of the stimuli and, hence, does not elicit such a response strategy. In principle, orthographic, phonological and semantic information can all be used to determine whether a presented stimulus is a word or not. Thus, a standard auditory lexical decision task that involves an implicit manipulation of orthographic properties, e.g. by manipulating the orthographic consistency of rimes, investigates orthographic influences on auditory speech processing on a more general level. Orthographic consistency effects in lexical decision would demonstrate that orthographic influences on spoken word recognition are not restricted to strategic activations in metaphonological tasks but can be regarded as general effects in spoken word recognition which “affect the core process of lexical access” (Pattamadilok, Perre & Ziegler, 2011: 117).

Third, the three paradigms chosen for the empirical investigation focus on units of different grain sizes, i.e. rimes (in rhyme judgement and lexical decision) and phonemes (in phoneme deletion). Recall that cross-linguistic comparisons of orthographic processing have shown that participants from deep orthographies preferably rely on a processing strategy of units of small and large grain sizes (e.g. phonemes, rimes and their corresponding orthographic units). By contrast, participants who are familiar with shallow orthographies primarily rely on small-unit processing (phonemes and graphemes). Concerning the present investigation, it was of particular interest how participants from a shallow L1 orthographic background performed in those tasks that involved orthographic inconsistencies of the rime level, i.e. rhyme judgement and lexical decision. Their sensitivity to rime-sized units would demonstrate to what extent orthographic processing in L2 is affected by the socialization in a deep or shallow L1 writing system.

Finally, the three selected tasks reflected different levels of difficulty. While auditory rhyme judgement is a rather simple metaphonological task, involving a perceptual task which is carried out by YES/NO-button responses, auditory phoneme deletion involves a perceptual and a productive component. After hearing the word, participants were required to delete the respective phoneme and pronounce the response word as quickly as possible. Besides, lexical decision is a particularly challenging task for non-native participants (e.g. Lemhöfer, Dijkstra & Michel, 2004). Although this paradigm is “one of the most popular tasks in psycholinguistics” (Keuleers & Brysbaert, 2011: 34), it is predominantly used in L1 and rarely applied to L2 research. In the present study, stimulus materials for this task were adapted to the specific requirements of non-native speakers, e.g. it was checked that word stimuli consisted of items that non-native participants were familiar with. Moreover, only highly proficient speakers of the target language were tested. Thus, it was ensured that non-native speakers of English were able to cope with an English lexical decision paradigm.

5.2.2 Choice of languages

The languages involved in the present study are English, German and Danish. Stimuli used in the experiments consisted of English words and nonwords. Participants comprised German and Danish non-native speakers of English as well as a control group of English native speakers. In the following, I will explain why these three languages are of particular interest for the present investigation.

English was chosen as the target language in this bilingual investigation for several reasons. First, the majority of monolingual studies on orthographic effects were conducted with English stimuli. By using English stimuli and native speakers of English as a control group, the results are comparable to previous findings obtained in this field of research. Second, English is one of the most frequently spoken second or foreign languages, not only in the European Union but also in other parts of the world. The relevance of English in the European context, for instance, was illustrated in a survey by the European Commission (2006), which revealed that English is the most widely known foreign language in 19 out of 29 countries in the European Union[35]. From this perspective, the choice of English as the non-native target language in the present study reflects its high relevance as a second or foreign language for the participants. Finally, English was selected since its highly inconsistent relation between spelling and pronunciation was considered to be particularly challenging for those non-native speakers of English whose first language is characterized by a transparent orthography. Recall from section 5.1 that one of the goals of the present study was to investigate the effects of the writing system's transparency on orthographic activation during auditory speech processing. For this reason, the most extreme example of a deep alphabetic orthography was selected as a counterpart to the shallow orthography of German.

[35] 38% of the European citizens stated that they were able to have a conversation in English as a foreign language, followed by German (14%) and French (14%) (European Commission, 2006: 12).

The choice of the non-native participants' first language was determined by several theoretical and practical considerations. According to the objectives of the study, the two non-native groups were aimed to differ in terms of orthographic depth of their respective first language. Consequently, two languages were chosen that represent contrary stages on the continuum of orthographic depth (outlined in section 2.2.4.1, Figure 2.3). As shown, European languages not only differ in terms of orthographic depth but also in terms of syllabic structure. For the present study, though, orthographic depth was considered the critical distinctive feature of the alphabetic orthographies involved in the investigation. Hence, such languages were chosen which share a complex syllabic structure with English. This criterion narrows the choice of languages down to German, Norwegian, Icelandic (as examples of considerably shallow orthographies with a complex syllabic structure) and Danish (as an example of a considerably deep orthography with a complex syllabic structure)[36]. For practical reasons, German was selected as the representative of a shallow orthography. The only European language characterized as a deep orthography (apart from English) is Danish. Therefore, the Danish language was chosen as an example of an inconsistent writing system.

In the following, I will discuss the characteristics of the English, Danish and German orthographic systems in more detail. As mentioned earlier, all three languages share a complex syllabic structure but differ in terms of their orthographic depth. For this reason, the discussion of the selected orthographies will be limited to the distinguishing feature, i.e. orthographic depth.

English

English is regarded as an example of a deep orthography with highly inconsistent grapheme-to-phoneme correspondences. The main reason for this inconsistency is seen in the high number of vowel phonemes which are represented by few graphemes (Frost, 2004). Grapheme-to-phoneme mappings are quite inconsistent, with vowel graphemes

[36] Dutch and Swedish contain a complex syllabic structure of similar complexity as English but are considered to represent a medium stage on the continuum of orthographic depth. However, for the purpose of the present investigation two languages were selected which represent contrary positions, such as the considerably shallow (German, Norwegian, Icelandic) and deep orthographies (Danish).

representing a large number of phonemes. For instance, the grapheme <a> can be transcribed by several different phonemes, such as /a:/ in *arm*, /eɪ/ in *fake*, /æ/ in *bad*, /e/ in *many*, /ɔ:/ in *all*, /ə/ in *canal* and /ɪ/ in *village*. In the other direction, i.e. from sound to spelling, the English language is also highly inconsistent. For example, the phoneme /u:/ can be transcribed by the graphemes <o> in *to*, <oo> in *too*, <ew> in *few*, <wo> in *two*, <oe> in *shoe*, <ue> in *clue*, <ough> in *through*, etc. (see Carney, 1994, for a detailed description of the interaction of sounds and spelling in the English language). Thus, English is highly inconsistent in the direction from grapheme to phoneme (feedforward inconsistency) as well as in the direction from phoneme to grapheme (feedback inconsistency) (Ziegler, Stone & Jacobs, 1997). Moreover, relations between orthography and phonology have been also characterized as inconsistent at units of larger grain sizes, such as correspondences between orthographic bodies and phonological rimes (Treiman, Mullennix, Bijeljac-Babic & Richmond-Welty, 1995; Ziegler, Stone & Jacobs, 1997). This large discrepancy between spelling and pronunciation at levels of various grain sizes can be explained with regard to the historical development of the English language. During the Great Vowel Shift in the 15th and 16th century, fundamental changes in pronunciation of the English language – especially in the vowel system – took place, which resulted into many idiosyncrasies of the correspondences between spelling and pronunciation in English (see Barber, 1993; DeFrancis, 1989, for an overview).

Danish

Danish, like English, is characterized as a deep orthography (Juul & Sigurdsson, 2005). Similar to English, inconsistencies in grapheme-to-phoneme mappings are due to the large number of vowel phonemes which cannot be represented by different letters. The Danish language contains 12 vowel phonemes but not enough letters to transcribe the sounds in a one-to-one relation although three additional vowel letters, i.e. å, æ and ø, were added to the alphabet (Basbøll & Wagner, 1985; Elbro, 2001). Danish has a number of frequent words which contain unique pronunciations of single letters or combinations of letters, such as the letter e in the word *de* (meaning they) pronounced /i/ rather than the standard pronunciation /e/ or /ɛ/. A detailed account of the correspondences between letters and sounds in Danish has been provided by Becker-Christensen (1988). However, Danish is not only inconsistent in spelling-to-sound relationships but also inconsistent in the other direction, i.e. specific sounds are represented by different spellings. Similar to English, such inconsistencies also comprise orthographic and phonological units of larger grain sizes. The origin of the highly inconsistent orthography goes back to the historical development of the Danish language. Changes in pronunciation as well as the influx of a large number of loan words with deviant orthographic peculiarities from other languages are considered the main reasons for the huge discrepancies between Danish spelling and pronunciation (see Elbro, 2006, for further details).

German

In contrast to English and Danish, German is considered an example of a shallow orthography. It is characterized by highly regular grapheme-to-phoneme correspondences. For example, the grapheme <a> is consistently pronounced as /a/ in the words *Hand* [hand] or *Ball* [ball] whereas the pronunciation differs for the corresponding English equivalents provided in square brackets (Goswami, Ziegler & Richardson, 2005). Only few graphemes in German represent different phonemes, such as the grapheme <v>, which is either pronounced /v/ as in *Vase* [vase] or /f/ as in *Vater* [father] (see Nerius, 2007, for an overview). Similar to Danish, the German alphabet contains three additional vowel letters, i.e. ä, ö and ü, but all German vowel graphemes, with the exception of the graphemes corresponding to the diphthongs /ɑɪ/ and /ɔɪ/, can be mapped in a one-to-one relation to the corresponding vowel phonemes. While German has highly consistent and predictable grapheme-to-phoneme relations[37], it is less consistent in the opposite direction, i.e. from phonemes to graphemes. For example, the orthographic marking of vowel length is particularly unpredictable, such as /a:/ in *Zahl* [number], *Tal* [valley] and *Saal* [hall]. Therefore, with reference to the

[37] When implementing the DRC model for German words, Ziegler, Perry & Coltheart (2000) found only 48 “multiletter rules”, i.e. rules about the mapping of more than one letter into a single phoneme, for monosyllabic and monomorphemic German words compared to 146 “multiletter rules” in English. This example illustrates the highly consistent grapheme-to-phoneme correspondences in German compared to English.

direction of sound-to-spelling mappings, German can only be considered a moderately shallow orthography. However, as Landerl (2006) pointed out, the phoneme-to-grapheme correspondences are still more consistent than in English. The feedback inconsistency in German can be explained by the morphophonemic nature of the German orthography. Similar to English and Danish, the German orthographic system reflects morphological information even if they interfere with well-established grapheme-to-phoneme mappings. For example, the words *Hund* [dog] and *Hunde* [dogs] both contain the same morphological root and are hence both spelled with <d> although this grapheme is pronounced differently, i.e. /t/ in *Hund* and /d/ in *Hunde*. But German is not the only orthography which is highly consistent in one direction and inconsistent in the opposite direction. As detailed earlier, this discrepancy with respect to orthographic transparency for reading and spelling is typical of a number of alphabetic writing systems, for instance, Spanish, French, Swedish, Dutch or Greek (Landerl, 2006). Thus, the main difference concerning orthographic depth between German and highly inconsistent orthographies like English and Danish lies in the regularities of mappings from orthography to phonology, both at grapheme-to-phoneme levels and levels of larger grain size.

Taken together, Danish and English are highly irregular in both the spelling-to-sound and sound-to-spelling directions of units of small and larger grain sizes whereas the German orthography is highly regular from the perspective of orthography-to-phonology but less regular from phonology-to-orthography correspondences. Despite this asymmetric consistency of the German orthography, the German language is still considered a shallow orthography whereas English and Danish are at the deep end of the continuum of orthographic depth.

5.2.3 Controlling for linguistic and non-linguistic confounding variables

In order to obtain reliable and usable data in psycholinguistic experiments, confounding variables that might skew the collected data in unintended ways have to be properly controlled for. This section comprises an outline of those linguistic and non-linguistic confounding variables that have been considered relevant and, hence, have been controlled for in the present investigation.

5.2.3.1 Linguistic variables

The discussion of linguistic confounding variables will be divided into two groups of variables. The first group of linguistic variables refers to item-related factors, i.e. characteristics of the selected stimuli that have been shown to affect language processing. The second group of linguistic variables describes participant-related factors, i.e. linguistic characteristics of the participants that were taken into account to form homogenous groups.

Item-related linguistic factors

An abundant number of studies has contributed to the search for stimulus characteristics which determine the speed of language processing. As noted by Lewis & Vladeanu, "(t)he range of potential predictors of psycholinguistics outcome variables appears to be growing all the time" (2006: 978). Over the last decades, so many relevant item-related variables have been identified in psycholinguistic research that it is impossible to control all of them (see Cutler, 1981, for a discussion). It is far beyond the scope of this section to provide an exhaustive review of psycholinguistic variables. Rather, I will briefly discuss those psycholinguistic variables that have been demonstrated to be most relevant for research on word recognition (e.g. Balota, Cortese, Sergent-Marshall, Spieler & Yap, 2004) and, consequently, were controlled for in my experimental investigation. These variables comprise word frequency, word length, orthographic and phonological neighbourhood size.

One of the most powerful variables in experimental psycholinguistic research is word frequency. Broadly speaking, this factor predicts that more frequently used words are recognized and responded to more quickly than less frequently used ones (e.g. Marslen-Wilson 1990; Oldfield & Wingfield, 1965; Whaley, 1978; see section 2.1.1 and 2.2.1 for a more detailed overview of studies on the word frequency effect).

Even if the impacts of word frequency on language processing have been undoubtedly demonstrated, this variable has to be treated with caution. First, word frequency counts as used for psycholinguistic experiments are aimed to reflect the number of times a particular person encountered a specific word. This is estimated by using linguistic corpora which consist of large amounts of texts from different domains. The word frequency counts of the corpora are generally considered to reflect the number of times an average person has encountered this word. However, as also noted by Lewis & Vladeanu (2006), the choice of texts used in the corpora influences the accuracy of the frequency counts. Moreover, Gernsbacher (1984) demonstrated that frequency counts do not necessarily depict the participants' experiential familiarity with respective words. Especially for low-frequency words, experiential familiarity seems to be a more reliable predictor of language processing speed than objective frequency counts taken from linguistic corpora. Second, there are different measures of word frequency. For instance, word frequency can be calculated by reference to the lemma frequency of a word (e.g. *pick*) or the summed frequency of the uninflected and regularly inflected wordforms (e.g. *pick*, *picked*, *picks*, *picking*). There has been a controversial debate about which frequency measure accounts best for reported findings (e.g. Cutler, 1981; Kresse, Kirschner, Dipper & Belke, 2011). Third, distinctions have to be made between written and spoken word frequencies. Frequency counts in corpora have been typically based on written texts (e.g. Kučera & Francis, 1967). It has been suggested, though, that stimuli for auditory tasks should be controlled for spoken word frequencies based on corpora of spoken texts (see Gaygen & Luce, 1998, for a discussion). Despite the presented criticism and shortcomings of frequency counts discussed in this paragraph, word frequencies are, without doubt, one of the most powerful variables in psycholinguistic research and, hence, have to be carefully controlled for. In the present investigation, written and spoken word frequency of all words was established by using the lemma frequency counts of the CELEX database (Baayen, Piepenbrock & van Rijn, 1993).

It is noteworthy to mention that frequency counts might be a misleading measure in bilingual research. Usually, frequency counts in corpora estimate the number of times a native speaker has encountered the word. However, the experience of non-native speakers might differ from native speakers. While particular stimuli might be familiar to native speakers, those stimuli might be unknown or hardly known to non-native participants. For this reason, stimulus lists that were developed for psycholinguistic studies with native speakers cannot be transferred unmodified to experiments with non-native participants but have to be adapted to the specific requirements of the latter group. Subjective ratings of familiarity, as proposed for the monolingual field by Gernsbacher (1984) and Gilhooly & Logie (1980), appear to be a useful measure in this respect. This is usually done by a familiarity test, i.e. participants from the intended population who do not take part in the experiments evaluate whether they are familiar with the non-native stimuli or not (e.g. Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger & Zwitserlood, 2008). Those stimuli which are unknown to the majority of the evaluation group will not be used in the experiments. As will be detailed in the methods section of my experiments, a familiarity rating was carried out by a group of non-native speakers of English for all stimuli used in the present investigation.

Another variable which has been shown to influence language processing is word length. Word length can be calculated by orthographic measures (number of letters) or phonological measures (number of phonemes and syllables). Originally, researchers thought that longer words are processed more slowly than shorter words (Forster & Chambers, 1973). But the effect of word length turned out to be more complex when other stimulus characteristics were controlled for. Most research on the effect of word length has been conducted in studies on visual word recognition (see New, Ferrand, Pallier & Brysbaert, 2006, for a review) and word naming (see Damian, Bowers, Stadthagen-Gonzalez & Spalek, 2010, for a recent review). Although the direction of the word length effect is not unequivocally clear yet, stimuli should be matched on word length to make sure that this factor does not interact with any other variables in unintended ways. For this reason, I controlled word length by using monosyllabic words that were controlled for number of letters and number of phonemes. Moreover, the duration of the recorded stimuli was measured.

In addition to word frequency and word length, stimuli in psycholinguistic research are usually matched for orthographic neighbourhood size. As detailed earlier, orthographic neighbourhood size has been defined as the number of existing words of the same length that can be obtained by changing one letter of the target word (Coltheart, Davelaar, Jonasson & Besner, 1977). Words that occurred in large orthographic neighbourhoods were typically processed faster and more accurately than words with only few orthographic neighbours (see Andrews, 1997, for a comprehensive review). When selecting stimuli for the present investigation, orthographic neighbourhood size of all words was calculated by using the WordGen word selection tool (Duyck, Desmet, Verbeke & Brysbaert, 2004), which is based on CELEX.

Similar to orthographic neighbourhood, phonological neighbourhood size has been defined as the number of words that can be generated from the target word by addition, deletion or substitution of one phoneme (Luce & Pisoni, 1998). An effect of phonological neighbourhood size has been demonstrated in different tasks, though pointing in different directions depending on the nature of the task. For instance, words with few phonological neighbours were named more slowly in picture-naming (Vitevitch, 2002) but were identified faster and more accurately than words from dense phonological neighbourhoods in perceptual identification and auditory lexical decision (Vitevitch, Stamer & Sereno, 2008). Phonological neighbourhood size of all words used in my experiments was taken from a database of phonological neighbhourhood density by DeCara & Goswami (2002), which is based on CELEX.

As stated at the beginning of this section, the presented item-related variables are only a subset of a list of relevant psycholinguistic factors that have been proved to affect word processing. Therefore, when planning experiments, the researcher has to control for a wide selection of factors. It is impossible to match stimuli on all of these factors but there is widespread agreement that stimuli should at least be matched on those variables that have been discussed above (e.g. Balota, Cortese, Sergent-Marshall, Spieler & Yap, 2004).

Participant-related linguistic factors

Besides item-related factors, researchers have to pay attention to participant-related linguistic characteristics that might otherwise skew the collected data. Given that the performance of two groups of non-native speakers of English was compared in the empirical investigation, it was of particular interest that the L2 participants did not differ concerning their proficiency and usage of the non-native target language. For this reason, the participant-related factors L2 proficiency and experience as well as language mode were of central importance for my investigation and will be discussed in the following.

Grosjean (2008) lists a number of individual differences that need to be taken into account when selecting bilingual participants for empirical investigations. Relevant participant-related factors of bilinguals are, among others, number of languages known as well as the languages' typological properties and frequency of usage, language history, i.e. when and how were the languages acquired, and the participants' competence within the four skills speaking, listening, reading and writing. Note that I will use the term *language proficiency* to refer to the participants' competence levels whereas *language experience* will be used to refer to the frequency of language usage and the participants' language history.

Proficiency and experience in the non-native target language has been shown to affect bilingual language processing. For example, several neuroimaging studies demonstrated that L2 proficiency level and usage influence the neural organization of the bilingual brain (e.g. Abutalebi, Cappa & Perani, 2001; Chee, Hon, Lee & Soon, 2001; Perani, Paulesu, Galles, Dupoux, Dehaene, Bettinardi, Cappa, Fazio & Mehler, 1998; Wartenburger, Heekeren, Abutalebi, Cappa, Villringer & Perani, 2003). Effects of L2 proficiency have been also found on behavioural data, e.g. higher language proficiency correlates with shorter response times and greater accuracy, for instance in semantic categorization (e.g. Chee, Hon, Lee & Soon, 2001) or lexical decision (e.g. Lemhöfer, Dijkstra & Michel, 2004). In other words, L2 words are activated faster by participants with a higher than by participants with a lower proficiency level of that language. Taken together, proficiency level is one of the central participant-related factors that has to be controlled for in experimental research on bilingual language processing if this factor is not used as an independent variable.

While L2 language experience can be measured relatively easily by a background questionnaire (e.g. Marian, Blumenfeld & Kaushanskaya, 2007), collecting reliable data on the participants' language proficiency is a more challenging endeavour. In previous studies with bilinguals, different methods were used to measure the participants' proficiency level of the non-native target language. Selected methods will be briefly presented in the below.

First of all, language proficiency can be measured by standardized language tests (e.g. Akamatsu, 2003). For instance, participants are asked prior to the experiments to complete a section of a diagnostic test, such as DIALANG (Alderson & Huhta, 2005), or a proficiency test, such as the Test of English as a Foreign Language (TOEFL). These standardized tests provide objective data about the participant's language competences with respect to the basic skills reading, listening, speaking and writing. However, this method is rather complex and time-consuming and is usually not feasible for testing large groups of participants.

Another method which provides objective measures of proficiency is to analyze the participants' performance in a lexical decision task with stimuli of the target language (e.g. Lemhöfer, Dijkstra & Michel, 2004; van Hell & Dijkstra, 2002). There is general agreement that response times and error rates in lexical decision correlate with the participants' proficiency level (also see Montrul, 2010, for a discussion). Although a lexical decision task is a rather unnatural and challenging task for non-native speakers, this type of measure can be easily incorporated into an experimental testing session.

In most psycholinguistic studies, though, L2 proficiency level is not measured independently and objectively but by self-assessment, usually on a scale from 0 (no proficiency) to 7 or 10, respectively (native speaker proficiency) (e.g. Escudero, Hayes-Harb & Mitterer, 2008; Lemhöfer, Dijkstra, Schriefers, Baayen, Grainger & Zwitserlood, 2008; Marian, Blumenfeld & Kaushanskaya, 2007). The problem of self-assessed proficiency levels is that the ratings are highly subjective and might be influenced by participants over- or underestimating their proficiency level. However, if these self-assessed ratings are accompanied by questions about the language experience, the researcher gets a clearer picture of the participant's language proficiency and is able to form relatively homogenous groups of participants with respect to their language proficiency. Thus, even if measuring the language proficiency levels entails a certain amount of extra work, this work is worthwhile doing since this factor is a central predictor of bilingual language processing.

In my empirical investigation, L2 proficiency of the German and Danish non-native speakers of English was measured by self-assessment. Participants were asked to complete a background questionnaire which contained a language proficiency scale ranging from 0 (no proficiency) to 10 (native speaker proficiency). The questionnaire also contained questions on their L2 experience (e.g. language history, frequency of usage etc.). A copy of the questionnaire is attached in Appendix B. A detailed description of the participants and the data collected by means of the questionnaire will be provided in the methods section of Experiment 1. In addition to the questionnaire, error rates and response times in lexical decision (Experiment 3) were analyzed as objective measures of L2 proficiency and experience (see section 5.6).

Apart from language proficiency and experience, language mode is another important factor which is considered to affect bilingual speech processing (see Grosjean, 2001, for a review). Language mode is defined as "the state of activation of the bilingual's languages and language processing mechanisms at a given point in time" (Grosjean, 2001: 3). The level of activation of two languages is seen as a continuum ranging from the monolingual mode (activation of only one language) to the bilingual mode (activation of both languages). Although an increasing number of studies has shown that both languages of a bilingual are activated during native or non-native language processing (see section 3.1 and 3.2 for evidence in favour of this language non-selective approach to lexical access), Grosjean (2001) argued that the degree of interaction of two languages depends on whether the bilingual speaker is in a monolingual or bilingual language mode. Thus, a pre-activated language has a larger influence on bilingual processing than if the language is activated unexpectedly. In order to compare data from various bilingual participants, it has to be ensured that all participants are in the same language mode, usually a monolingual language mode. During the testing sessions of my study, a monolingual language mode was induced by using English as the language of instruction and for all kinds of communication between experimenter and participant.

5.2.3.2 Non-linguistic variables

Apart from the item- and participant-related *linguistic* factors discussed in the previous section, data collection in psycholinguistic experimental research might also be affected by a number of *non-linguistic* confounding factors (e.g. see Bittrich & Blankenberger, 2011; Cozby, 2009, for an overview). In order to avoid such influences, these non-linguistic factors have to be properly controlled for.

For instance, participants should form a homogenous group in terms of age and socioeconomic status (unless, of course, a difference with respect to these participant-related factors is used as an independent variable). In my empirical investigation, all participants were students at university level. This means, they were at a similar age and had a similar socioeconomic background.

Furthermore, it is noteworthy that experimental data can be biased by order effects. For example, the participant's performance may improve during a testing session due to increasing practice with the task. Similarly, performance may decline at the end of a testing session as the participant gets bored or tired. To avoid such influences, the order of presented stimuli was randomized within the experiments, i.e. all participants received the same stimuli but in randomized order. Moreover, the order of the tasks was counterbalanced across participants within the testing session.

Finally, it should be noted that the testing situation was kept constant for all participants of my investigation. That is, all participants were tested individually in a silent room, received the same instructions and used the same hardware and software equipment.

5.2.4 Overall design of the empirical investigation

The present empirical investigation consists of the following three experiments: Experiment 1: Rhyme judgement task (RJT); Experiment 2: Phoneme deletion task (PDT); Experiment 3: Lexical decision task (LDT). The specific design of these experiments will be described in the respective methods sections. Two groups of non-native speakers and a control group of native speakers of English took part in the experiments. The groups consisted of sixty German and sixty Danish proficient non-native speakers of English and a group of sixty native English speakers. All participants received the same stimuli but in randomized order. Moreover, all participants took part in all three tasks. However, the order of experiments was counterbalanced across participants to make sure that task order did not interact with any critical variables.

In all experiments, error rates and response times constituted the dependent variables. Language group (3)[38] and order of experiments (6)[39] were included as independent variables (i.e. between-participants and within-items factors). Additional independent measures of the critical stimuli were task-specific and will be described in the respective tasks below. In the statistical analyses, error rates and response times were submitted to analyses of variance by participants (F1) and by items (F2).[40]

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[38] As mentioned above, the three language groups were German, Danish and English.

[39] The 6 different orders of the experimental set-up were as follows: RJT-PDT-LDT; RJT-LDT-PDT; PDT-RJT-LDT; PDT-LDT-RJT; LDT-RJT-PDT; LDT-PDT-RJT.

[40] For an overview on statistical analyses in psycholinguistic research, see Clark (1973).

5.3 Experiment 1: Rhyme judgement task

As detailed above, the first clear evidence for orthographic activation in auditory speech processing was obtained in an auditory rhyme judgement task (Seidenberg & Tanenhaus, 1979). Since this classic study, this paradigm has been used in a number of studies which investigated different aspects of monolingual language processing (e.g. Damian & Bowers, 2009b; Donnenwerth-Nolan, Tanenhaus & Seidenberg, 1981; Pattamadilok, Perre & Ziegler, 2011; Zecker, Tanenhaus, Alderman & Siqueland, 1986). However, auditory rhyme judgements have not been extended systematically to the field of non-native word processing. Due to its considerably simple and straightforward nature, it was regarded to be a good starting point for explorations of orthographic effects in non-native speech processing. Especially with regard to its explicit metaphonological awareness of the rime unit, this task was believed to reveal interesting insights into the processing of rime-sized units of the non-native German and Danish speakers of English. This was of particular interest because German in contrast to Danish participants were believed to be less familiar with orthographic inconsistencies on the rime level due to their shallow L1 orthographic background.

The present experiment is essentially a replication of experiment 3 by Seidenberg & Tanenhaus (1979). Hence, relevant methodical aspects, such as procedure, conditions, etc., were borrowed from the original study. However, as will be illustrated below, stimulus materials were adapted to the specific conditions of non-native speakers.

Predictions

Based on previous findings in auditory rhyme judgement tasks, it was predicted that an orthographic bias was expected to be found for the native English participants in the rhyme and non-rhyme condition, i.e. orthographically similar rhyme pairs (e.g. *turn* - *burn*) were expected to be judged significantly faster than orthographically different rhyme pairs (e.g. *turn* - *learn*), orthographically similar non-rhymes (e.g. *howl* - *bowl*) were expected to be judged more slowly than orthographically dissimilar pairs (*howl* - *pole*). With reference to the non-native speakers of English, I predicted a stronger orthographic effect than for the native speakers both in the rhyme and non-rhyme condition, with the German participants displaying a stronger orthographic bias than the Danish group.

5.3.1 Method

Participants

Sixty German and sixty Danish proficient non-native speakers of English as well as sixty native speakers of English participated in the experiments. All of them had a monolingual background, having acquired other languages than their first language at school at the earliest. They were all volunteers and received a little gift for their participation. None of them reported any hearing problems.

The German participants were students from the English Department at Technische Universität Dortmund (N = 60, 9 male, 51 female, mean age = 22.7 years, age range 19-32 years). The Danish group of participants was recruited at the English Department at Aarhus University (N = 60, 16 male, 44 female, mean age = 24.6 years, age range 20-36 years) and the English volunteers were students at the Department of Linguistics and Phonetics at the University of Leeds (N = 60, 15 male, 45 female, mean age = 20.7 years, age range = 18-29 years). All participants filled out a background questionnaire prior to the experiments. German and Danish participants had to answer a number of questions about their English proficiency and experience and were matched as closely as possible on these factors. A copy of the questionnaire is attached in Appendix B. The self-estimated English proficiency level was 7.67 (SD = 0.90) for the German and 8.15 (SD = 1.19) for the Danish group on a scale between 0 (no proficiency) and 11 (native speaker proficiency), which suggests that they considered themselves to be on a low advanced level.[41] Both groups had received approximately 9 years of English instruction at school (German: mean = 9.22 years, SD = 1.24; Danish: mean = 9.25, SD = 1.45). Nearly 27% of the German and 28% of the Danish participants had stayed in an English-speaking country for longer than 6 months. However, some differences were found concerning

[41] Although German and Danish participants indicated a similar level of English proficiency, an independent t-test revealed a significant difference between mean proficiency levels of the two non-native groups ($t(118) = 2.51$, $p < .05$).

the regular usage of English in their everyday lives: While German and Danish participants spent about the same number of hours per week speaking English (German: mean = 5.1 hours, SD = 6.4, Danish: mean = 5.3 hours, SD = 5.7), the number of hours differed for the receptive skills reading English texts (German: 8.2 hours, SD = 6.3; Danish: 15.4, SD = 9.0) and listening to native speakers (German: 6.5 hours, SD = 8.0, Danish: 14.6, SD = 14.7).

Materials

Stimuli consisted of 28 triplets of monosyllabic words. Each triplet consisted of the target and two cues. In 14 triplets, target and cues rhymed but only one cue of each triplet was orthographically similar to the target whereas the other cue was orthographically different (e.g. cues: *turn*, *learn*; target: *burn*). In the other 14 triplets, target and cues did not rhyme. Each of the non-rhyming triplets consisted of one target, one orthographically similar cue to the target and one orthographically different cue (e.g. cues: *tomb*, *room*; target: *bomb*). Homophones, homographs and homonyms were avoided. A number of stimuli were taken from the stimulus list by Seidenberg & Tanenhaus (1979), however, new stimuli were generated which were considered to be more suitable for non-native speakers of English (i.e. low frequency words were substituted by moderately high frequency words). Altogether, the stimulus list shared 44% of the stimuli with the original list by Seidenberg & Tanenhaus (1979). The full list of stimuli is presented in Appendix A.

Stimuli were matched as closely as possible on all item-related psycholinguistic factors which have been shown to influence language processing in section 5.2.3, except for their rhyme status and their orthographic similarity. To make sure that all English words would be known to the non-native participants, a preliminary stimulus list was given to 40 undergraduate students at Technische Universität Dortmund, who were drawn from the intended population of German participants for the experiments but did not participate in the main experiment. They were asked to go through the list and indicate which English words they did not know. Words that were unknown to more than 30% of the students were removed from the stimulus list.

Table 5.1 and 5.2 display the characteristics of the stimulus materials used in Experiment 1. All stimuli were monosyllabic words with three to six letters and two to five phonemes. The written and spoken frequency of the lemmas of all stimuli was established by using the CELEX database (Baayen, Piepenbrock & van Rijn, 1993). The size of the orthographic neighbourhood was calculated by using the WordGen word selection tool (Duyck, Desmet, Verbeke & Brysbaert, 2004), which is based on CELEX. The number of phonological neighbours was taken from a database of phonological neighbourhood density by DeCara & Goswami (2002), which is also based on CELEX.

All stimuli were recorded by a male native speaker of British English in a quiet room using an Acer Extensa 5630EZ laptop with *Audacity* audio recording and editing software and a Sennheiser HSP2 microphone. Based on the recordings, the stimulus duration was established manually, by measuring the time elapsing from the onset to the offset of the spoken stimulus in a digital audio recorder.

Variable	cues (OS)	cues (OD)	targets
no. of letters	4.13 (.74)	4.53 (.83)	4.07 (.59)
no. of phonemes	3.47 (.83)	3.20 (.86)	3.20 (.77)
written frequency	143.67 (176.39)	106.20 (104.79)	161.33 (210.83)
spoken frequency	123.60 (200.89)	76.00 (100.96)	122.60 (199.74)
orthographic neighbourhood	9.07 (5.34)	3.73 (3.47)	7.73 (4.95)
phonological neighbourhood	23.80 (18.10)	22.80 (12.84)	25.47 (16.58)
stimulus duration (ms)	664.1 (73.8)	653.1 (64.4)	642.4 (83.5)

Table 5.1. Stimulus characteristics of orthographically similar (OS) and orthographically different (OD) cues and targets in the rhyme condition (mean values, standard deviation in parentheses).

Variable	cues (OS)	cues (OD)	targets
no. of letters	4.27 (.46)	4.27 (.80)	4.07 (.46)
no. of phonemes	3.07 (.46)	3.13 (.52)	2.93 (.26)
written frequency	137.40 (160.29)	113.13 (141.65)	136.20 (153.08)
spoken frequency	110.53 (194.28)	70.13 (87.93)	101.07 (147.23)
orthographic neighbourhood	7.80 (4.18)	6.80 (5.75)	10.47 (5.60)
phonological neighbourhood	20.00 (11.63)	24.07 (13.69)	25.27 (13.01)
stimulus duration (ms)	631.6 (76.7)	652.0 (51.6)	636.2 (79.6)

Table 5.2. Stimulus characteristics of orthographically similar (OS) and orthographically different (OD) cues and targets in the non-rhyme condition (mean values, standard deviation in parentheses).

Apparatus

The experiment was run on an Acer Extensa 5630EZ laptop. Stimulus presentation and data collection were controlled by the experimental software *Presentation* (Neurobehavioral Systems Inc.). The left and right laptop mouse buttons were used for button responses. Auditory stimuli were presented over headphones (t.bone stereo HD-990D).

Design

Stimuli were presented in word pairs. The 56 target-cue pairs were assigned to one of the four conditions: orthographically similar rhymes (R_OS), e.g. *turn* - *burn*; orthographically dissimilar rhymes (R_OD), e.g. *turn* - *learn*; orthographically similar non-rhymes (NR_OS), e.g. *bomb* - *tomb*; orthographically dissimilar non-rhymes (NR_OD), e.g. *bomb* - *room*. These four conditions were assigned to two different blocks. Block 1 contained all word pairs of conditions R_OS and NR_OD, block 2 consisted of stimuli of conditions R_OD and NR_OS. Within each block, the order of word pairs was randomized for each participant. Half of the participants received block 1 before block 2, the other half vice versa. As mentioned earlier, the experiment was embedded in a testing session with two other experiments (phoneme deletion and lexical decision). The order of experiments was counterbalanced across participants.

Response times and accuracy measures for the stimuli in the four different conditions constituted the dependent variables. Data were analyzed with language group (3) as between-participants and within-items variable and rhyme (rhyme, non-rhyme) and orthography (similar, different) as within-participants and between-items variable. Moreover, the order of presented blocks (2) and the ordinal position of the rhyme judgement task within the sequence of the three experiments completed by all participants (6) were included as between-participants and within-items variables in order to make sure that the order of presented item blocks and the order of completing the experiments did not interact with any of the critical independent variables.

Procedure

Participants were tested individually in a quiet room in their respective home universities in Dortmund (Germany), Aarhus (Denmark) or Leeds (England). They completed three experiments in a single session (rhyme judgement, phoneme deletion and lexical decision). The order of the experiments was counterbalanced. The whole testing session took about 35 minutes including short breaks between the experiments.

For the rhyme judgement task, the procedure was taken from Seidenberg and Tanenhaus' (1979) experiment 3. On each trial, the cue word was presented over headphones at a comfortable listening level, followed by the target word 2000 ms after offset of the cue word. Participants were instructed to decide whether the presented pair of words rhymed or not by pressing the "Yes" or "No" button. They were instructed to make their decisions as accurately and quickly as possible. A practice part consisting of 6 word pairs (3 rhyming, 3 non-rhyming stimuli), which were not used in the actual experiment, was presented to familiarize participants with the task. No feedback was given. Response times were measured from the onset of the stimulus to the button response. Each trial was followed by an interval of 2000 ms. The computer screen was blank during the whole experiment. All instructions were given in English. The present experiment took approximately 10 minutes.

5.3.2 Results

Statistical analyses were performed on both the subject and item means, including language group (3) as between-participants and within-items variable and rhyme (rhyme, non-rhyme) and orthography (similar, different) as within-participants and between-items variable. Moreover, the order of presented blocks (2) and the order of experiments (6) were included as between-participants and within-items variables in order to make sure that the order of presented item blocks and the order of completing the experiments did not interact with any of the critical independent variables.

Error rates

The overall error rate in this task was 4.5% (5.9%, 6.6% and 1.2% for the German, Danish and English participants, respectively). Particular item pairs caused high error rates for the German and Danish participants while the error rate for the English group was very low; e.g. *cough* - *stuff* (German: 36.7%, Danish: 60.0%, English 1.7%), *cough* - *tough* (56.6%, 85.0%, 1.7%), *done* - *John* (23.3%, 55.1%, 3.3%), *June* - *tune* (40.0%, 6.7%, 1.7%).

Error rates broken down by language group and orthographic similarity are presented in Figure 5.1 (rhyme condition) and Figure 5.2 (non-rhyme condition). The analyses of error rates revealed higher error rates for non-rhymes (6.3%) than for rhymes (2.5%). Moreover, higher error rates were found for orthographically similar (5.1%) compared to orthographically different stimulus pairs (3.6%). Consequently, main effects of rhyme and orthography were established that were highly significant by participants (rhyme: $F1(1, 162) = 68.18$, $MSE = 39.17$, $p < .001$; orthography: $F1(1, 162) = 20.93$, $MSE = 18.87$, $p < .001$) but not by items (rhyme: $F2(1, 56) = 2.64$, $MSE = 1516.71$, $p = .11$; orthography: $F2(1, 56) = .39$, $MSE = 1516.71$, $p = .53$). As noted above, German and Danish participants yielded higher error rates than English participants, which resulted in a main effect of language that was highly significant in the analyses by participants and by items ($F1(2, 162) = 52.33$, $MSE = 35.77$, $p = < .001$; $F2(2, 112) = 7.58$, $MSE = 370.48$, $p < .001$). The interaction of rhyme and orthography was significant in the analyses by participants ($F1(1, 162) = 6.23$, $MSE = 20.96$, $p = .014$) but not by items ($F2(1, 56) = .13$, $MSE = 1516.71$, $p = .72$) whereas the three-way interaction of rhyme, orthography and language did not reach significance ($F1(2, 162) = 1.85$, $MSE = 20.96$, $p = .16$; $F2(2, 112) =$

.16, MSE = 370.48, p = .77). Order of stimulus blocks as well as order of experiments had no significant effect on error rates and did not interact with any of the other variables.

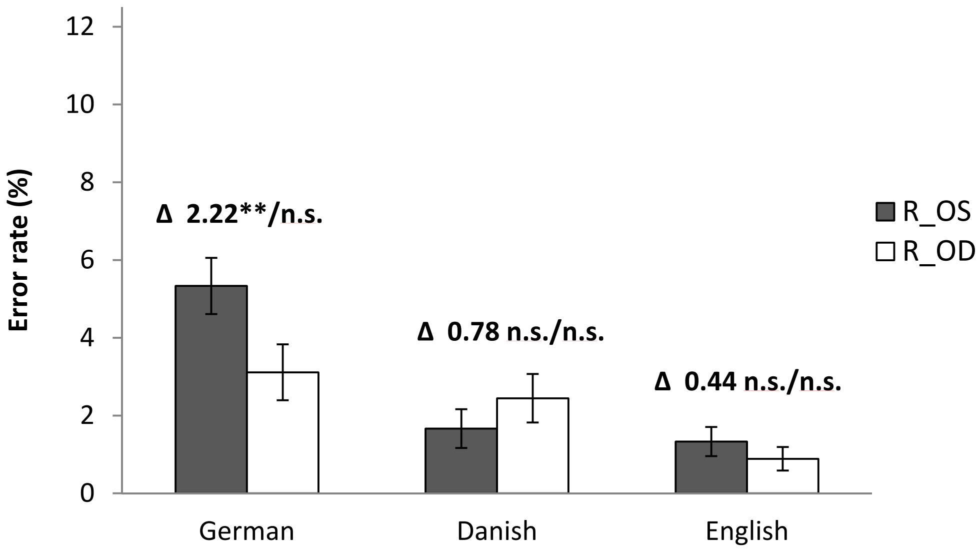

*Figure 5.1***.** Error rate by language group for orthographically similar (R_OS) and orthographically different (R_OD) rhymes. Error bars represent one standard error. Levels of significance for the orthographic effect in each group are based on individual analyses of variance of the error rates in each group by participants/by items (*** p < .001; ** p < .01; * p < .05).

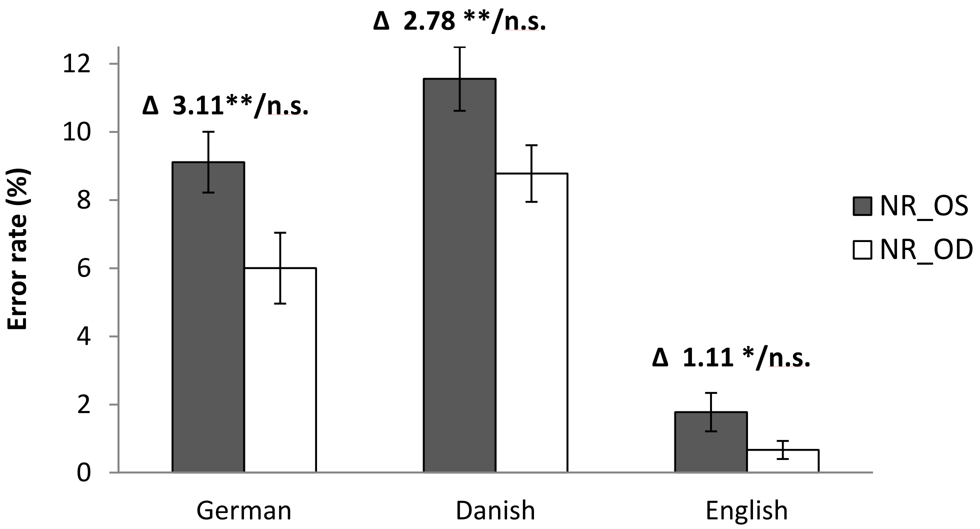

Figure 5.2. Error rate by language group for orthographically similar (NR_OS) and ortho-graphically different (NR_OD) non-rhymes. Error bars represent one standard error. Levels of significance for the orthographic effect in each group are based on individual analyses of variance of the error rates in each group by participants/by items (*** p < .001; ** p < .01; * p < .05).

In order to investigate the effect of orthography on rhyme/non-rhyme decisions, statistical analyses were performed separately on the error rates in the rhyme and non-rhyme condition. A main effect of language was discovered in both conditions (rhymes: $F1(2, 162) = 12.73$, $MSE = 23.99$, $p < .001$; $F2(2, 56) = 5.28$, $MSE = 86.73$, $p < .01$; non-rhymes: $F1(2, 162) = 49.83$, $MSE = 50.95$, $p < .001$; $F2(2, 56) = 5.82$, $MSE = 654.22$, $p < .01$) whereas the main effect of orthography was only significant in the by-participants analyses of the non-rhyming stimuli ($F1(1, 162) = 19.05$, $MSE = 25.72$, $p < .001$; $F2(1, 18) = .26$, $MSE = 2799{,}74$, $p = .612$). The interaction of orthography and language group was only significant in the by-participants analyses in the rhyme condition ($F1\ (2, 162) = 4.84$, $MSE = 14.12$, $p = .009$; $F2\ (2, 56) = 1.81$, $MSE = 86.73$, $p = .31$).

Response times

Response times that were shorter or longer than 2.5 standard deviations of the participants' mean of correct responses were excluded from the analysis of response latencies (2.5% in total over all language groups; German: 2.8%, Danish: 2.6%, English: 2.3%). In order to exclude the influence of stimulus duration on response times, covariance analyses were conducted with stimulus duration as covariate. If not reported otherwise, stimulus duration had no significant effect on response times and did not interact with any of the independent variables mentioned above.

Average response times broken down by language group and orthographic similarity are presented in Figure 5.3 (rhyme condition) and Figure 5.4 (non-rhyme condition). Overall, response times were 34 ms faster to rhyming than non-rhyming pairs and 19 ms faster to orthographically similar than orthographically different pairs. The covariate stimulus duration established a significant effect on response times in the by-items analyses over all participants ($F2(1, 55) = 12.02$, $MSE = 81490.31$, $p < .001$). Nevertheless, a main effect of orthography was found that was significant by participants but not by items ($F1(1, 161) = 8.03$, $MSE = 4281.95$, $p < .01$; $F2(1, 55) = 1.93$, $MSE = 81490.31$, $p = .17$). A main effect of rhyme was not significant in the analyses by participants but reached significance in the by-items analyses ($F1(1, 161) = .09$, $MSE = 10456.00$, $p = .76$, $F2(1, 55) = 7.62$, $MSE = 81490.31$, $p < .01$). As would be expected, native speakers produced faster response times than non-native speakers. Accordingly, a main effect of language was established (F1(2, 161) = 3.16, MSE = 118462.68, p < .05; F2(2, 112) = 100.60, MSE = 6923.51, p < .001). The interaction of rhyme and orthography was not significant (F1(1, 161) = 3.42, MSE = 5160.82, p = .07; F2(1, 55) = .66, MSE = 81490.31, p = .42). However, the three-way interaction of rhyme, orthography and language reached significance in the analyses by participants and by items (F1(2, 161) = 4.14, MSE = 5160.82, p < .05; F2(2, 112) = 3.89, MSE = 6923.51, p < .05).

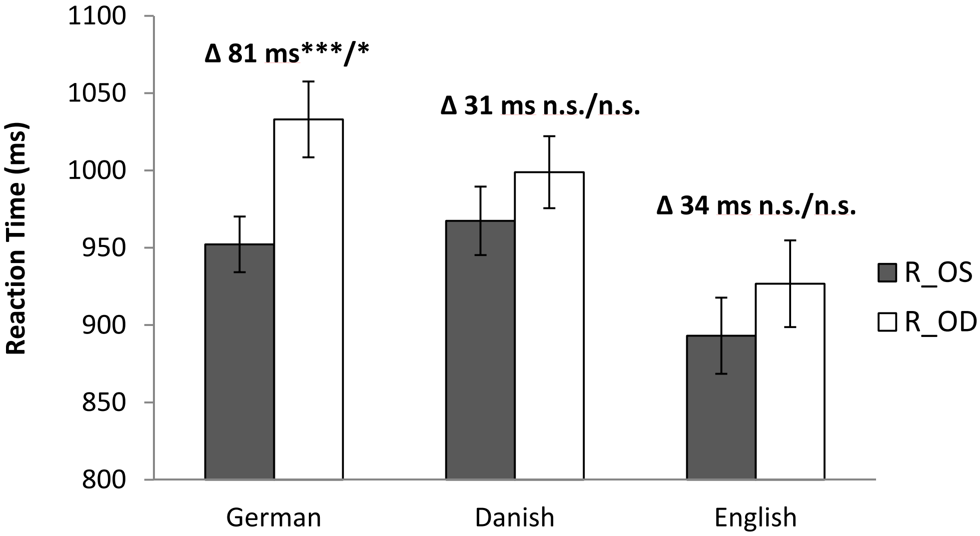

Figure 5.3. Mean reaction times (participant means) by language group for orthographically similar (R_OS) and orthographically different (R_OD) rhymes, uncorrected for the covariate stimulus duration. Error bars represent one standard error. Levels of significance in each group are based on individual analyses of covariance of the response times in each group by participants/by items (*** p < .001; ** p < .01; * p < .05).

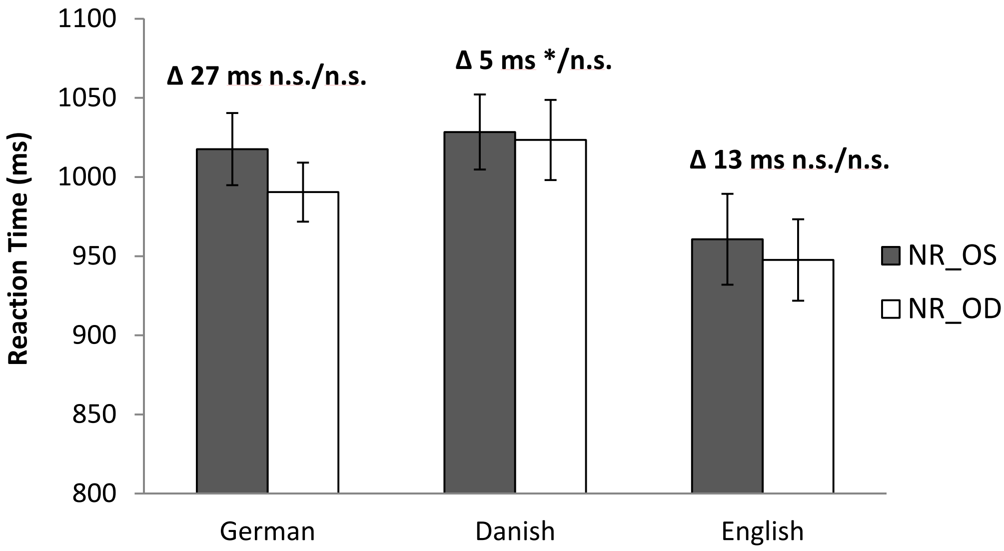

Figure 5.4. Mean reaction times (participant means) by language group for orthographically similar (NR_OS) and orthographically different (NR_OD) non-rhymes, uncorrected for the covariate stimulus duration. Error bars represent one standard error. Levels of significance in each group are based on individual analyses of covariance of the response times in each group by participants/by items (*** $p < .001$; ** $p < .01$; * $p < .05$).

The interaction of orthography and language group in the rhyme condition was further investigated by conducting analyses of covariance with the data from pairs of language groups. These analyses showed a significant interaction of language and orthography for the German and Danish participants ($F1(1, 107) = .31$, $MSE = 6113.84$, $p < .05$; $F2(1,28) = 7.25$, $MSE = 5074.55$, $p < .05$) as well as for the German and English groups ($F1(1, 107) = 1.87$, $MSE = 5363.02$, $p < .05$; $F2(1, 28) = 7.03$, $MSE = 4675.09$, $p < .05$) but no significant interaction for the Danish and English group ($F1(1, 107) = .02$, $MSE = 3349.26$, $p = .89$; $F2(1, 28) = .02$, $MSE = 6503.99$, $p = .89$). Block order and task order did not show significant interactions in the pairwise comparisons.

As mentioned above, covariance analyses were conducted on response times to exclude the influence of stimulus duration. However, the predecessor studies on auditory rhyme judgements by Seidenberg & Tanenhaus (1979) and Damian & Bowers (2009b) did not control for the influence of stimulus duration in their analyses. In order to make the results of the present study comparable to their results, I will briefly describe the results of analyses of variance (ANOVA) conducted on the response times of the present rhyme judgement task. The analyses of variance were performed with the same between-participants and within-items variables as described for the covariance analyses. These analyses showed a main effect of rhyme ($F1(1, 162) = 18.61$, $MSE = 10421.00$, $p < .001$; $F2(1, 56) = 4.56$, $MSE = 97526.03$, $p < .05$) and a main effect of orthography which was, however, only significant in the by-participants analyses ($F1(1, 162) = 11.55$, $MSE = 4381.90$, $p < .001$; $F2(1, 56) = .80$, $MSE = 97526.03$, $p = .37$). The interaction of rhyme and orthography was significant by participants but not by items ($F1(1, 162) = 35.36$, $MSE = 5170.29$, $p < .001$; $F2(1, 56) = 1.76$, $MSE = 97526.03$, $p = .19$). In the rhyme and non-rhyme condition, the main effects of orthography and language were very similar to the results of the covariance analyses described above. However, individual analyses of variance conducted on the rhymes in each language group yielded a significant effect of orthography in the by-participants analyses for Danish and English, which had not been found in the covariance analyses (Danish: $F1(1, 54) = 7.43$, $MSE =3996.56$, $p < .01$; $F2(1, 28) = 1.19$, $MSE = 29640.29$, $p = .28$; English: $F1(1, 54) = 12.73$, $MSE = 2659.28$, $p < .001$; $F2(1, 28) = 1.63$, $MSE = 25217.06$, $p = .21$). The individual analyses of the rhymes in the German group showed a similar strength of orthographic influence as in the covariance analyses ($F1(1, 54) = 24.05$, $MSE = 196077.42$, $p < .001$; $F2(1, 28) = 5.63$, $MSE = 37398.53$, $p = .02$). Moreover, interactions of language group and orthography performed on the data of pairs of language groups revealed no differences to the results of the covariance analyses. No significant effects were found in the non-rhyme condition.

5.3.3 Discussion

The results of this experiment indicate that orthography affects spoken language processing both in native and non-native word recognition. In all language groups, participants responded more slowly to orthographically different than orthographically similar rhymes. A weak orthographic influence was also established in the non-rhyme condition. However, the pattern of results differs between language groups and will be discussed in more detail in the following, starting with the group of native speakers of English. Then, response data of native and non-native participants will be compared before I discuss the data of both non-native groups in more detail. Finally, the results of all language groups will be discussed in a concluding discussion with reference to possible explanations.

Native speakers of English

The results of the English participants largely replicated the findings of the original study by Seidenberg & Tanenhaus (1979), which have been recently replicated by Damian & Bowers (2009b). Orthographic similarity facilitated response times for rhyming pairs but inhibited latencies for non-rhyming pairs. However, the obtained orthography effect in the present investigation was notably smaller compared to the two studies mentioned above. While Seidenberg & Tanenhaus (1979) obtained a mean facilitatory effect of 99 ms between orthographically similar and orthographically different rhymes (Damian & Bowers (2009b): 100 ms), the present results revealed a difference of 34 ms. The inhibitory effect of orthographically similar non-rhymes compared to orthographically different rhymes was only 13 ms in the present experiment (Seidenberg & Tanenhaus (1979): 58 ms; Damian & Bowers (2009b): 25 ms). Moreover, it is noteworthy that none of the orthographic effects reached significance for the English group in the current study.

Two possible explanations might account for the fairly weak orthographic effect in the present experiment that is in contrast to the studies by Seidenberg & Tanenhaus (1979) and Damian & Bowers (2009b). First of all, the stimulus list of the present and original task shared only 44% of the items. Hence, differences might be due to specific characteristics of the selected stimulus materials. Second, analyses of response times in the present experiment included the covariate stimulus duration. This factor was not properly controlled for in the studies by Seidenberg & Tanenhaus (1979) and Damian & Bowers (2009b). Indeed, results of the analyses of variance (ANOVA) of the present data without the covariate stimulus duration demonstrated a highly significant main effect of orthography on rhymes in the analyses by participants, which, however, lost significance when the covariate stimulus duration was partialled out. These findings suggest that the present results in the rhyme condition are largely comparable to previous results and lost significance due to the covariance analyses. This result demonstrates that stimulus duration had a strong influence on response latencies although stimuli were matched as closely as possible on this factor during stimulus selection.

In contrast to the rhyme condition, the fairly small and non-significant orthographic effect observed in the non-rhyme condition cannot be explained by influences of the covariate stimulus duration. Damian & Bowers (2009b) reported a comparable inhibitory effect for non-rhymes, which was similar in size and did not reach significance either. This pattern of results suggests that the orthographic effect tends to occur predominantly for rhyming, but not for non-rhyming stimuli. Interestingly, several studies on auditory rhyme judgements and rhyme monitoring did not investigate responses to non-rhyming stimuli (e.g. Donnenwerth-Nolan, Tanenhaus & Seidenberg, 1981; Pattamadilok, Perre & Ziegler, 2011; Zecker, Tanenhaus, Alderman & Siqueland, 1986 (experiment 1)). However, other studies revealed larger orthographic effects for non-rhyming compared to rhyming stimuli (Cone, Burman, Bitan, Bolger & Booth, 2008; McPherson, Ackerman & Dykman, 1997). Given that the procedure of the latter mentioned studies differed substantially from the original rhyme judgement task by Seidenberg & Tanenhaus (1979), discrepancies between previous findings are likely to be due to a number of methodical changes between the studies. With respect to the interpretation of the results of the present study, I will primarily focus my discussion on the studies by Seidenberg & Tanenhaus (1979) and Damian & Bowers (2009b), which resemble the present experiment both in procedure, choice of stimuli and types of statistical analyses.

A follow-up experiment by Damian & Bowers (2009b) demonstrated that the original results by Seidenberg & Tanenhaus (1979) are likely due to the specific design of the task and the choice of stimuli. They showed that the orthographic effect disappeared when a large number of filler trials were added to the original stimuli. This finding illustrates that the impressive and straightforward results by Seidenberg & Tanenhaus (1979) are less robust than assumed. As discussed above, the present results further suggest that stimulus duration is another critical factor which seems to affect response data but has not been considered in previous studies. The influence of stimulus duration on response times is quite understandable given that participants usually waited for the end of the second stimulus before they made their decision. Hence, the influence of stimulus duration on response times was not only found for the English group but also for the German and Danish participants (as I will discuss below).

In sum, the results obtained for the English native speakers essentially replicated the orthographic effects found in previous studies although they did not reach significance in the present investigation. It has been argued that this difference is likely to be due to the factor of stimulus duration, which was not taken into account in previous studies on rhyme judgements.

Having discussed the results of the native speakers of English in terms of previous findings, I will now turn to the discussion of non-native language processing. I will start with a comparison of the results of native and non-native participants and then discuss differences and similarities between both non-native groups.

Native vs. non-native speakers of English

Comparing the results between native and non-native participants displayed two fundamental differences. Native speakers demonstrated both faster response times and lower error rates than non-native participants. This pattern is not surprising, however, the considerable difference in overall error rates between native (English: 1.2%) and non-native participants (German: 5.9%, Danish: 6.6%) is of particular interest. Recall that an auditory rhyme judgement task is a rather simple task for non-native participants compared, for instance, to a lexical decision task since it does not necessarily involve lexical access. The differences between L1 and L2 participants, however, indicate that this task was considerably challenging for the latter group of participants. Given that the task involves decisions on spoken word stimuli, it is likely that these problems are related to the non-natives' inferior comprehension skills relative to the native speakers. For rhyme judgements, participants have to listen carefully to detect subtle phonological differences which their rhyme/non-rhyme decisions are based on. However, response data reveal that their decisions tended to be *not* solely based on phonological information but were – as predicted – affected by the orthographic form of the stimuli. In the non-rhyme condition, both German and Danish participants made significantly more errors to orthographically similar than to orthographically different stimuli whereas the corresponding response times did not indicate orthographic biases. Moreover, the error rates of the non-native participants were substantially higher than the native speakers' error rate which suggests that the non-native participants were affected more strongly by the presentation of conflicting orthographic information than the native participants.

However, the analyses of error rates and response latencies in the rhyme condition showed a less consistent pattern. While the effects of response times and error rates point in the same direction in the non-rhyme condition (i.e. longer response times and higher error rates for orthographically similar non-rhymes compared to orthographically different non-rhymes), the direction of the orthographic effects in the rhyme condition is rather mixed. For rhyming pairs, participants of all language groups demonstrated longer response times for orthographically different relative to orthographically similar stimuli but this pattern was not found in the analyses of error rates. English and Danish participants demonstrated a very small difference between orthographically similar and different rhymes whereas German participants displayed a significant difference, which was, though, contrary to the pattern of response times.

In general, it has to be emphasized that the differences in error rates across and within all language groups were not significant in the by-items analyses, which suggests that participants were particularly inaccurate in some of the items. A closer inspection of the error data by items revealed that especially the non-native groups produced particularly high error rates for some stimuli in the non-rhyming condition, e.g. *cough - stuff* (German: 36.7%, Danish: 60.0%, English 1.7%), *cough - tough* (56.6%, 85.0%, 1.7%), or *done - John* (23.3%, 55.1%, 3.3%). Moreover, as already mentioned above for the English participants, response latencies of the non-native groups were biased by stimulus duration, which led to non-significant results in the by-items analyses.

Collectively, comparing the performance of native and non-native participants demonstrated primarily an overall difference in error rates and response times. The pattern of orthographic effects in native and non-native speech processing was, however, rather mixed for native speakers and learners of English, i.e. German and Danish participants did not show an identical pattern of response data in all conditions. In the following, I will take a closer look at the individual behavioural data of the German and Danish groups.

German vs. Danish non-native speakers of English

As outlined above, German participants showed a significant facilitatory effect on response times for orthographically similar relative to orthographically different rhyme pairs whereas no significant effect was found for the Danish participants. Likewise, the size of the orthographic effect varied significantly between both non-native groups (German: 81 ms vs. Danish: 31 ms). While the error rate of the German group indicates an inhibitory effect of orthographic similarity in the rhyme condition, which contrasts with the facilitatory bias of the corresponding response times, the pattern of error rates for the Danish group demonstrates a particularly small effect. Especially the reversed pattern of response times and error rates needs some further clarification. Error rates for rhyming stimuli were twice as high for German compared to Danish participants (German: 4.2%; Danish: 2.1%). While German and Danish participants demonstrated a comparable error rate for nearly all rhyming stimuli, the only stimulus pair which yielded a considerable difference between both groups in the rhyme condition was *June* - *tune* (German: 40%, Danish: 6.7%). Due to the limited number of only 30 stimulus pairs in each condition it is likely that the particularly high error rate for this stimulus pair contributed to a substantial extent to the higher error rate in the rhyme condition of the German compared to the Danish participants. Indeed, when the stimulus pair *June* - *tune* was excluded from the analyses, the error rate for German participants in the rhyme condition dropped from 5.3% to 2.8%, which rendered the difference between error rates of orthographically similar and different stimuli non-significant once again. Thus, the contradictory finding of an inhibitory effect for orthographically similar rhymes, which was in contrast to the facilitatory effect found for response times, disappeared when the most error-prone pair of stimuli was eliminated. Hence, after the exclusion of the stimulus pair no orthographic effects were found in the error rates of the German group, which was consistent with the findings of the Danish and English group.

Having discussed the results of the rhyme condition, I will now take a closer look at the non-rhyme data. With respect to the non-rhyme condition, analyses of the response times of the German and Danish group revealed slightly faster response times for orthographically similar in contrast to orthographically different stimulus pairs. Nevertheless, the main effect of orthographic congruency did not reach significance. On that account, the pattern of response latencies resembled the non-significant findings obtained for the English group. Analyses of error rates demonstrated an orthographic effect for both German and Danish participants, which was only significant in the analyses by participants. Accuracy data in the by-items analyses showed that both

German and Danish participants produced particularly high error rates for the non-rhyming stimulus pairs *cough* - *stuff* (German: 36.7%, Danish: 60.0%, English 1.7%) and *cough* - *tough* (56.6%, 85.0%, 1.7%). When both pairs were excluded from the analyses, the difference in error rates lost significance for all three language groups. Error rates for orthographically similar non-rhymes were still larger than for orthographically different non-rhymes but the significant effect of orthographic congruency disappeared. Thus, response times and error rates of non-rhyming stimuli did not indicate significant orthographic influences on all language groups after exclusion of two stimulus pairs with the highest error rates.

As already discussed above for the English participants, the non-significant orthographic effect for non-rhymes is consistent with the study by Damian & Bowers (2009b). Nonetheless, other studies demonstrated a strong orthographic effect in the non-rhyme condition (Cone, Burman, Bitan, Bolger & Booth, 2008; McPherson, Ackerman & Dykman, 1997). The counterintuitive finding that decisions on non-rhymes were not influenced by orthographic congruency might be explained by a phenomenon often referred to as the *fast-"same" effect* (see Farell, 1985, for a review). This effect describes the finding that response times in tasks that involve "same"-"different" judgements are faster for "same" than for "different" judgements. Concerning the present experiment, significantly faster response times were found for rhymes ("same" judgements) than for non-rhymes ("different" judgements). Consequently, it might be possible that the overall tendency to longer response times for non-rhymes masked the difference between orthographically congruent and incongruent stimuli in this condition. As a result, response latencies did not show orthographic influences on non-rhyming stimuli.

Overall, after exclusion of two error-prone stimulus pairs, comparisons of the German and Danish participants' performance demonstrated a similar pattern in the non-rhyme condition. Both response times and error rates did not show significant orthographic effects. In the rhyme condition, by contrast, German participants showed a different pattern than Danish participants. While the response times of the German speakers of English were significantly influenced by conflicting orthographic information, no significant orthographic bias was found for the Danish group. The size of orthographic bias found for the Danish group was notably smaller compared to the German group and resembled the size of the effect obtained for the English native speakers. Error rates for both non-native groups did not reveal significant orthographic influences after removal of a stimulus pair with particularly low accuracy scores.

Concluding discussion

In conclusion, the results of the present experiment replicate the general trend of the pioneering study on orthographic interactions during auditory speech processing by Seidenberg & Tanenhaus (1979). Longer response times for orthographically different compared to orthographically similar rhymes were found in all three language groups. However, the strongest and only significant difference was found for German participants, which suggests that their performance was affected to a larger extent by orthographic information than for the Danish and English group. In the non-rhyme condition, by contrast, no main effect of orthographic congruency was found on response times, which is consistent with a recent study by Damian & Bowers (2009b). It has been argued that stimulus duration had a strong impact on response times in the present experiment. This factor, which was not addressed in the predecessor studies, is assumed to have reduced the significance level of the orthographic main effect especially for the Danish and English participants.

The question of whether orthography is activated during non-native language processing can be answered with a clear “yes”. Similar to orthographic effects in L1 auditory word recognition, it appears that strong links between orthographic and phonological forms of words have been established when the second language was learned. As divergent results were observed in the present experiment for German and Danish speakers of English, the strength of these links is likely to differ between non-native groups. Consequently, the data do *not* unequivocally support the assumption that (late) bilinguals have developed stronger connections between L2 phonological and orthographic units compared to native speakers as a consequence of the bilinguals’ simultaneous acquisition of spoken and written English during English lessons at school. While the assumption of stronger links is consistent with the data of the German group, it does not apply to the data of the Danish participants.

A closer inspection of the German and Danish data revealed that the German participants demonstrated the strongest orthographic influence whereas the orthographic effect observed for the Danish participants was similar in size to the native speakers of English. Two different explanations can be found for the different response patterns obtained for the German and Danish participants.

The first explanation that accounts for the difference between the German and Danish participants refers to different levels of English proficiency and experience. German and Danish participants were matched as closely as possible on English proficiency and experience. Moreover, the similar size of error rates (German: 5.9%; Danish: 6.6%) and mean response times (German: 998 ms; Danish: 1004 ms; in contrast to English: 932 ms) in the present experiment can be interpreted as evidence for a similar level of English proficiency. However, at this point, it cannot be completely excluded that differences in English proficiency and experience might have affected the magnitude of the orthographic effect. This explanation for the different size of orthographic effect between the German and Danish group will be discussed in section 6.2.

The alternative explanation refers to the transparency of the languages involved in this study. In contrast to the shallow orthography of German, the Danish and English languages are characterized by an inconsistent writing system. Due to their L1 orthographic background, Danish participants might be more familiar than German participants with processing conflicting information about spelling and pronunciation, such as orthographic inconsistencies at the rime level, as tested in the present task. For this reason, Danish participants might have demonstrated a smaller orthographic influence than the German participants. This assumption will be further discussed in section 6.3.

Taken together, Experiment 1 demonstrated that the findings of the landmark study on orthographic influences on auditory speech processing by Seidenberg & Tanenhaus (1979) were generally reproduced. The simple and straightforward method of this paradigm allowed a repetition of this task with non-native speakers. In contrast to the present experiment, Experiment 2 involved a more complex and challenging metaphonological task, which will be reported in the next section.

5.4 Experiment 2: Phoneme deletion task

Phoneme manipulation tasks, such as phoneme addition, deletion or reversal have been frequently used to measure the interface between orthographic and phonological structures in language processing (see section 2.3.1.2). Like the rhyme judgement task in Experiment 1, the phoneme deletion paradigm is a metaphonological task which involves explicit awareness of phonological units. However, in contrast to rhyme judgements, the present phoneme deletion task contains a perceptual and productive component and is *not* based on binary YES/NO-button decisions. Therefore, Experiment 2 investigates more complex and challenging processing skills compared to Experiment 1. Furthermore, rhyme judgements and phoneme deletion tasks differ in terms of the phonological unit of interest. While rhyme judgements focus on the awareness of rhymes, Experiment 2 investigates phonological units of smaller grain sizes, i.e. phonemes. Participants from deep orthographies have been shown to be more sensitive to manipulations of the rime level whereas participants from transparent orthographies are more sensitive to manipulations of the phoneme level (Goswami, Ziegler & Richardson, 2005). Given that the non-native participants of the present study differed with regard to the transparency of their orthographic L1 background, the phoneme deletion task might right reveal a different pattern of orthographic activation during non-native auditory word processing than the rhyme judgement task.

The present experiment is a replication of experiment 3 by Tyler & Burnham (2006), which was inspired by the phoneme manipulations tasks of the pioneering study by Morais, Cary, Alegria & Bertelson (1979). Hence, the present experiment resembles the experiment by Tyler & Burnham (2006) in basic design and procedure, though the stimulus list was slightly modified and adapted to the requirements of non-native participants.

Predictions

It was predicted that orthographic influences should be found both for native and non-native speakers of English, i.e. orthographically incongruent stimuli (e.g. *worth* - *earth*) should produce longer response times than congruent stimuli (e.g. *wage* - *age*). The size of the orthographic effect was expected to differ between the native and non-native participants as well as between the two non-native groups. It was expected that non-native participants should demonstrate a stronger orthographic effect than the English native speakers, with German participants displaying a stronger influence than the Danish participants.

5.4.1 Method

Participants

The same German, Danish and English participants who participated in Experiment 1 took part in this experiment.

Materials

Stimuli consisted of 18 congruent and 18 incongruent monosyllabic English words. For congruent items, deletion of the first phoneme as well as the first grapheme would lead to the correct response, e.g. <wage> minus <w> = <age>, <wage> minus /w/ = /eɪdʒ/ (*age*). Incongruent items, on the other hand, were constructed in such a way that only the removal of the initial phoneme would result in a correct response. Deletion of the first grapheme would result in an incorrect or ambiguous spelling of the response word, e.g. <worth> minus <w> = <orth>, but <worth> minus /w/ = /ɜːθ/ (*earth*). The to-be-deleted phoneme always occurred at initial position and was matched across congruent and incongruent items. The response word was always a real English word. A number of stimuli were taken from the original study by Tyler & Burnham (2006) but, similar to the stimulus list in Experiment 1, new stimuli were created, which were more suitable for non-native speakers of English (e.g. stimuli with low frequency counts, such as *froth*, *snort* or *smear*, were substituted by more frequent stimuli). The new stimulus list contained 42% of the original stimuli used by Tyler & Burnham (2006).

Similar to Experiment 1, stimuli were matched as closely as possible on relevant item-related variables (number of letters, number of phonemes, written and spoken word frequency, orthographic and phonological neighbourhood, stimulus duration), except for their orthographic congruency. Since response times were measured by a voice key, the participants' response words were also controlled for type of initial phonemes. It has been shown in several studies that inaccuracies in voice key measurements are related to different word-initial phonemes (e.g. Kessler, Treiman & Mullennix, 2002; Pechmann, Reetz & Zerbst, 1989; Rastle & Davis, 2002). For instance, Kessler, Treiman & Mullennix (2002) discovered that obstruents (plosives, affricates, fricatives) were detected more slowly by a voice key than sonorants (nasals, approximants, vowels) when occurring at initial position of the spoken stimulus. Moreover, voiced phonemes were detected faster than unvoiced ones. For this reason, all response words of the present experiment were controlled for type of initial phoneme (obstruent, sonorant) and voice (voiced, unvoiced). With regard to second phonemes, Kessler, Treiman & Mullennix (2002) discovered that front vowels produced longer response times than back vowels and high vowels longer response times than lower vowels. However, the present list of response words was only controlled for initial phonemes because half of the present response words began with a vowel and therefore did not contain another vowel as a second phoneme.

Finally, the preliminary stimulus list was checked for familiarity by the same group of non-native students of English as in Experiment 1. All items that were unknown to more than 30% of the students were excluded from the stimulus list.

Table 5.3 presents the characteristics of the stimulus materials used in Experiment 2. In addition to the 36 stimuli used in the main part of the experiment, 6 warm-up items (3 congruent, 3 incongruent) and 6 practice items (3 congruent, 3 incongruent) were generated. The full list of stimuli is presented in Appendix A. All stimuli were monosyllabic words with three to five letters and two to five phonemes.

Stimuli were spoken by the same male native speaker of British English as in Experiment 1 by using the same sound recording equipment. The duration of the stimuli was measured manually from the onset to the offset of the spoken stimulus with sound editing software.

Variable	congruent		incongruent	
	stimulus	response	stimulus	response
no. of letters	4.28 (.57)	3.28 (.46)	4.61 (.92)	3.61 (.70)
no. of phonemes	3.56 (.70)	2.50 (.71)	3.44 (.62)	2.44 (.62)
written frequency	151.28 (231.33)	195.22 (186.01)	141.61 (178.71)	122.33 (226.30)
spoken frequency	140.78 (324.08)	165.83 (206.33)	147.39 (290.32)	73.83 (173.52)
orthographic neighbourhood	7.83 (4.26)	9.67 (5.81)	6.00 (5.50)	8.00 (4.86)
phonological neighbourhood	17.00 (10.97)	27.61 (13.94)	19.44 (11.62)	29.50 (13.66)
stimulus duration (ms)	665.2 (61.5)	---	643.8 (68.4)	---
characteristics of initial phonemes:				
sonorants	---	15	---	15
obstruents	---	3	---	3
+ voice	---	15	---	15
- voice	---	3	---	3

Table 5.3. Stimulus characteristics of orthographically congruent and incongruent stimuli and response words (mean values, standard deviation in parentheses).

Apparatus

The experiment was conducted using an Acer Extensa 5630EZ laptop. Stimulus presentation, data collection and response recordings were controlled by the experimental software *Presentation* (Neurobehavioral Systems Inc.). Auditory stimuli were presented over headphones (t.bone stereo HD-990D). The onset of the participants' response was measured by a voice key which was integrated in the *Presentation* software. A high-quality headset microphone (Buchholz Acoustics & Electronics) was used to ensure that the distance between the participants' mouth and the microphone did not vary throughout the experiment. The validity of the voice key measurements was checked manually prior to the experiment by analyzing test data of 5 participants who did not participate in the actual experiment. Differences between voice key and manual measurements ranged from +55 ms to -6 ms, with only 10% of triggered responses exceeding a delay of 30 ms. This result was regarded to be well within an acceptable range of inaccurate triggers as found in previous comparisons of different types of voice key measurements (e.g. Belke, Katzberg, Schillingmann & Wrede, 2008; Rastle & Davis, 2002). All verbal responses were recorded in single .wav files for further analysis. Recordings started on the presentation of a stimulus and lasted for 5000 ms. Additionally, the whole testing session was recorded by an external digital recording device.

Design

As mentioned earlier, the experiment was integrated into a testing session with two other experiments (rhyme judgement, lexical decision). The order of experiments was counterbalanced across participants. Participants received the same items but in randomized order. Stimuli differed in terms of congruency, i.e. half of the stimuli were congruent (e.g. stimulus: *wage*; response: *age*), the other half incongruent (e.g. stimulus: *worth*; response: *earth*). Response times and error rates in the congruent and incongruent condition constituted the dependent variables. Similar to Experiment 1, language group (3) and order of experiments (6) were included in the data analysis as between-participants and within-items factors.

Procedure

Participants were tested in the same facilities as described for Experiment 1. The whole testing session consisted of three experiments in counterbalanced order (rhyme judgement, phoneme deletion, and lexical decision) and took approximately 35 minutes. The procedure of the present experiment was identical to experiment 3 of the study by Tyler & Burnham (2006). Participants were instructed to delete the first sound of the aurally presented word and say the response as accurately and quickly as possible. They were informed that the response word would always be a real English word. Moreover, they were told that their responses would be recorded and, for this reason, participants were instructed to avoid any extraneous sounds that could trigger the voice key. The experimenter used two examples (*gold* - *old*, *quite* - *white*) to explain the task. To make the nature of the task more clearly, six warm-up examples were presented over headphones. For the warm-up trials, participants did not have to give a response but pre-recorded correct responses were provided. The warm-up trials were followed by six practice trials. In these practice trials, participants were instructed to say the response word quickly and clearly in the microphone. None of the stimuli in the warm-up and practice trials were used in the main experiment. A short break after the practice trials and the main part of the experiment was used by the experimenter to check the voice key measurements and readjust the headset microphone, if necessary. The main part consisted of 18 congruent and 18 incongruent stimuli which were presented in randomized order. Each stimulus was followed by a silence of 5000 ms which gave the participant sufficient time for a response. After this interval the next trial was presented. Response latencies were measured from the onset of the presented stimulus to the onset of the participants' response. The computer screen turned blank during the experiment. All instructions were given in English. The experiment lasted for approximately 10 minutes.

5.4.2 Results

In the statistical analyses, all data were analyzed by participants (F1) and by items (F2) including congruency (2) as within-participants and between-items variable and language (3) as between-participants and within-items variable. The order of experiments (6) was included as a between-participants and within-items variable to make sure that the order of completing the experiments did not interact with any of the critical variables.

Error rates

The overall error rate in the phoneme deletion task was 9.2% (7.6%, 9.8% and 10.1% for the German, Danish and English participants, respectively). Some items which consisted of complex onsets caused high error rates across all three language groups because participants did not delete the first phoneme but the first two phonemes (e.g. *spy*, 28.9%, *still* 30.6% and *street* 36.7%).

Figure 5.5 shows the error rates broken down by congruency and language groups. Statistical analyses revealed a higher error rate for incongruent than for congruent items. Consequently, a main effect of orthographic congruency was yielded, which was significant by participants but not by items ($F1(1,171) = 11.35$, $MSE = 33.90$, $p < .001$; $F2(1, 34) = .37$, $MSE = 934.17$, $p = .55$).

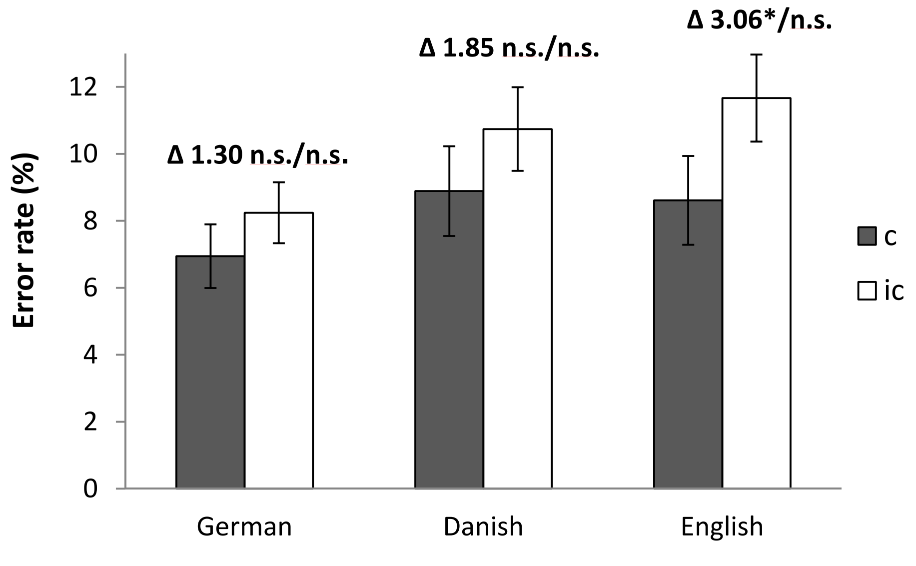

Figure 5.5. Error rate by language group for congruent (c) and incongruent (ic) items. Error bars represent one standard error. Levels of significance for the orthographic congruency effect in each group are based on individual analyses of variance of the error rates in each group (*** p < .001; ** p < .01; * p < .05).

Besides, a main effect of language group was found in the by-items but not in the by-participants analyses ($F1(2, 171) = 1.68$, $MSE = 136.83$, $p = .19$; $F2(2, 68) = 4.33$, $MSE = 47.91$, $p < .05$), with higher error rates for the Danish and English compared to the German participants. The interaction of congruency and language group was not significant. Task order had no significant influence on error rates and did not interact with any of the other variables.

Response times

Of all correct responses, 4.3% of the voice key measurements were corrected manually due to false triggers. Response times that deviated more than 2.5 standard deviations of the participants' mean of correct responses were excluded from the further analyses (2.7% in total, German: 2.5%, Danish: 2.4%, English: 3.1%). In order to control for the influence of stimulus duration on response times, analyses of covariance were carried out with stimulus duration as covariates. In the following, the results of the covariance analyses will be reported.

As would be expected, non-native speakers produced slower response times than native speakers. Moreover, in each of the three language groups, response times were faster for congruent than for incongruent items. Consequently, covariance analyses of the reaction time data revealed highly significant main effects of orthographic congruency ($F1(1, 170) = 1.29$, $MSE = 19886.97$, $p < .001$; $F2(1, 33) = 18.23$, $MSE = 148258.64$, $p < .001$) and language group ($F1(1, 170) = 5.19$, $p < .05$; $F2(2, 68) = 62.62$, $MSE = 16343.66$, $p < .001$). Figure 5.6 presents the mean response times broken down by congruency and language group with uncorrected means for the covariate stimulus duration.

The interaction of congruency and language group was significant in the by-participants analyses ($F1(2, 170) = 4.03$, $MSE = 19886.97$, $p < .05$) and by-items analyses ($F2(2, 68) = 3.57$, $MSE = 16343.66$, $p < .05$). As can be seen in Figure 5.6, the congruency effect was smaller in the English participants than in the German and Danish participants. No significant effect was found for the interaction between congruency and task order ($F1(2, 170) = 1.88$, $MSE = 19886.97$, $p = .156$; $F2(2, 68) = 3.05$, $MSE = 6571.19$, $p = .06$). The covariance analyses yielded a significant influence of the covariate (stimulus duration) on response times in both the by-participants and by-items analyses (F1(1,

170) = 3.99, MSE = 180728.40, $p < .05$; F2(1, 33) = 13.06, MSE = 148258.64, $p < .001$). However, the main effect of congruency and language groups were still significant.

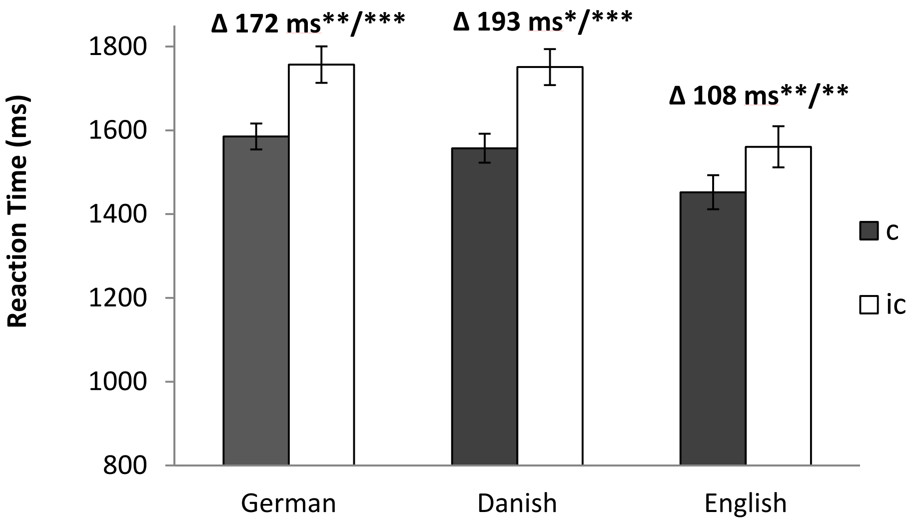

Figure 5.6. Mean reaction times (participant means) by language group for congruent (c) and incongruent (ic) items, uncorrected for the covariate stimulus duration. Error bars represent one standard error. Levels of significance in each group are based on individual analyses of covariance of the response times in each group (*** $p < .001$; ** $p < .01$; * $p < .05$).

Analyses of covariance with the data from pairs of language groups were carried out to explore the interaction of language group and congruency in more detail. These analyses showed a significant interaction of orthographic congruency and language group for the Danish and English groups (F1(1, 113) = 7.43, MSE = 15079.13, $p < .01$; F2(1, 34) = 5.01, MSE = 20492.20, $p < .05$) as well as for the German and English participants (F1(1, 113) = 5.37, MSE = 13315.16, $p < .05$; F2(1, 34) = 4.59, MSE = 14977.29, $p < .05$) but no significant effects between the German and Danish participants (F1(1, 113) = .35, MSE = 17845.52, $p = .56$; F2(1, 34) = .25, MSE = 13561.49, $p = .62$).

5.4.3 Discussion

The results demonstrate that native and non-native participants activated orthographic knowledge during performance of this auditory task. Overall, participants produced significantly longer response times and more errors to orthographically incongruent than to congruent stimuli. Hence, the results replicated the finding by Tyler & Burnham

(2006) with respect to English native speakers and, in addition, demonstrated orthographic effects for both non-native groups. In the next paragraphs, I will discuss the findings of the experiment in more detail. First, the results of the English native speakers will be discussed and compared to previous findings obtained for native speakers. Second, data of native and non-native participants will be compared before I will discuss the results of the German and Danish non-native speakers of English in more detail. Finally, the results of all language groups will be discussed with reference to possible explanations for the observed effects.

Native speakers of English

With respect to the English native speakers, clear significant orthographic effects were found in the pattern of response times. On average, congruent stimuli were responded to 108 ms faster than incongruent stimuli. It is noteworthy that the equivalent experiment in the original study by Tyler & Burnham (2006) yielded a much stronger facilitatory effect of orthographic congruency (380 ms). The finding that the orthographic effect in the present study is much smaller in size (but still significant) compared to the results of the original study is surprising. In addition, Tyler & Burnham (2006) also reported a considerably high overall error rate of 21.4%, which was more than twice as high as the error rate obtained for the English group in the present experiment (10.1%). Most probably, these differences can be explained by the adaptation of the original stimuli. Recall that only 42% of the original stimuli were involved in the present replication of the original task. Especially, those stimuli that produced substantially high error rates in the original study by Tyler & Burnham (2006), such as *quite* and *sphere*, were not used in the present experiment. For this reason, it is most likely that the considerable differences between the size of orthographic effect and overall error rate in the original study and my replication are due to a careful adaptation of the original stimulus list. As argued in the methods section above, this adaptation was considered necessary to make the task more suitable for non-native speakers of English. As a consequence, the general level of difficulty was slightly decreased, which resulted in smaller sizes of orthographic effects on response times and error rates for the English participants in the present experiment compared to the original study.

While the orthographic effect on response times reached significance in the analyses by participants and by items, this effect was only significant by participants in the analyses of error rates. The non-significant item-analyses suggest that English speakers were particularly inaccurate with some stimuli. A closer inspection of the response data revealed that English participants yielded considerably high error rates of more than 20% for six stimuli (*chart* (35.0%), *school* (21.7%), *sheet* (33.3%), *spy* (25.0%), *still* (21.7%), *street* (40.0%)).

A qualitative evaluation conducted on the error data of these stimuli showed that participants tended to delete more than the initial phoneme in words with complex onsets (*school*, *still*, *spy*, *street*). For instance, participants gave the response /u:l/ instead of /ku:l/ (*cool*) for the stimulus word *school*, /ɪl/ instead of /tɪl/ (*till*) for *still*, /aɪ/ instead of /paɪ/ (*pie*) for *spy* and /i:t/, /ri:t/ or /ri:d/ instead of /tri:t/ (*treat*) for the stimulus *street*. Overall, it became obvious that participants tended to make more errors with words that contained complex onsets compared to words starting with simple onsets. However, even within the group of complex-onset words, the stimuli *school*, *still*, *spy*, *street* produced higher error rates than other stimuli with complex onsets, such as *blast* (11.7%), *cloud* (8.3%), *crane* (5.0%), *crush* (8.3%), *swing* (10.0%), *slip* (5.0%), *sleep* (11.7%), *slow* (13.3%), *slam* (11.7%). It is suggested that the stimuli *still*, *spy* and *street* produced notably higher error rates compared to other stimuli with complex onsets because *still*, *spy* and *street* would result in a real English word even if the whole complex onset instead of the initial phoneme was deleted (*still* - *ill*; *spy* - *eye*, *street* - *eat*). By contrast, other complex-onset stimuli, such as *crane*, *crush* or *swing*, did not yield such high error rates because the deletion of the complex onset did not result in a real English word.

A similar explanation can be used to explain the high error rates for the stimuli *sheet* (33.3%) and *chart* (35.0%), which do not contain a phonological complex onset but start with a cluster of two consonantal letters. Concerning *sheet* and *chart*, a qualitative inspection of errors demonstrated that participants tended to delete the first letter instead of the first sound because the pronunciation of the response word would then correspond to a real English word, i.e. /hi:t/ *(heat*) for the stimulus *sheet* and /ha:t/ (*heart*) for the stimulus *chart*. Hence, participants obviously used an orthographic strategy to delete the initial phoneme of *sheet* and *chart* but unfortunately, the orthographic strategy brought them on the wrong track.

In sum, the results of the English participants replicated the orthographic effect found in the study by Tyler & Burnham (2006), even though the orthographic influence was much smaller than in the original study. The orthographic effect did not reach significance in the by-items analyses of error rates because the participants were particularly inaccurate with some stimuli. A qualitative inspection of errors revealed that those items which would result into real English words after the removal of the first letter or whole onset (instead of removal of the first phoneme) produced particularly high error rates. Given that a much higher error rate was observed for stimuli with complex relative to simple onsets, possible interactions between onset complexity and orthographic congruency were analyzed. The results of this analysis will be reported and discussed later in this section.

Native vs. non-native speakers of English

Having discussed the results of the English native speakers, I will now compare their performance to the results of the non-native participants. As expected, the orthographic effect was not limited to native participants but significant orthographic influences were also found for the two non-native groups. Both German and Danish participants demonstrated significantly longer response times for orthographically incongruent relative to congruent stimuli. The analyses of error rates revealed a similar pattern for German and Danish participants, with higher error rates for incongruent compared to congruent stimuli. However, the differences did not reach significance. Native and non-native task performance differed in two respects which will be discussed in the following.

First, English participants demonstrated faster response times than the non-native groups whereas their error rate (10.1%) did not differ significantly from the error rates of the Danish (9.8%) and German (7.6%) groups. It is quite surprising that the error rates between native and non-native participants did not differ in size although tasks on auditory speech processing are usually considered to be easier for native compared to non-native speakers due to their superior comprehension skills. However, the comparatively high error rates of the English participants might be due to a speed-accuracy trade-off. As outlined in section 5.2.1, increased speed might come at cost of accuracy. For this reason, it is possible that the substantially fast response times, which were in contrast to the results of the non-native participants, generated an increased error rate. Hence, a speed-accuracy trade-off is likely to reduce the difference in overall response times between the English and the non-native language groups.

As a consequence, the comparison of native and non-native task performance has to be treated with some caution. The pattern of response times suggests that both non-native groups demonstrated a significantly stronger orthographic effect on response times (German: 172 ms; Danish: 193 ms) than the English participants (108 ms). However, due to a possible speed-accuracy trade-off, it cannot be argued with certainty that non-native participants activated the orthographic code to a stronger degree than native speakers.

German vs. Danish non-native speakers of English

As already outlined above, both German and Danish participants' task performance was significantly affected by the activation of the orthographic code. Incongruent stimuli produced significantly longer response times than congruent stimuli. Contrary to my predictions, the size of the orthographic effect did not differ significantly between the German and the Danish group. Although the analyses indicated a difference in response times between the German (172 ms) and Danish (193 ms) group, this difference was not significant. This finding suggests that the activation of the orthographic code slowed down auditory speech processing of both non-native groups in a similar way.

Error rates displayed a similar pattern for both non-native language groups, i.e. higher error rates were found for incongruent than for congruent stimuli, but this difference did not reach significance. Interestingly, those stimuli that caused high error rates for the English native speakers (as discussed earlier) also posed difficulties for the non-native participants. As error rates illustrate, German and Danish participants had to struggle with the same stimuli to a similar extent than the English native speakers: *school* (German: 26.7%, Danish: 27.1%), *still* (German: 38.3%, Danish: 30.0%), spy (German: 28.3%, Danish: 33.3%), *street* (German: 40.0%; Danish: 41.7%), *sheet* (German:

8.3%, Danish: 28.3%), *chart* (German: 15.0%, Danish: 31.7%). In line with the performance of the English group, both non-native groups demonstrated similar types of qualitative errors for these stimuli, e.g. /ɪl/ instead of /tɪl/ (*till*) for *still* or /hi:t/ *(heat*) for the stimulus *sheet*. Moreover, consistent with the findings of the English group, the pattern of error rates for the German and Danish group suggests that stimuli with complex onsets produced higher error rates compared to stimuli with simple onsets. This assumption will be discussed further in the next paragraphs.

Concluding discussion

Overall, the results demonstrate that participants across all language groups produced longer response times and higher error rates for orthographically incongruent than congruent stimuli. This finding indicates that participants activated the orthographic code while performing this auditory task.

Interestingly, participants across all groups tended to make more errors for stimuli with complex onsets compared to stimuli with simple onsets. This finding was also established in the original study by Tyler & Burnham (2006). The assumption that onset complexity had an effect on participants' response data made the authors of the original study conduct an additional experiment in which all stimuli in the congruent and incongruent condition were matched for onset complexity. Although they found a significant main effect of onset complexity on error rates – which is in line with a study by Mann & Wimmer (2002) on phoneme deletion of American and German children – no effect was found on response times. Furthermore, the interactions between onset complexity and orthographic congruency were not significant.

Concerning the present experiment, complex and simple onsets were equally distributed over the congruent condition (9 complex-, 9 simple-onset stimuli) and nearly equally distributed over the incongruent condition (8 complex-, 10 simple-onset stimuli). However, across all language groups, participants showed about three times higher error rates for complex-onset stimuli than for simple-onset stimuli (overall: 14.1% vs. 4.7%; German: 12.6% vs. 3.1%; Danish: 15.1% vs. 5.1%; English: 14.8% vs. 5.9%). In order to test the effect of onset complexity on response data, the factor onset complexity (simple, complex) was included as a between-items and within-participants factor.

Consistent with Tyler & Burnham (2006), a main effect of onset complexity was found on overall error rates ($F1(1, 171) = 51.26$, $MSE = 312.81$, $p < .001$; $F2(2, 64) = 4.04$, $MSE = 50.46$, $p < .05$) but not on response times ($F1(1, 170) = .009$, $MSE = 120732.98$, $p = .92$; $F2(1, 32) = 10.23$, $MSE = 201440.63$, $p = .25$). Interactions between orthographic congruency and onset complexity were not significant for error rates ($F1(1, 171) = 1.12$, $MSE = 72.28$, $p = .29$; $F2(1, 32) = .47$, $MSE = 767.52$, $p = .83$) and only marginally significant for response times in the by-participants analyses ($F1(1, 170) = 4.02$, $MSE = 32908.01$, $p = .049$; $F2(1, 32) = .50$, $MSE = 201440.63$, $p = .48$). These analyses suggest that the main effect of orthographic congruency and the main effect of onset complexity appear to be independent of one another. Thus, the observed effect of orthographic congruency was not biased by onset complexity.

The overall result that orthographic representations affect performance in auditory phoneme deletion tasks is in line with previous findings obtained in tests with monolingual participants (e.g. Castles, Holmes, Neath & Kinoshita, 2003; Morais, Cary, Alegria & Bertelson, 1979; Tyler & Burnham, 2006). Similar to orthographic biases in rhyme judgements (Experiment 1), it is at first sight quite remarkable that a purely auditory task is not carried out by a purely phonological strategy but involves orthographic activation. In the original study by Tyler & Burnham (2006), two different explanations have been proposed which attempt to account for the interaction of orthographic and phonological codes during auditory metaphonological tasks. First and foremost, it has been hypothesized that phonemic awareness is a consequence of literacy acquisition in alphabetic orthographies (Ehri, 1980; Morais, Cary, Alegria & Bertelson, 1979; Read, Zhang, Nie & Ding, 1986). This explanation suggests that literate people performing phoneme manipulation tasks do not access phonemes directly via the phonological code of the stimulus but access phonemes by activation of the corresponding orthographic representations. Hence, “alphabetically literate individuals can perform well on phoneme manipulation tasks not because they are aware of phonemes, but rather because they have learned about speech sounds via their relationships with the letters that represent them in text” (Tyler & Burnham, 2006: 2023). Therefore, the hypothesis suggests that participants use an orthographic strategy to get access to the phonological structure of the stimuli.

The second possible explanation for orthographic activations in phoneme manipulation tasks refers to the interaction of conflicting information similar to a kind of Stroop effect. Although participants attempt to use a phonological strategy, mismatching information between phonological and orthographic units slows down language processing and makes it more prone to errors in the incongruent condition. Interestingly, several participants of the present experiment remarked that the phoneme deletion task reminded them of the Stroop effect because it was, at times, very difficult to suppress the conflicting orthographic information which was, as a student noted, “automatically visualized in the mind”.

As mentioned earlier, empirical evidence for the first explanation comes primarily from studies which demonstrated the superiority of literate people over illiterates in phoneme manipulation tasks (see also section 2.3.1.2). Nonetheless, it is difficult to argue whether phonemes are processed by activating the corresponding orthographic representations (as suggested in the first explanation) or whether a phonological strategy is used in phoneme manipulation tasks that is deeply affected by information about the spelling (as proposed in the second explanation). However, the increasing number of studies on this topic, including the present experiment and the rhyme judgement task in Experiment 1, has made it undoubtedly clear that the orthographic code is accessed during auditory metaphonological tasks even when the exact processes have not been clarified yet. What is clear is that both explanations presume the existence of connections between phonological and orthographic representations in the mental lexicon. Consequently, such links must have been established during literacy acquisition.

As the present results reveal, non-native speakers had developed strong links between the phonological and orthographic form of non-native words when they acquired their L2. Thus, similar to the native speakers, both L2 groups activated the orthographic representations during this auditory metaphonological task. The larger congruency effect obtained for both non-native groups compared to native participants appears to suggest that orthographic representations of spoken words are stronger activated for non-native than for native participants. It has to be noted, though, that a direct comparison between the results of the English native speakers and the non-native participants may be biased by a possible speed-accuracy trade-off observed for the

English group. Consequently, it is difficult to conclude whether both non-native groups demonstrated a stronger orthographic influence than the native speakers or whether the size of the orthographic effect was similar for all three language groups.

However, the response data reveal an interesting pattern concerning the comparison of the German and Danish non-native speakers. While Experiment 1 revealed a significantly different orthographic effect for German and Danish participants, the orthographic effect in the present experiment did not differ significantly between these groups. This finding suggests that non-native language processing of German and Danish participants was affected to a similar extent by the activation of the orthographic code in the phoneme deletion task. In contrast to Experiment 1, the present results suggest that different L1 orthographic backgrounds did *not* result in different processing strategies of phonological and/or orthographic units.

Recall from section 2.2.4.2 that the psycholinguistic grain size theory (PGST) proposes that participants from shallow orthographies are more familiar with processing small units whereas participants from deep orthographies developed processing strategies for both small- and large-unit processing. Thus, according to the PGST, similar results for the German and Danish group can be explained by a similar sensitivity to units of small grain size. Given that participants from both language groups were used to mappings between phonemes and graphemes, a similar orthographic effect was yielded.

It should be noted, though, that the present experiment was a considerably challenging and complex task about orthographic processing during auditory word recognition. Participants were instructed to delete the initial phoneme of the auditory stimuli. Consequently, the primary focus was on units of small grain size, i.e. phonemes and the corresponding graphemes. However, in the incongruent condition, presented stimuli and required response words also involved a manipulation on the rime level. For instance, after removal of the first phoneme, the stimulus *worth* resulted in the word *earth*, i.e. the phonological rime was spelled differently. As a consequence, the present task did not only investigate small-unit processing of grapheme-phoneme correspondences but also processing of body-rime units. Processing of body-rime units was, though, examined in a less explicit way than in rhyme judgement in Experiment 1 since the main focus was on the initial phoneme and not on the rime.

It is likely that both non-native groups demonstrated a similar size of orthographic influence because the present task involved a complex strategy of orthographic processing, which might have masked individual processes of small- and/or large-unit processing. The complex interaction of orthography and phonology comprised an explicit awareness of phonemes and, to a lesser extent, awareness of rimes. Therefore, the underlying processes that initiated the responses are too complex to get interpreted unequivocally by the PGST. Nevertheless, clear orthographic effects were observed which were considerably larger for all language groups compared to Experiment 1. This finding may indicate that explicit awareness on the phoneme level and at the same time less explicit focus on the rime level may have generated these strong orthographic effects.

Participants from all language groups mentioned the particularly challenging nature of this task. In addition to the complex processing strategy to form the correct response, the present task involved a productive component, i.e. participants were instructed to say the response word aloud as quickly as possible. The increased complexity and difficulty of the present experiment in contrast to Experiment 1 is reflected by the comparably high overall error rates and large orthographic effects in response times relative to Experiment 1 observed in all three language groups. For this reason, it can be argued that the increased complexity and difficulty of the task induced a considerably strong activation of the orthographic code. It is even likely that the English native speakers demonstrated a similar size of orthographic effect than the non-native groups. However, due to a possible speed-accuracy trade-off, the size of the orthographic effect in the native speakers' response times might be reduced.

Similar to the interpretation of Experiment 1, especially the comparison of the German and Danish task performance in the present experiment has to be treated with some caution. As noted earlier, differences in English proficiency level between two non-native groups are likely to affect patterns of language processing in psycholinguistic experiments. Thus, behavioural data of two non-native groups might be skewed by different proficiency levels. Nevertheless, as German and Danish participants demonstrated a similar pattern of language processing with respect to overall mean response times (German: 1671 ms; Danish: 1654 ms) and error rates (German: 7.6%;

Danish: 9.8%), it is likely that the observed differences are *not* due to different levels of English proficiency and experience. This topic will be further discussed in section 6.2.

In conclusion, the behavioural data collected in the phoneme deletion task provide straightforward evidence for the existence of orthographic effects in native and non-native auditory word processing. Mean response times for incongruent stimuli were significantly longer than for congruent stimuli in all three language groups. This finding indicates that correct responses by native and non-native participants were slowed down by orthographic incongruent information, which can be interpreted as a clear evidence for the activation of orthographic representations during performance of this auditory task. In contrast to Experiment 1, German and Danish non-native speakers of English demonstrated an equally strong orthographic activation, which was significantly stronger than the effect of the native English participants. However, the small effect observed for the native speakers of English might be due to a speed-accuracy trade-off. Furthermore, it has been argued that the present experiment required complex processing strategies given that the task involved explicit awareness of phonemes and also, though to a lesser degree, awareness of the rime level. German and Danish participants demonstrated a similar pattern of orthographic activation, which appears to be unaffected by characteristics of their L1 orthographic background. However, it is noteworthy that the complex and challenging nature of the task may have masked individual differences in orthographic processing between the German and Danish participants.

5.5 Experiment 3: Lexical decision task

In Experiment 1 and 2, the role of orthography during auditory word recognition was investigated in two different metaphonological tasks. Recall from section 2.3 that orthographic effects during monolingual spoken word processing are not restricted to metaphonological tasks but have been also demonstrated in tasks without metaphonological components. Especially the existence of the orthographic consistency effect suggests that orthographic interactions during auditory speech processing are not limited to auditory tasks that explicitly focus on phonological or orthographic units. Since its discovery by Ziegler & Ferrand (1998), the orthographic consistency effect has been reproduced in a number of studies with different paradigms and different languages (see section 2.3.2.2, for a review). However, this effect has not been tested in non-native speech processing. For this reason, Experiment 3 aimed at investigating the orthographic consistency effect with non-native speakers. The existence of the orthographic consistency effect in the present experiment would demonstrate that orthographic effects during non-native speech processing are not restricted to metaphonological tasks (as shown in Experiment 1 and 2) but can be considered a general effect in non-native spoken word recognition.

The present experiment replicates the landmark study on the orthographic consistency effect by Ziegler & Ferrand (1998) by using the same method, procedure and design. However, the original study was conducted in French. Therefore, a stimulus list with appropriate English stimuli was generated for the present experiment.

Predictions

It was predicted that the orthographic consistency effect, i.e. longer response times and more errors for orthographically inconsistent in contrast to consistent words, should be found for the English native speakers as well as for the non-native participants. Furthermore, I expected a stronger effect for the non-native compared to the native speakers of English. With regard to the non-native groups, it was predicted that the German participants should demonstrate a stronger orthographic bias than the Danish participants.

5.5.1 Methods

Participants

The same German, Danish and English participants who participated in Experiment 1 and 2 took part in this experiment.

Materials

The list of stimuli consisted of 50 monosyllabic English words and 50 monosyllabic nonwords. Half of the word stimuli were orthographically consistent, i.e. their rimes could be spelled in only one way (e.g. /ʌk/ may only be spelled <uck>), the other half was inconsistent, i.e. their phonological rimes could be spelled in multiple ways (e.g. /i:p/ can be spelled <eap> or <eep>).

Inconsistent and consistent English words were controlled for a number of relevant item-related variables which have been introduced in section 5.2.3, i.e. number of phonemes, number of letters, written and spoken word frequency, orthographic neighbourhood, phonological neighbourhood and stimulus duration. In line with Experiment 1 and 2, written and spoken word frequency were calculated by using the CELEX database (Baayen, Piepenbrock & van Rijn, 1993), calculations of orthographic and phonological neighbourhood were established by using WordGen (Duyck, Desmet, Verbeke & Brysbaert, 2004) and a database by DeCara & Goswami (2002), respectively. Since the CELEX lemma database did not contain frequency counts for the inflected words *dealt*, *taught* and *meant,* the spoken frequency of these stimuli was determined with reference to the value of the corresponding infinitive, i.e. *deal*, *teach* and *mean*. In addition, stimuli were controlled for number and frequency of “friends” and “enemies” as well as consistency ratios. *Enemies* are defined as words with the same phonological rime but a different spelling whereas *friends* are defined as words with the same phonological rime and the same spelling pattern (Ziegler & Ferrand, 1998). For example, the rime /aʊd/ is spelled as <owd> in the word *crowd* but as <oud> in the words *loud*, *proud* and *cloud*. This means, the word *crowd* has three enemies and no friend. All inconsistent words were chosen in such a way that the summed frequency of enemies was bigger than the summed frequency of friends (with exception of the word *type*, which has no friends but a greater frequency than all six enemies together). The number and frequency of friends and enemies were established using consistency calculations by Ziegler, Stone & Jacobs (1997), which were based on the Kučera & Francis corpus (1967) of American English. Given that native speakers of British English and primarily L2 speakers of British English were tested in the present experiment, stimuli that had different pronunciations in British and American English (e.g. *source* and *sauce* have the same pronunciation in British English but are pronounced differently in American English) were excluded from the stimulus list. Consistency ratios were calculated by dividing the number of friends by the number of friends and enemies. For consistent words, the consistency ratio is 1 whereas consistency ratios vary between 0 and 1 for inconsistent words.

Nonwords were selected from the ARC nonwords database (Rastle, Harrington & Coltheart, 2002). All nonwords were pronounceable, monosyllabic, orthographically legal English nonwords which were controlled for number of phonemes, number of letters, phonological neighbourhood, orthographic neighbourhood and stimulus duration. No consistency manipulation was performed on the nonwords.

Finally, the preliminary stimulus list was given to the same group of non-native students as in Experiment 1 and 2, who checked the words for familiarity. Stimuli that were unknown to more than 30% of the students were excluded from the item list. Table 5.4 lists the mean characteristics of the final stimuli broken down by consistent words, inconsistent words and nonwords. The full stimulus list is given in Appendix A.

Stimuli were spoken by the same male native speaker of British English as in Experiment 1 and 2 by using the same sound recording equipment. In line with the original study by Ziegler & Ferrand (1998), the acoustic duration of the stimuli was measured manually from the onset to the offset of the spoken stimulus. The mean word length for consistent stimuli was 617 ms (range: 470-765 ms) and 642 ms (range: 406-894 ms) for inconsistent stimuli. Due to this difference, stimulus duration was included as a covariate in the data analyses.

Variable	consistent words	inconsistent words	nonwords
no. of letters	4.24 (.83)	4.80 (.76)	4.66 (.59)
no. of phonemes	3.36 (.49)	3.44 (.65)	3.58 (.70)
written frequency	137.16 (147.57)	119.72 (126.56)	---
spoken frequency	157.60 (301.01)	190.96 (463.99)	---
orthographic neighbourhood	7.28 (5.40)	3.20 (3.57)	3.60 (3.40)
phonological neighbourhood	13.84 (8.12)	18.96 (13.24)	11.02 (7.86)
no. of friends	5.76 (4.57)	1.68 (2.70)	---
no. of enemies	---	9.40 (5.80)	---
frequency of friends	288.40 (430.96)	31.12 (53.48)	---
frequency of enemies	---	772.96 (928.58)	---
consistency ratio	1.00 (.00)	.13 (.17)	---
stimulus duration (ms)	616.9 (68.7)	641.6 (105.3)	647.5 (75.0)

Table 5.4. Stimulus characteristics of consistent words, inconsistent words and nonwords (mean values, standard deviation in parentheses).

Apparatus

As detailed previously, the experiment was conducted using the same hardware and software equipment as in Experiment 1 and 2, i.e. Acer Extensa 5630EZ laptop with experimental software *Presentation* (Neurobehavioral Systems Inc.). Stimuli were presented binaurally over headphones (t.bone stereo HD-990D). The left and right mouse buttons were used for button responses.

Design

The present experiment was part of a testing session which consisted of two other experiments (rhyme judgement, phoneme deletion). The order of experiments was counterbalanced across participants. Participants received the same stimuli but in randomized order. Response times and error rates for consistent and inconsistent words constituted the independent variables. Language group (3) and order of experiments (6) were included in the data analysis as between-participants and within-items factors.

Procedure

Participants were tested individually in the same facilities as described for Experiment 1 and 2. As previously mentioned, the whole testing session included 3 experiments (rhyme judgement, phoneme deletion, lexical decision) and took about 35 minutes including short breaks between the experiments. For the present experiment, the procedure was taken from the original study by Ziegler & Ferrand (1998). Stimuli were presented in randomized order binaurally over headphones at a comfortable listening level. Participants were instructed to decide as quickly and accurately as possible whether the presented stimulus was a real English word or not by pressing the “Yes” or “No” button (standard auditory lexical decision task). Response latencies were measured from the onset of the stimulus to the button response. Participants were given 20 practice trials (5 consistent words, 5 inconsistent words, 10 nonwords) consisting of items that were not used in the actual experiment. Each trial was followed by a 2000 ms interval. All instructions were given in English. No feedback was given. The computer screen turned blank during the experiment, which lasted for approximately 10 minutes.

5.5.2 Results

All statistical analyses were conducted by participants and by items, including language group (3) as between-participants and within-items variable, and consistency (2) as within-participants and between-items variable. In addition, the variable order of experiments (6) was included as a between-participants and within-items variable.

Error rates

An initial inspection of the data suggested that the overall error rate was quite substantial (7.8%; 11.8%, 8.4% and 3.2% for the German, Danish and English participants, respectively). It turned out that the high error rates were largely due to misclassifications of nonwords as words by the non-native speakers, as in *feave* (German group: 61.7%; Danish group: 55.0%), *brype* (40.0%; 73.3%) and *tauce* (60.0%; 38.2%). The error rates for the word stimuli were notably lower (overall: 3.0%; 3.5%, 3.3% and 1.8% for the German, Danish and English participants, respectively).

All analyses reported in the following were restricted to the data obtained for word stimuli. Figure 5.7 presents the error rates broken down by language group and consistency. As shown, non-native speakers produced more errors than native speakers. Overall, higher error rates were observed for inconsistent than consistent items. Statistical analyses of the error rates yielded main effects of orthographic consistency and language group by participants but not by items (orthographic consistency: $F1(1, 171) = 8.89$, $MSE = 10.12$, $p < .01$; $F2(1, 48) = .74$, $MSE = 153.01$, $p = .39$; language group: $F1(2, 171) = 6.13$, $MSE = 16.90$, $p < .01$; $F2(2, 96) = 2.95$, $MSE = 43.92$, $p = .06$). The interaction of consistency and language group was significant in both the by-participants and the by-items analyses ($F1(2, 171) = 20.75$, $MSE = 10.12$, $p < .001$; $F2(2, 96) = 5.98$, $MSE = 43.92$, $p < .01$). As shown in Figure 5.7, the consistency effect on error rates was considerably larger in the German group than in the Danish and English groups. Task order had no significant effect on error rates and did not interact with any of the other variables.

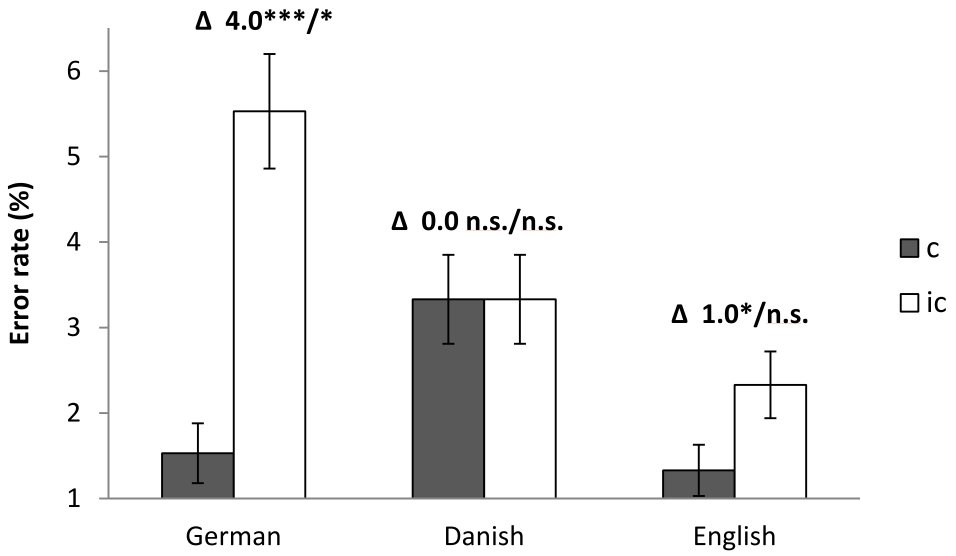

Figure 5.7. Error rate by language group for consistent (c) and inconsistent (ic) items. Error bars represent one standard error. Levels of significance for the consistency effect in each group are based on individual analyses of variance of the error rates in each group (*** $p < .001$; ** $p < .01$; * $p < .05$).

Response times

Response times that were shorter or longer than 2.5 standard deviations of the participants' mean of correct responses were excluded from the analyses (2.3% in total over all language groups; German: 2.3%, Danish: 2.4%, English 2.3%). As mentioned above, responses to nonword stimuli were not relevant for the investigation of orthographic consistency effects and will not be reported here. Similar to Experiment 1 and 2, it is likely that the absolute duration of the auditory stimuli influenced the response times. In order to control for this influence, analyses of covariance were conducted on response times, including stimulus duration as a covariate. If not reported otherwise, stimulus duration had no significant effect on response times and did not interact with any of the independent variables listed above.

Figure 5.8 presents the average response times, broken down by language group and consistency. As would be expected, the response times of the non-native speakers were slower than those of the native speakers. Moreover, as seen in Figure 5.8, response times were faster for consistent items than for inconsistent items in each of the three language groups. Accordingly, the overall statistical analysis yielded highly significant main effects of orthographic consistency ($F1(1, 170) = 25.26$, $MSE = 28696.93$, $p < .001$; $F2(1, 47) = 10.07$, $MSE = 55298.42$, $p < .01$) and language group ($F1(2, 170) = 4.77$, $MSE = 28696.93$, $p < .01$, $F2(2, 96) = 26.04$, $MSE = 5377.45$, $p < .001$) as well as a significant interaction of consistency and language group ($F1(2, 170) = 18.04$, $MSE = 1067.52$, $p < .001$; $F2(2, 96) = 4.79$, $MSE = 5377.45$, $p < .01$).[42]

The interaction between consistency and task order was neither significant in the participant analyses ($F1(2, 170) = 2.07$, $MSE = 1067.52$, $p = .13$) nor in the item analyses ($F2(2, 96) = 2.75$, $MSE = 1566.63$, $p = .07$). The by-items analyses established a significant influence of the covariate (stimulus duration) on response times ($F2(1, 47) = 9.04$, $MSE = 55298.42$, $p < .01$). However, as reported above, the main effect of consistency and the interaction of consistency and language groups were nevertheless significant.

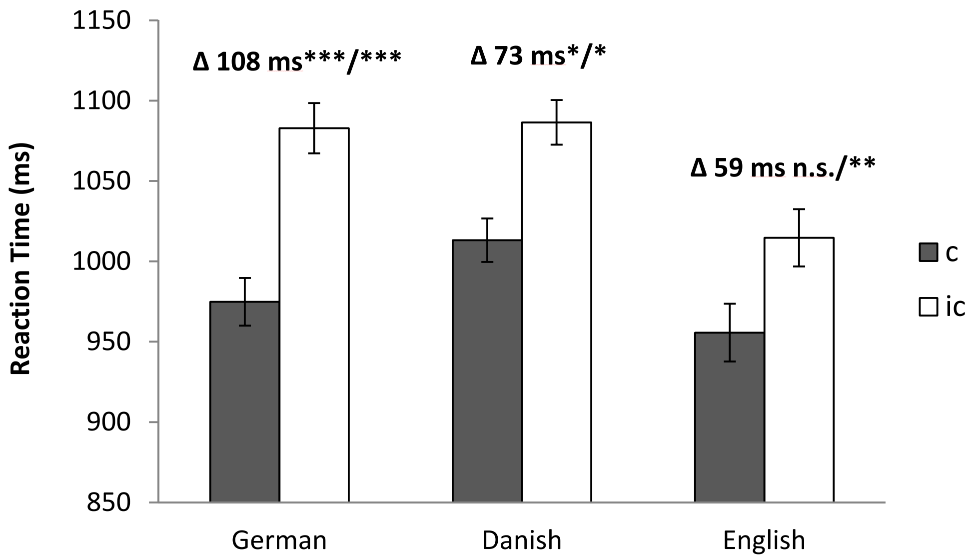

Figure 5.8. Mean reaction times (participant means) by language group for consistent (c) and inconsistent (ic) items, uncorrected for the covariate stimulus duration. Error bars represent one standard error. Levels of significance for the consistency effect in each group are based on individual analyses of covariance of the response times in each group (*** $p < .001$; ** $p < .01$; * $p < .05$).

[42] As shown in Figure 5.8, no significant consistency effect was found for the English speakers in the covariance analyses by participants. It should be noted, though, that the consistency effect for the English native speakers was highly significant in the analyses of variance without the covariate stimulus duration ($F1(1, 57) = 163.46$, $MSE = 638.96$, $p < .001$; $F2(1, 48) = 9.42$, $MSE = 14920.99$, $p < .01$).

In order to explore the interaction of language group and consistency further, analyses of covariance were carried out with the data from pairs of language groups. These analyses showed a highly significant interaction of orthographic consistency and language for the German and English groups ($F1(1, 113) = 35.84$, $MSE = 443.57$, $p < .001$; $F2(1, 48) = 7.69$, $MSE = 5894.89$, $p < .01$) as well as for the German and Danish participants ($F1(1, 113) = 14.57$, $MSE = 1777.75$, $p < .001$; $F2(1, 48) = 5.89$, $MSE = 5156.72$, $p < .05$) but no significant interaction for the English and Danish groups ($F1(1, 113) = 3.22$, $MSE = 485.04$, $p = .08$; $F2(1, 48) = .29$, $MSE = 5080.75$, $p = .59$). Task order did not show significant interactions in the pairwise comparisons.

5.5.3 Discussion

The results of the present experiment extend the findings of Experiment 1 and 2 by demonstrating that orthographic interactions during non-native auditory word processing are not restricted to metaphonological tasks. Instead, the existence of an orthographic consistency effect indicates that orthographic influences exist in paradigms that do not involve explicit awareness of phonological units, such as lexical decision. In the following, I will first discuss the results of the native speakers of English with reference to previous findings on the orthographic consistency effect. Thereafter, I will compare the data obtained for the native and non-native groups before I will discuss the performance of German and Danish non-native speakers of English. Finally, the results of all language groups will be discussed in a concluding discussion with reference to possible explanations.

Native speakers of English

Native speakers of English demonstrated longer response times and higher error rates for inconsistent compared to consistent stimuli. However, these differences were only significant in some of the statistical analyses. That is, differences in error rates reached significance in the by-participants analyses only whereas the observed differences in response times were only significant in the by-items analyses.

It is quite remarkable that English participants produced particularly low error rates for consistent and inconsistent stimuli in the present study, i.e. 2.3% vs. 1.3%. By contrast, the original study by Ziegler & Ferrand (1998) yielded error rates of 7.8% vs. 20.9% for consistent and inconsistent stimuli. Such high error rates were also obtained in a very recent study on the orthographic consistency effect with English native speakers by Dich (2011), i.e. 6.7% vs. 13.0%. However, other recent studies that examined the orthographic consistency effect found extremely low error rates (e.g. Pattamadilok, Knierim, Kawabata Duncan & Devlin, 2010; Ziegler, Petrova & Ferrand, 2008 (experiment 3)), which are in line with the size of error rates observed in the present study.

The reason for these large differences in error rates across studies has not been clarified yet. It appears that choice of stimuli and procedure varied substantially between some of the reported studies, which might have affected the size of error rates. Concerning the present study, although the error rates for consistent and inconsistent stimuli were extremely low, a significant main effect of orthographic consistency was found in the by-participants analyses. In contrast, other studies that found extremely low error rates did not yield a significant orthographic consistency effect for error rates but only for response latencies (e.g. Pattamadilok, Knierim, Kawabata Duncan & Devlin, 2010; Ziegler, Petrova & Ferrand, 2008 (experiment 3)). Thus, given a significant effect on response times, it can be argued that the effect on error rates is rather subsidiary for the existence of a general orthographic consistency effect, especially when error rates for consistent and inconsistent items are fairly low.

The pattern of response times in the present experiment revealed that response latencies in the consistent condition were on average 59 ms faster than in the inconsistent condition. The size of the orthographic effect is in line with previous findings obtained with English stimuli (Dich, 2011: 39 ms, Pattamadilok, Knierim, Kawabata Duncan & Devlin, 2010: 60 ms; Ziegler, Ferrand & Montant, 2008: 56 ms). However, this difference reached only significance in the analyses by items. This finding suggests that the consistency effect was not established for all participants. Indeed, only 53 out of 60 participants demonstrated, on average, longer response times for inconsistent than for consistent items. Recall that all analyses included the covariate stimulus duration. As noted in footnote 42, analyses of variances without the covariate established a highly significant effect in the analyses by participants and by items.

Hence, it can be suggested that stimulus duration masked the consistency effect in the covariance analyses.

Nevertheless, the results of the English group indicate that orthographically inconsistent words produced longer response times and more errors than orthographically consistent words, even though they only reached significance in one of the analyses, either by participants (error rates) or by items (response times). Thus, the results obtained for the native speakers of English suggest that the design and the stimuli of the experiment are generally appropriate for producing an orthographic bias on spoken word recognition of English stimuli.

Native vs. non-native speakers of English

In the motivation of selected tasks (see section 5.2.1), I have argued that a lexical decision task is a rather challenging task for non-native speakers of English because they have to decide whether the presented English stimulus is a real English word or not. Indeed, these concerns were confirmed during the testing sessions when non-native participants reported that they had been, at times, uncertain whether a presented stimulus was a nonword or a real English word that they simply did not know. Consequently, the overall error rate for non-native participants was considerably higher (German: 11.8%; Danish: 8.4%) compared to the English group (3.2%). It is noteworthy that the high error rates for the non-native groups were primarily due to misclassifications of nonwords as words. In contrast, non-native participants detected English words with high accuracy, i.e. corresponding error rates for word stimuli were quite low for all language groups (German: 3.5%, Danish: 3.3%; English: 1.8%).

However, a closer inspection of the distribution of error rates broken down by language group and orthographic consistency revealed that error rates were unevenly distributed across conditions and languages. While the English native speakers demonstrated more errors for inconsistent than for consistent words (as described above), the effects obtained for non-native participants demonstrated an ambivalent pattern. The German group displayed a large and highly significant difference between low error rates for consistent and considerably high error rates for inconsistent words whereas Danish participants produced exactly the same size of error rates in both conditions.

In spite of this ambivalent finding, the question of whether an orthographic consistency effect has been found in non-native auditory speech processing can be answered with a clear “yes” for both non-native groups. Similar to the English participants, both non-native groups produced significantly longer response times for inconsistent compared to consistent words. Therefore, a significant orthographic consistency effect was found on response times of both German (108 ms) and Danish (73 ms) non-native speakers of English.

Taken together, significant orthographic influences were found for both non-native groups in Experiment 3. Keep in mind that orthographic effects on non-native speech processing have been also demonstrated in Experiment 1 and 2. However, in contrast to the previous experiments, the present task did not draw the participants’ attention to the spelling or pronunciation of the words in any obvious ways. Therefore, the observed orthographic influence in the present experiment can be interpreted as a general effect on non-native auditory speech processing, which is not restricted to auditory tasks with metaphonological components. In addition, in contrast to Experiment 2, both non-native groups did not display a congruent pattern of orthographic influences but demonstrated significantly different orthographic effects that will be discussed in the following.

German vs. Danish non-native speakers of English

The differences between the two non-native groups outlined in the preceding paragraphs require some further examination. As described above, an orthographic consistency effect was found on response times in both non-native groups, but the size of the effect differed between these groups. In line with Experiment 1 but in contrast to Experiment 2, the German participants demonstrated the strongest orthographic effect with a difference in response times of 108 ms, which was significantly different to the effect of the Danish (73 ms) and English (59 ms) group. In agreement with these findings, the German participants also produced a large and significant effect on error rates whereas Danish participants did not show an effect on error rates at all. Therefore, consistent with Experiment 1 of the present study, the data suggest that the size of the orthographic impact varies across non-native groups. Interestingly, the size of the orthographic effect on response times observed for the Danish participants did not differ significantly from the results of the English participants. Thus, the findings obtained for the German and Danish participants can be summarized as follows: While the German group displayed a strong orthographic consistency effect which differed significantly from the effect established for the Danish and English groups, the Danish participants demonstrated an orthographic consistency effect that was similar in size to the English native speakers.

Concluding discussion

The present findings provide the first evidence for the existence of the orthographic consistency effect in non-native auditory word processing. Hence, activation of orthography is not restricted to metaphonological tasks (as investigated in Experiment 1 and 2) but can also be established in tasks without metaphonological components. This finding clearly supposes the existence of links between orthography and phonology that are accessed during spoken L2 word recognition. Furthermore, Experiment 3 confirms the finding of an orthographic consistency effect for English native speakers, as observed in previous studies (Dich, 2011; Pattamadilok, Knierim, Kawabata Duncan & Devlin, 2010; Ziegler, Petrova & Ferrand, 2008).

As detailed earlier, the present task did not explicitly focus on phonological units and/or the corresponding orthographic representations. Consequently, it is quite remarkable that the orthographic code is activated even though it is not for the benefit of the participant. This means, language processing is slowed down for words that contain inconsistently spelled rimes in contrast to words with consistently spelled rimes. A possible explanation for this finding is that a phonological rime that can be spelled in multiple ways activates several corresponding orthographic representations. In order to resolve this conflict, more processing time is needed compared to a rime with only one possible spelling. Although the benefit of this processing mechanism is unclear, the present finding demonstrates that such a mechanism of orthographic processing has to be integrated in models of native and non-native auditory word recognition.

In line with Experiment 1, the present findings reveal that the group of German non-native speakers of English demonstrated the strongest orthographic influence whereas Danish and English participants showed an orthographic consistency effect of a similar magnitude. Given that the present experiment is the first investigation of an orthographic consistency effect in non-native speech processing, the present results cannot be compared to a similar study. However, a cross-linguistic L1 study by Pattamadilok, Morais, Ventura & Kolinsky (2007) appears to be of particular interest for the interpretation of the present results. This study, which is considered the only cross-linguistic investigation on the orthographic consistency effect available so far, involved an auditory lexical decision task with French and Portuguese stimuli and L1 participants of the respective languages. Recall from section 2.3.3 that the authors expected that Portuguese participants would be more affected by orthographic manipulations than French participants due to the considerably shallow orthography of Portuguese compared to French. Contrary to their assumptions, though, they found a smaller orthographic consistency effect in auditory lexical decision with Portuguese stimuli and participants (52 ms) compared to French stimuli and participants (69 ms). It is noteworthy that their study did *not* investigate non-native language processing and, therefore, the results cannot be directly compared to the present study. Nonetheless, the study demonstrated that a language's orthographic consistency appears to affect the magnitude of the orthographic consistency effect in auditory speech processing.

Although the investigation by Pattamadilok and colleagues cannot be directly compared to the present study, their results demonstrated an interesting counter-intuitive direction of the orthographic consistency effect dependent on the transparency of a language's orthography. However, this direction is in contrast to the present findings described for the German and Danish non-native speakers of English. While a *smaller* orthographic influence was found for Portuguese (relatively shallow orthography) compared to French (deep orthography), the present findings demonstrate a *stronger* orthographic effect for German L2 participants (shallow orthographic background) relative to Danish L2 participants (deep orthographic background).

Concerning the present data, a possible explanation for the different sizes of the orthographic consistency effect between the German and Danish group may refer to the different orthographic backgrounds of their first languages. Similar to the finding by Pattamadilok, Morais, Ventura & Kolinsky (2007), it can be assumed that participants who were raised in shallow or deep orthographies developed distinct processing strategies during literacy acquisition in their first language which shaped their sensitivity to inconsistent mappings between orthography and phonology. As the present data suggest, these processing strategies are then transferred from native to non-native language processing.

With reference to the psycholinguistic grain size theory, the data assume that German participants coming from a transparent orthographic background are more prone to spelling-to-sound inconsistencies of larger grain sizes, i.e. body-rime inconsistencies, because such inconsistencies rarely occur in the transparent German orthography. By contrast, Danish participants seem to be less influenced by orthographic inconsistencies on the rime level given that they had become familiar with inconsistent units of larger grain size during literacy acquisition in their first language. The hypothesis that the consistency of the L1 orthographic background affected orthographic processing in the non-native language will be further discussed in section 6.3.

An alternative explanation suggests that the different sizes of orthographic influences between the German and Danish performance might be due to different levels of English proficiency and experience. Especially, since the Danish participants demonstrated a consistency effect which was of similar size as the effect found for the English native speakers, it is likely that the Danish non-native participants had a higher level of English proficiency than the German non-native participants. Recall that both non-native groups were matched as closely as possible on their English proficiency level and experience. Nevertheless, a possible influence of different proficiency levels cannot be completely excluded. For this reason, a detailed discussion of the impact of different levels of language proficiency on the results of all three tasks will be provided in section 6.2.

5.6 Analyses of task performance in lexical decision as an indicator of English proficiency

In section 5.2.3, it has been argued that task performance of non-native participants in lexical decision tasks can be used as an indicator of language proficiency. For this reason, error rates and response times collected for the German and Danish non-native speakers of English in Experiment 3 were compared in order to evaluate their language proficiency from an objective point of view.

When task performance in lexical decision is used as a measure of foreign language proficiency, it is primarily of interest how many words non-native participants detected correctly. For this reason, the overall error rates by language group in lexical decision are typically divided into error rates for words (i.e. how many words were not correctly recognized) and error rates for nonwords (i.e. how many nonwords were not correctly recognized). Table 5.5 displays an overview of the different error rates in the present lexical decision task, broken down by L2 language group.

	German		Danish	
overall % errors	11.8	(11.3)	8.4	(7.8)
% errors in word detection	3.5	(3.3)	3.3	(3.2)
% errors in nonword detection	20.0	(10.5)	13.4	(7.8)

Table 5.5. Mean error rates in lexical decision task by language group (standard error in parentheses).

Nonword detection is a rather challenging task for non-native speakers because nonwords used in lexical decision tasks, such as Experiment 3, are usually orthographically and phonologically legal nonwords (pseudowords) that resemble real words in phonological and orthographic structure. Consequently, non-native participants are often unsure whether a nonword stimulus is a nonword or whether it is a real word of the target language that they have not encountered yet. For this reason, non-native speakers are likely to rely on a “guessing strategy” during nonword detection. The error rate for nonwords is, therefore, a less adequate measure of language proficiency than the error rate for words. Error rates in word detection measure whether the stimulus is present in the non-native speaker’s mental lexicon, which is a more suitable measure of language proficiency. With reference to the present data, an independent t-test between the mean error rates for word stimuli of the German (3.5%) and Danish (3.3%) participants revealed no significant difference ($t1(118) = .34$, $p = .74$; $t2(98) = .18$, $p = .85$).

In addition to error rates, response times in lexical decision are considered to reflect language proficiency, i.e. highly proficient non-native speakers tend to display faster response times in lexical decision than less proficient speakers (see section 5.2.3.1). Therefore, the overall mean response times of German (1159 ms) and Danish (1149 ms) participants collected in Experiment 3 were compared to investigate whether a significant difference could be established. However, an independent t-test did not reach significance ($t1(238) = .39$, $p = .70$; $t2(198) = .14$; $p = .89$). Taken together, analyses of error rates and response times in lexical decision suggest that the proficiency levels of German and Danish participants did not differ significantly.

As argued in section 5.2.3.1, self-assessed ratings of L2 proficiency are assumed to correlate with error rates and response times in lexical decision. For this reason, correlation analyses were calculated with the factors self-reported English proficiency level and the factors error rate and response times in lexical decision. Results revealed no significant correlations between the factors proficiency level and error rate for the German ($r = -.146$, $p = .13$) and Danish participants ($r = -.081$, $p = .27$). However, different results were found in the analyses of proficiency level and response times. Correlations between these factors were not significant for the German participants ($r = -.011$, $p = .47$) but reached significance for the Danish group ($r = -.217$, $p = .048$). Taken together, these findings suggest that German and Danish participants tended to over- or underestimate their self-estimated proficiency level because their proficiency data did not correlate with the objective measures of error rates and response times in lexical decision. Consequently, the significant difference in self-reported English proficiency level between the German and Danish groups should not be over-interpreted.

In conclusion, the analyses of task performance in lexical decision did not reveal significant differences between error rates and response times of German and Danish non-native speakers of English. These findings suggest that two homogenous groups of non-native speakers with similar proficiency levels participated in the experiments. Nevertheless, it is noteworthy that this finding is in contrast to the significant difference observed in the self-assessed proficiency levels in the questionnaire (for details, see section 5.3.1). However, correlation analyses revealed that participants might have over- or underestimated their self-reported proficiency levels. The implications of these findings for the interpretation of the orthographic effects in the present study will be discussed further in section 6.2.

6 General discussion

The findings of the empirical investigation provide an interesting insight into the interactions of phonological and orthographic representations during non-native auditory word recognition. In the general discussion of the results, I will first provide a summary of the main findings obtained in the reported series of experiments. The findings will be discussed with reference to two possible explanations, i.e. the role of L2 proficiency and experience and the influence of the participants' L1 orthographic background. Finally, I will discuss the present findings in light of the working model of bilingual word recognition and suggest implications for foreign language learning and teaching.

6.1 Summary of main findings

The present study explored orthographic effects in non-native auditory language processing. Three different experiments on auditory language processing were conducted to answer the question of whether non-native speech processing is affected by orthographic activation (research question 1). Furthermore, it was investigated whether differences between orthographic activation of native and non-native speech processing (research question 2) as well as differences between two non-native groups with deep and shallow orthographic background (research question 3) could be observed. These questions were explored by repeating three landmark studies on orthographic influences on auditory speech processing. Participants consisted of German and Danish proficient non-native speakers of English and a control group of English native speakers.

Experiment 1 repeated the auditory rhyme judgement task by Seidenberg & Tanenhaus (1979) with German and Danish non-native speakers and a control group of native speakers of English. Orthographic effects were observed for all three language groups in the rhyme condition, i.e. orthographically congruent rhymes facilitated response times compared to orthographically incongruent rhymes. However, the German participants demonstrated the strongest orthographic activation. The orthographic effect observed for the Danish participants was similar in size to that seen in the native speakers of English. Two different explanations were proposed for the different response patterns obtained for the German and Danish participants. The first explanation suggests that the different sizes of orthographic influences between the German and Danish participants are due to different levels of English proficiency and experience. Alternatively, it has been suggested that the transparency of the German and Danish participants' first language, i.e. whether participants were raised in a deep orthography (Danish) or a shallow orthography (German) affected the degree of orthographic activation during L2 auditory word recognition. While Danish participants were familiar with processing orthographically inconsistent units of larger grain sizes, such as rimes, from their L1, German participants did not develop a processing strategy for inconsistent rimes during literacy acquisition in their L1. These differences in orthographic processing might have resulted in the findings observed.

Experiment 2 repeated a phoneme deletion task by Tyler & Burnham (2006). Strong orthographic effects were established for all three language groups, i.e. orthographically incongruent stimuli produced larger response times than congruent stimuli. Both German and Danish participants showed a strong orthographic influence of a similar size. In contrast, the control group of native speakers of English was less affected by the spelling than the two non-native groups. However, the small orthographic influence observed for the English group might be affected by a speed-accuracy trade-off. Given that the experiment focused on the awareness of the initial phoneme and also involved a manipulation of the rime, this task was regarded a considerably complex and challenging one. Compared to Experiment 1, it was argued that the increased complexity and difficulty of the task induced a notably stronger activation of the orthographic code for all three groups, but especially for the non-native groups.

While Experiments 1 and 2 involved metaphonological tasks that explicitly focused on the awareness and manipulations of phonological units (and their corresponding orthographic representations), Experiment 3 did not contain metaphonological components. By repeating the landmark study by Ziegler & Ferrand (1998), it was investigated whether the orthographic effects observed in Experiments 1 and 2 were restricted to paradigms with a metaphonological component or could be observed as general effects in non-native auditory word recognition. Participants from all language groups showed longer response times for words that contained inconsistently spelled rimes than for words with consistently spelled rimes. In terms of the size of this effect, the results revealed a similar pattern compared to Experiment 1, i.e. the group of German participants demonstrated the strongest orthographic consistency effect whereas the effect seen in the Danish group was smaller and did not differ from the effect seen in the English participants. Consistent with Experiment 1, differences in English proficiency and experience between the German and Danish participants may have resulted in the different degree of orthographic activation. The alternative explanation suggests that Danish participants were more familiar with inconsistencies of larger phonological units, such as rimes, due to the deep writing system of their L1 whereas German participants were less familiar with inconsistencies on the rime level due to the transparent orthography of German. Consequently, the transparency of the L1 orthographic system may have affected orthographic activation in a second language.

With reference to the research questions outlined above, it can be concluded that orthographic information is recruited during non-native speech processing, not only in metaphonological tasks (Experiments 1, 2) but also in tasks that are not metaphonological in nature (Experiment 3). Differences in orthographic activation between non-native and native speech processing were found in Experiment 2. However, non-native participants did not demonstrate a uniform pattern of results in Experiments 1 and 3. The pattern observed for the German and Danish groups rather suggests that the degree of orthographic activation depends on different levels of English proficiency and experience between the German and Danish participants or, alternatively, the orthographic transparency of the participants' first language. In the following sections, I will evaluate and discuss these explanations on the basis of the results from all three experiments.

6.2 Effects of L2 proficiency and experience on present findings

Comparisons of non-native language processing between different L1 groups require careful selection and matching of participants. As argued in section 5.2.3, special emphasis has to be placed on comparable levels of L2 proficiency and experience when language processing of bilinguals is compared. In the present investigation, English language proficiency and experience were measured by a questionnaire in order to match German and Danish non-native speakers of English as closely as possible on these factors. In this section, I will discuss to what extent the German and Danish participants of the present study were successfully matched on English language proficiency and experience. Furthermore, I will evaluate whether effects of different levels of language proficiency might have biased the results of the experiments.

Recall from section 5.2.3 that the term language experience is used to refer to the participant's language history and the exposure and frequency of usage of that language in the participants' everyday lives. On the whole, the data of the background questionnaire demonstrated that German and Danish participants shared a similar language history. As outlined in section 5.3.1, all participants were raised as monolinguals who started to learn English as a foreign language at primary or secondary school and attended on average 9.2 years of English lessons at school. Furthermore, approximately the same number of participants had stayed in an English-speaking country for longer than six months (German: 26.7%; Danish: 28.3%). However, the groups differed with respect to the regular usage of English in their everyday lives. Danish participants reported a significantly higher number of hours per week reading English texts (e.g. books, magazines) and listening to native speakers of English (e.g. on radio / TV / in personal communication) than German participants. Given that the overall community of native speakers of Danish with its approximately 5.3 million speakers is particularly small in contrast to the community of native speakers of German with approximately 95.4 million speakers (Gordon, 2005), it is obvious that English as a foreign or second language plays a more prominent role in the everyday lives of Danish speakers. Consequently, the prominence of the English language for Danish speakers was reflected in the data collected by the questionnaire.

In addition to the higher exposure to English in their everyday lives, Danish participants also reported watching English films with L1 or L2 subtitles more frequently than the

German group. This finding is of particular interest in light of the present study since watching films with subtitles involves auditory speech processing with simultaneous presentation of the orthographic form. This might establish strong links between the orthographic and phonological representations of words in the mental lexicon, which are likely to produce strong orthographic effects during auditory word recognition. However, the behavioural data of the experiments demonstrated significantly stronger orthographic effects for the German relative to the Danish participants in two out of three experiments. This pattern of results indicates that a higher exposure to English films with subtitles does *not* induce stronger links between orthography and phonology.

So far, the analyses of the language experience data reveal an appropriate but not perfect match of German and Danish non-native speakers of English on important aspects of language experience. Note that a comprehensive match of participants on all relevant factors was not possible. Nevertheless, the data suggest that the German and Danish participants formed a relatively homogenous group in terms of language experience. I will now take a closer look at the proficiency levels of the two non-native groups.

English language proficiency was measured by self-assessment on a 10-point scale ranging from 0 (no proficiency) to 10 (native speaker proficiency). In the present investigation, similar proficiency levels were established for German (average value: 7.67) and Danish (average value: 8.15) non-native speakers of English. Although these levels appeared to be quite similar, a significant statistical difference was established (see section 5.3.1). Without doubt, self-ratings tend to be subject to participants' over- or underestimating their proficiency level. This means that data collected by self-assessment have to be evaluated critically in the framework of further indicators of language proficiency and language experience. As argued in section 5.2.3, error rates and response times in lexical decision are considered objective indicators of language proficiency level. For this reason, inference statistical tests were performed on error rates and response times in lexical decision. However, the analyses did not reveal significant differences in English proficiency between the German and Danish non-native speakers of English (see section 5.6). Moreover, as also discussed in section 5.6, self-reported proficiency levels did not correlate with error rates or response times in lexical decision.

In addition to the analyses of response data in lexical decision, correlation analyses were also calculated for the factors self-rated proficiency level and response times in rhyme judgement and phoneme deletion, respectively. These analyses did not reach significance in rhyme judgement (German: $r = .093$, $p = .24$; Danish: $r = -.071$, $p = .27$). The only significant correlation was found in phoneme deletion for the Danish participants ($r = -.319$, $p = .007$) whereas the correlation was not significant for the German group ($r = -.168$, $p = .10$). This finding confirms the assumption that German and Danish participants might have over- or underestimated their self-reported proficiency level of English (as already argued in section 5.6).

Taken together, a critical evaluation of the self-reported language experience and proficiency data suggests that German and Danish participants were closely matched on most but not all relevant factors. Although both groups of participants had received English lessons for approximately the same number of years and had started to learn English at a similar age, i.e. after literacy onset in their native language, data on English usage in everyday lives suggest that Danish participants appear to be more experienced non-native speakers of English than the German participants. This assumption is consistent with a significant difference in self-reported proficiency levels of the German and Danish group. However, objective indicators of language proficiency, i.e. analyses of error rates and response times in lexical decision, suggest similar levels of English proficiency for both groups. Hence, at this point, it cannot be completely ruled out that different results between the German and Danish groups might be due to different levels of English proficiency or experience. For this reason, I will now discuss to what extent the results of the three experiments in the present study may be influenced by different levels of English proficiency or experience rather than different orthographic backgrounds.

In the present study, different magnitudes of orthographic effects were found for the German, Danish and English language groups. Across all tasks, the English participants demonstrated the smallest orthographic activation. In contrast, German participants demonstrated the strongest orthographic influence in two out of three experiments, whereas the Danish group demonstrated an orthographic effect in two out of three tasks which was similar in size to the effect of the native speakers of English. The distribution of different sizes of orthographic effects across experiments might suggest that the size of the orthographic effect is likely to correlate with the English proficiency level. To be more precise, given that German non-native speakers of English displayed a considerably stronger effect than English native speakers, effect size appears to be negatively correlated with language proficiency of English. That is, more proficient speakers might be less influenced by the spelling than less proficient speakers.

This hypothesis was tested by correlation analyses calculated individually for each experiment with the factors orthographic effect size (measured as differences in response times) and self-assessed proficiency and experience data from the questionnaire (i.e. English proficiency level (0-10), regular English reading, listening and speaking experience, measured in hours per week). However, no significant correlations were established between language proficiency and orthographic effect size for rhyme judgement ($r = .025$, $p = .39$), phoneme deletion ($r = -.075$, $p = .21$) and lexical decision ($r = -.08$, $p = .19$). Consistent with this finding, correlations of the size of the orthographic effect and reading, listening and speaking experience did not reach significance either. As discussed earlier, self-reported proficiency data do not provide objective measures of language proficiency. For this reason, correlation analyses were recalculated with the factor error rate in lexical decision as a more objective indicator of L2 proficiency. Nevertheless, results revealed no significant correlations between the size of the orthographic effect and error rate in lexical decision for German and Danish participants in rhyme judgement ($r = .087$, $p = .12$), phoneme deletion ($r = .125$, $p = .09$) and lexical decision ($r = .023$, $p = .38$). Thus, the results of the correlation analyses support the assumption that the systematic distribution of various sizes of orthographic activations across experiments is *not* related to different levels of English language proficiency.

In conclusion, although the self-reported proficiency ratings revealed that German and Danish participants differed to some extent in terms of English language proficiency and experience, there is evidence that these factors are unlikely to account for the differences in the size of the orthographic effects across groups and experiments. The observed differences in orthographic activation between German and Danish participants appear to indicate different processing mechanisms for mappings between orthography and phonology as a result of L1 literacy acquisition in a deep or shallow orthography. Nevertheless, this conclusion has to be treated with some caution. It cannot be completely excluded that non-native groups differed in a factor which has not been properly controlled. This factor may be language proficiency or a factor that has not been taken into consideration in the present study. However, the evaluation of the present data strongly suggests that language proficiency and experience did not cause fundamental differences in language processing between German and Danish speakers of English, which might have affected the present results. In other words, the results support the alternative explanation that the differences in orthographic activation between German and Danish participants discussed above are related to distinct processing strategies for orthographic units. As both groups differed in terms of orthographic background in their L1, it appears that literacy acquisition in a language with a deep or shallow orthographic system shaped the way orthographic information is processed in non-native auditory word recognition. This explanation will be discussed further in the next section.

6.3 The role of orthographic transparency

If we assume that the differences in orthographic activation between the German and Danish non-native speakers are not causally linked to different levels of English proficiency and experience (as discussed in the previous section), the alternative explanation would suggest that the transparency of the L1 orthographic background affected orthographic processing in non-native spoken word recognition. This assumption will be discussed in more detail in the following.

First of all, it has to be emphasized that the present data do *not* suggest that non-native participants demonstrated the same overall pattern of orthographic activation in all three tasks, which differed from the pattern of native speakers. In other words, the data do *not* confirm the hypothesis that stronger connections between orthographic and phonological representations are established for non-native compared to native speakers as a consequence of the L2 speaker's simultaneous acquisition of spelling and pronunciation of English words during institutional English learning. Although the German participants demonstrated a stronger orthographic effect than the English participants across all three experiments, an analogous pattern was not found for the comparison between Danish and English participants. Rather, a cross-language comparison between the performance of the German and Danish participants revealed that different sizes of orthographic effects found for the German and Danish participants in Experiments 1 and 3 are likely to be due to the participants' L1 orthographic backgrounds. Thus, it appears that the degree of orthographic recruitment was modulated by the transparency of the L1 orthographic system. I will now discuss this assumption in more detail.

Given that the Danish and English languages are characterized by highly inconsistent correspondences between orthography and phonology, which is in contrast to the German orthography, the data suggest that people raised in a shallow orthography are more sensitive to orthographic inconsistencies in a deep L2 writing system (and consequently show a stronger orthographic effect) than participants raised in a deep writing system. This assumption implies that the processing mechanism developed during literacy acquisition in L1 is applied to L2 word processing, as suggested for visual word recognition by Akamatsu (1998).[43] I will now discuss two explanations which take into account the transparency of the participants' orthographic background to explain the different sizes of orthographic activation between the Danish and German participants.

The first explanation suggests that the Danish participants prefer a phonological route of auditory word processing that disregards co-activation of the orthographic system. As a consequence, they demonstrated a smaller orthographic influence during auditory word recognition. This strong preference for a phonological route is motivated by the inconsistent mappings between phonology and orthography in their L1. Being familiar with discrepancies between spelling and pronunciation in their L1 that might hinder phonological processing, they have developed a processing strategy that neglects orthographic co-activation during auditory word recognition in their L1. This processing mechanism is then transferred to non-native language processing and results in a notably small orthographic effect. By contrast, German participants, who are familiar with a considerably shallow orthography in their L1, have developed a processing mechanism that involves co-activation of orthographic units during auditory word processing. This co-activation is motivated by consistent mappings between orthographic and phonological representations in the German language. The transparency of the German language does not hinder phonological processing. Instead, phonological units can be accessed in German by using corresponding orthographic representations. For this reason, German participants are more familiar with the co-activation of orthographic information in their L1 and do not prefer a solely phonological route during auditory word recognition. Similar to the Danish participants, they transfer this processing mechanism to non-native language processing. Due to the highly inconsistent correspondences between spelling and pronunciation in English, which German participants are not familiar with, a strong orthographic bias is yielded during auditory processing of English words.

It is noteworthy that orthographic interactions during auditory word recognition have not been tested in a monolingual study with German and Danish participants that were

[43] Note that Akamatsu (1998) suggested the transfer of processing skills in non-native word recognition for bilinguals that acquired literacy in a logographic and alphabetic writing system, not in two alphabetic writing systems with varying degrees of transparency. Nevertheless, this transfer of processing mechanism seems to be applicable to the present data.

exposed to German and Danish stimuli, respectively. This would, however, be necessary to determine whether a similar size of the orthographic effect as observed in L2 processing would be yielded in their first language. Moreover, the existence of a significant orthographic effect for the Danish participants in Experiment 2 and 3 suggests that Danish participants did not solely use a phonological route but were affected by the connections to the L2 orthographic system. Given that the first explanation requires further empirical validation, I will now discuss an alternative explanation for the assumption that the observed cross-linguistic differences between the German and Danish participants appear to be modulated by the orthographic transparency of the participants' first language.

The second explanation takes a closer look at the origin of the orthographic effect, i.e. how the orthographic effect emerges in the mental lexicon when phonological representations are mapped onto corresponding orthographic units. It suggests that the reduced orthographic effect for Danish participants is due to a smaller number of activated orthographic competitors that contain the manipulated phonological unit. Recall that stimuli that contain inconsistent rimes, such as the incongruent items in the rhyme judgement task (Experiment 1), e.g. the stimulus pair *vote* - *boat*, or the inconsistent stimuli in the lexical decision task (Experiment 3), e.g. the stimulus *burn*, were processed more slowly because several spellings were activated compared to stimuli that contained consistent rimes with only one possible spelling. Thus, given the same stimuli, Danish and German participants activated a different number of possible spellings (or lexical competitors that contained possible spellings) of the phonological input. The psycholinguistic grain size theory (PGST) appears to provide a promising approach to account for the cross-linguistic differences observed in the present study.

But before I discuss the present findings in light of the PGST, two aspects of the PGST should be noted. First, the PGST has been only vaguely applied to orthographic effects in *auditory* word recognition. Although Ziegler & Goswami (2005) argued that the PGST offers an explanation for orthographic effects in auditory word recognition, their theory did not receive much attention in studies on this field of research so far. As mentioned earlier in this thesis, the PGST is a theory of reading development and visual word recognition across orthographies. To date, only very few studies have investigated cross-linguistic interactions of orthography in auditory speech processing (see section 2.3.3).

Therefore, it is quite understandable that the PGST has not been applied to this field of research yet. Second, the PGST has been developed for *monolingual* language processing. Only recently, first attempts have been made to apply the PGST to *bilingual* visual word recognition (Haigh, Savage, Erdos & Genese, 2011; Kim, 2009). Taken together, the PGST has either been applied to orthographic effects in monolingual auditory word recognition or to bilingual visual word recognition. However, it has not been applied to explain cross-linguistic differences in orthographic effects during L2 auditory word recognition – as observed in the present investigation.

Recall from section 2.2.4.2 that according to the PGST participants from deep and shallow orthographies develop different processing strategies during literacy acquisition. Beginning readers of transparent orthographies develop processing strategies based on grapheme-phoneme correspondences. This means, they demonstrate a preference for small-unit processing. In contrast, beginning readers of inconsistent orthographies have to focus on correspondences between orthography and phonology based on units of various grain sizes. As outlined in section 2.2.4.1, deep orthographies are characterized by highly inconsistent grapheme-to-phoneme correspondences and inconsistent but slightly more consistent correspondences of larger units, such as onsets and rimes. Due to inconsistent grapheme-to-phoneme correspondences, readers of deep writing systems have to focus on more consistent mappings, such as correspondences on the body-rime or whole-word level. Consequently, readers of consistent orthographies are more familiar with small-unit processing whereas readers of inconsistent orthographies rely both on small- and large-unit processing. According to the PGST, these processing strategies, which are developed during literacy acquisition, have long-lasting effects on mechanisms and strategies of orthographic processing. Hence, they are not restricted to beginning readers but can be also observed with skilled readers (Ziegler, Perry, Jacobs & Braun, 2001). In the following, I will argue that these processing strategies of large- and/or small-unit processing, which have been shown to affect the monolingual "long-term organization and dynamics of the skilled adult reading system" (Ziegler & Goswami, 2005: 23), may be also transferred to non-native language processing.

Concerning the present findings, the different processing strategies suggested by the PGST are assumed to affect the number of activated spellings for a given phonological unit. As shown in Figure 6.1, a large number of graphemes correspond, for example, to the input phonemes of the English word /fəʊn/ (*phone*). However, if the stimulus is subdivided into onset and rime and mapped onto the corresponding orthographic units, the correspondences are still inconsistent but they amount to a smaller number of possible spellings than the grapheme-to-phoneme correspondences (see Figure 6.2). In other words, if the phonological form of an English word is processed by subdividing the word into units of small grain size, such as single phonemes, more corresponding orthographic units would be activated than by subdividing the word into onset and rime.

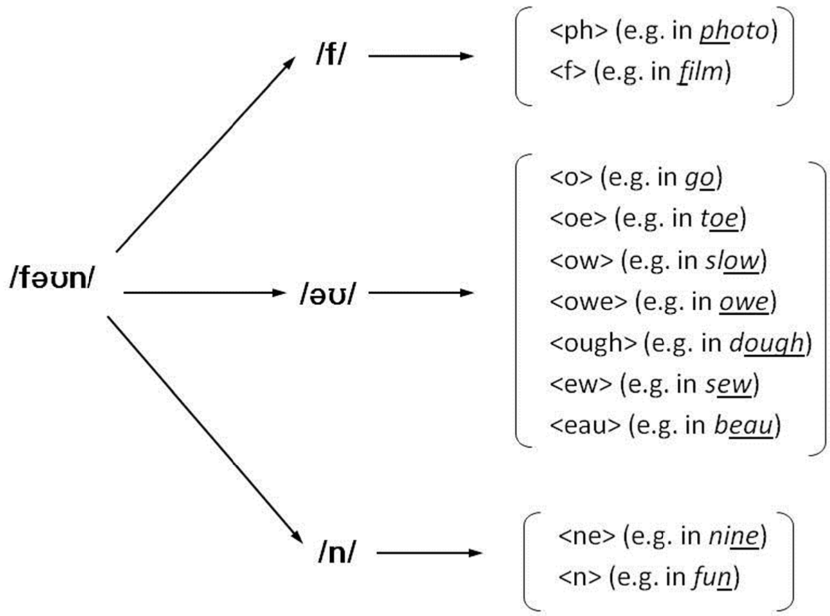

Figure 6.1. Segmentation of the phonological English word *phone* in phonological units of small grain size and corresponding orthographic representations.

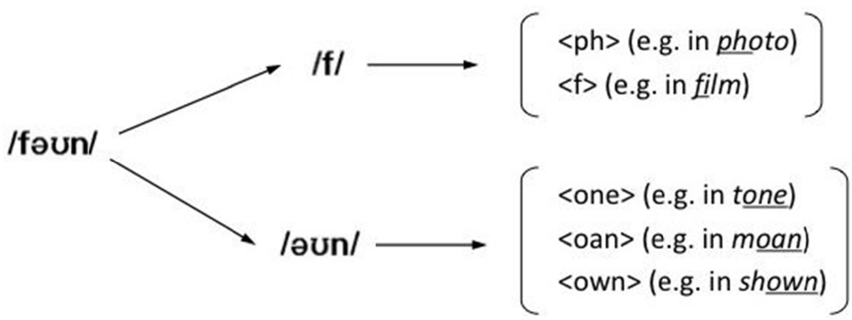

Figure 6.2. Segmentation of the phonological English word *phone* in phonological units of small and large grain size and corresponding orthographic representations.

Note that German and Danish participants received the same stimuli but appeared to have activated a different number of possible spellings (as demonstrated by a different degree of orthographic activation, particularly in Experiment 1 and 3). This finding suggests that German and Danish participants processed the words differently. Consistent with the assumption of the psycholinguistic grain size theory, it is reasonable to assume that German participants, who were raised in a shallow L1 orthography, applied a strategy of small-unit processing during auditory word recognition of English words. By contrast, Danish participants, who were raised in the deep orthography of Danish, relied on small-unit and large-unit processing, which resulted in the activation of a smaller number of corresponding orthographic English units.

The transfer of L1 processing strategies to non-native language processing resulted in the following pattern: Danish participants activated a smaller number of orthographic competitors for a given phonological input because they relied on a strategy of small and large-unit processing. That is, the phonological stimulus was subdivided into small and large units that activated a smaller number of corresponding English orthographic units compared to a strategy that is solely based on small-unit processing. The latter strategy was used by the German participants, who were familiar with the processing of small units from their L1. Given that the English language is more consistent for large than for small units (as shown in Figures 6.1 and 6.2), the German participants activated more possible spellings (or lexical competitors that contained the possible spellings) than the Danish participants, which resulted in a slowdown of processing. Thus, the German participants demonstrated a stronger orthographic effect than the Danish participants in Experiment 1 and 3, which involved orthographic manipulation of the rime.

Interestingly, the Danish participants demonstrated a similar magnitude of orthographic activation in Experiment 1 and 3 compared to the native speakers of English. These data suggest that the Danish and English participants used a similar processing strategy of small- and large-unit processing because the English orthography is characterized by a similar inconsistency as the Danish orthography. As a consequence, Danish and English participants demonstrated a similar size of orthographic effect in the two experiments that tested orthographic manipulations of the rime (Experiment 1 and 3).

With reference to small-unit processing, which was tested in Experiment 2, the PGST predicts similar results for German and Danish participants as a result of both groups' familiarity with small-unit processing in their first language. Indeed, Experiment 2 revealed a similar size of orthographic influence for German and Danish participants. However, it is noteworthy that the phoneme deletion task was particularly complex and challenging and did not only focus on the phoneme level but also, though less explicitly, on the rime level. Consequently, Experiment 2 involved complex processing strategies which cannot be solely interpreted by a strategy that involved preference for small-unit processing.

Although the present findings on rhyme judgement (Experiment 1) and the orthographic consistency effect (Experiment 3) are in line with the assumptions of the PGST, a cross-linguistic comparison of the orthographic consistency effect by Pattamadilok, Morais, Ventura & Kolinsky (2007) demonstrated a pattern of results which is in contrast to the assumptions of this theory. As mentioned earlier, their study compared performance of Portuguese and French participants during spoken word recognition of L1 stimuli. In other words, they investigated the orthographic consistency effect by manipulating the orthographic consistency of the rime level in two languages. Contrary to their assumptions, a larger orthographic consistency effect was found for French participants and French stimuli whereas Portuguese participants, who were familiar with a more transparent orthography, demonstrated a smaller orthographic consistency effect. It is noteworthy that the study by Pattamadilok and colleagues is the only study, to date, which investigated the orthographic consistency effect in auditory word recognition from a cross-linguistic perspective. However, in contrast to the present study, they tested two groups of monolingual speakers with different stimuli whereas the present investigation tested for this effect by using the same stimuli for two groups of bilingual participants from different orthographic backgrounds. More research is definitely needed to confirm my assumption that language-specific processing strategies of phonological and orthographic units – as proposed by the PGST – result in a different number of activated orthographic representations during spoken word processing.

In conclusion, I have presented two explanations for the observed cross-linguistic differences between German and Danish non-native speakers of English which take into account the different orthographic backgrounds of the L2 participants. The first explanation suggests that Danish participants have developed weaker connections than German participants between the orthographic and phonological system during literacy acquisition in the inconsistent L1 orthography. When a second language is learned, this processing mechanism is transferred to L2 processing and results in a similar size of orthographic influences as would be observed in the L1. The second explanation is based on the assumption of the PGST that readers of shallow and deep orthographies develop different processing strategies of small- and large-unit processing in their L1. I have argued that these strategies are transferred to L2 processing. As a consequence, German and Danish participants activated a different number of orthographic competitors for the same phonological input and, hence, yielded a different degree of orthographic activation during L2 spoken word recognition. Both explanations suggest that processing strategies and mechanisms that have once been acquired in response to the characteristics of the L1 writing systems get deeply entrenched and are transferred to L2 processing. Even when the characteristics of the L2 would require different and more efficient processing strategies, the processing mechanism is not adapted to the processing requirements of the non-native language. Consequently, the orthographic system of our first language appears to have fundamental effects on the way we process phonological and orthographic information in other (non-native) languages. More research is needed to investigate which of the two explanations provides a more comprehensive account of the effect of transparent and deep writing systems on orthographic effects during L1 and L2 auditory speech processing. At present, it appears that the cross-linguistic differences between L2 speakers from different orthographic backgrounds can be explained more conclusively with reference to the second explanation.

6.4 Finalizing the working model: Orthographic influences on L2 auditory word processing

The overall results of the present study confirm the assumption that auditory word recognition of native and non-native speakers of English is not solely based on phonological input but is affected by the co-activation of orthographic information. As mentioned earlier, spoken word recognition does not necessarily require information about the spelling. However, as soon as the spelling of a word has been acquired during literacy acquisition, strong links between the phonological and orthographic code have been established that affect auditory word recognition. The results of the present study demonstrate that the orthographic code is activated both in tasks that explicitly focus on phonological units and their corresponding orthographic units (Experiment 1 and 2) and in tasks that do not focus on phonological or orthographic structures in any obvious ways (Experiment 3). Therefore, the present series of experiments provided further evidence for the architecture of the working model, as will be illustrated below.

First of all, the present findings clearly demonstrate that non-native auditory word recognition is influenced by orthographic information. Thus, the data support the existence of connections from the phonological to the orthographic system for L2 word processing. By using these connections, L2 phonological representations co-activate the corresponding L2 orthographic representations. The experiments of the present study involved two metaphonological tasks (Experiment 1 and 2) that focused on the awareness and analysis of sublexical units. The finding of an orthographic effect in these two metaphonological paradigms confirms the existence of connections between orthographic and phonological units at the sublexical level in the working model of bilingual word recognition. Experiment 3 did not involve explicit awareness or manipulation of sublexical units. Thus, the finding of an orthographic consistency effect in Experiment 3 can be regarded as a lexically-rooted orthographic interaction during spoken word recognition. On the whole, Experiment 1 and 2 provide evidence for links between phonological and orthographic units at the sublexical level whereas Experiment 3 supports the existence of such connections at the lexical level.

Recall from chapter 3 that one of the central questions on bilingual language processing is whether words of both languages are activated (language non-selective access) or only words from the target language (language selective access). Based on previous research, the working model incorporates a language non-selective access to an integrated lexicon of both languages. It is noteworthy that the experiments carried out in the present study were not designed to assess the question of language dependent or independent access to the lexicon. All stimuli were presented in English only, and they did not include cognates or interlingual homographs that are typically used to test for language non-selective bilingual processing. The present findings rather support the view of within-language connections between orthographic and phonological units that occur in an integrated lexicon. This means, the L2 phonological unit activates the corresponding L2 orthographic representations. Given the assumption of an integrated lexicon, it is highly likely that the same L2 phonological unit simultaneously co-activates a corresponding orthographic unit in L1. However, such cross-linguistic activations were not tested in the present study.

Instead, the present study compared to what extent orthographic activation during L2 processing differed from L1 processing. The results do *not* suggest that stronger connections between phonological and orthographic units exist in non-native compared to native speakers. Rather, as discussed in the previous section, a cross-language comparison between the performance of the German and Danish participants revealed that the transparency of the L1 orthographic system is likely to shape the way phonological representations are mapped onto corresponding orthographic units during L2 auditory speech processing. This means that the working model has to be sensitive to the transparency of the L1 orthographic system. In the previous section, two different explanations have been proposed that are able to account for the cross-linguistic differences observed in the empirical investigation. These explanations will now be discussed in light of the working model of bilingual word recognition.

The first explanation suggests that the different sizes of orthographic effects between German and Danish participants are due to different processing routes in the working model. That is, a preference for a specific processing route has been developed during literacy acquisition in L1 and is then transferred to L2 word recognition. For instance, German participants, who are familiar with a considerably shallow orthography in their L1, have developed a processing mechanism for L1 spoken words that involves co-activation of orthographic representations and transfer this mechanism to L2 word processing (see Figure 6.3).

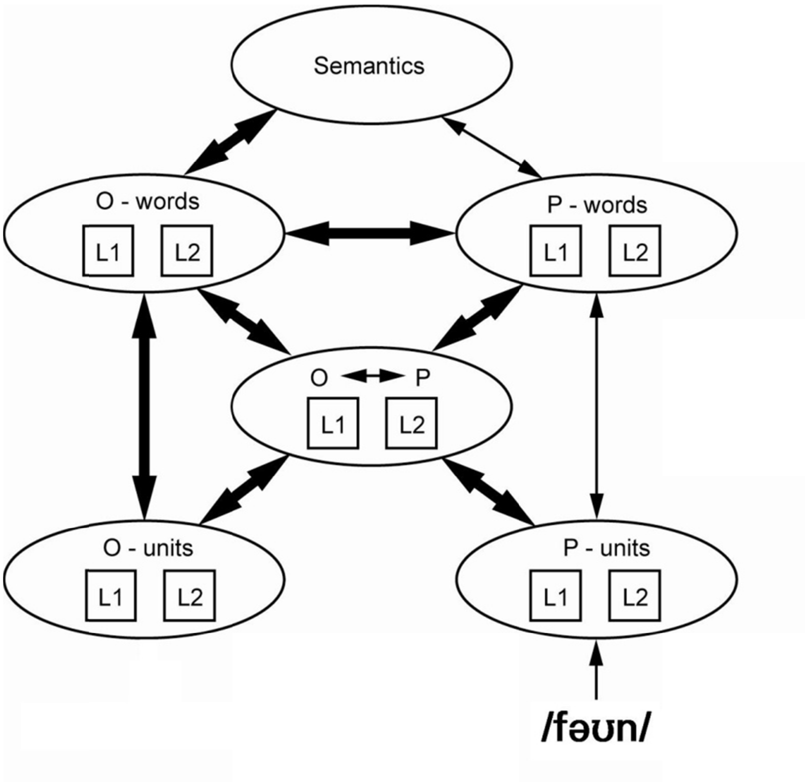

Figure: 6.3. Auditory language processing in German non-native speakers of English. The thick arrows indicate a stronger flow of activation in German as compared to Danish non-native speakers of English (see Figure 6.4).

By contrast, Danish participants have established a stronger phonological route to the semantic lexicon than the German participants (see Figure 6.4). This stronger route is motivated by their familiarity with an inconsistent orthography in their L1. This means, being used to inconsistencies between pronunciation and spelling (and vice versa) in their first language makes Danish participants less sensitive to such variations. In order to disregard the inconsistent spellings in their L1, they primarily use a solely phonological route for auditory speech processing in L1. This pattern is transferred to language processing of L2 words.

As stated earlier, this view requires further empirical validation. It is challenged, for instance, by the finding of orthographic effects for the Danish participants in Experiment 2 and 3. However, if we assume that the discussion is not about binary decisions in favour or against a *solely* phonological route but rather on probabilities of orthographic co-activation via the non-phonological route, the working model appears to account for the different results observed in the German and Danish participants in Experiment 1 and 3.

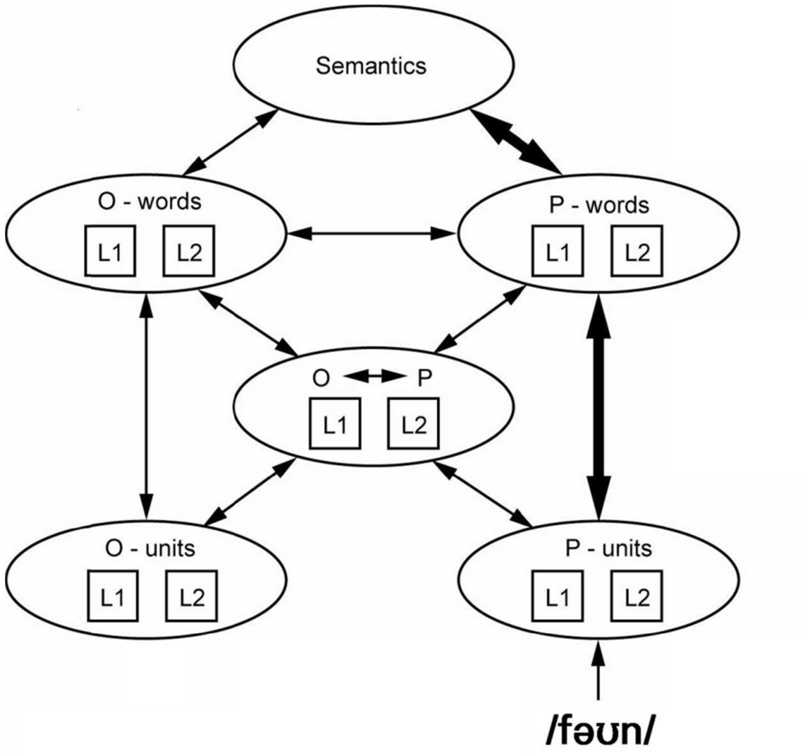

Figure: 6.4. Auditory language processing in Danish non-native speakers of English. The thick arrows indicate a stronger flow of activation in Danish as compared to German non-native speakers of English (see Figure 6.3).

The alternative explanation outlined in the previous section suggests that the different degrees of orthographic activation between Danish and German non-native participants in Experiment 1 and 3 can be explained with reference to different processing strategies for phonological and orthographic units of small and large grain sizes. According to the PGST, these different processing strategies have been developed during literacy acquisition in a shallow (German) and deep (Danish) writing system. How does the working model account for this finding?

When a second language is learned, new orthographic and phonological representations of words and sublexical units are stored in the respective levels of the working model. Moreover, correspondences between the orthographic and phonological units of the L2 are stored in the central interface. However, the fundamental strategy of sublexical processing, i.e. whether participants rely on small-unit processing or small- and large-unit processing, is transferred from the L1 to the L2. Figure 6.5 illustrates that German non-native speakers of English prefer a strategy of small-unit processing for English words. This strategy has been proved very efficient in their first language and is transferred to L2 processing. Thus, German non-native speakers of English subdivide the English phonological input into units of small grain size, i.e. single phonemes that are mapped on the corresponding graphemes.

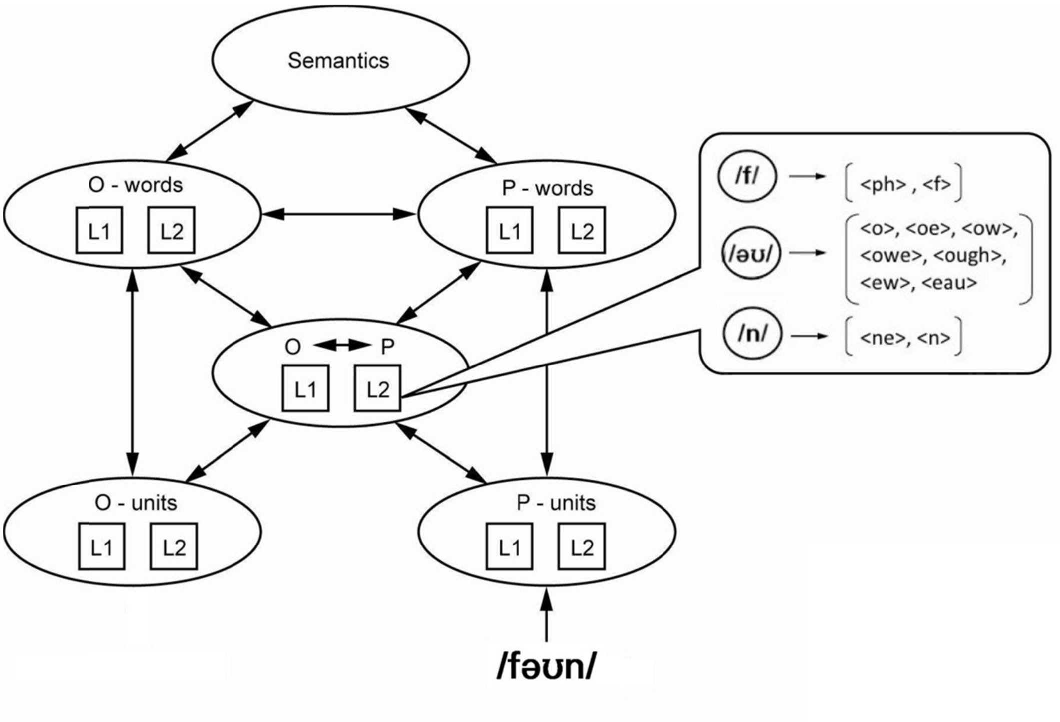

Figure 6.5. Auditory language processing in German non-native speakers of English. Segmentation of the phonological English word *phone* in phonological units of small grain size and corresponding orthographic representations.

By contrast, Danish participants, who are familiar with a strategy of small- and large-unit processing due to the inconsistent Danish orthography, transfer their strategy of small- and large-unit processing to L2 word recognition. As shown in Figure 6.6, Danish non-native speakers of English process the same English L2 word differently than German non-native speakers of English, by subdividing the phonological input into onset and rime.

Overall, the figures illustrate that the processing strategy of the German participants results in a higher number of activated spellings than observed for the Danish participants. This increased competition of orthographic units explains the stronger orthographic effect found for the German compared to the Danish participants. As noted earlier, the reason for this processing difference between German and Danish participants is rooted in the sensitivity to units of different grain sizes. Consequently, the working model has to incorporate a processing mechanism that is not restricted to grapheme-phoneme correspondences but may also account for mappings between orthographic and phonological units of larger grain sizes. This grain size mechanism is located in the central interface and determines whether phonological and orthographic sublexical representations are matched by using small units only or, alternatively, small and large units.

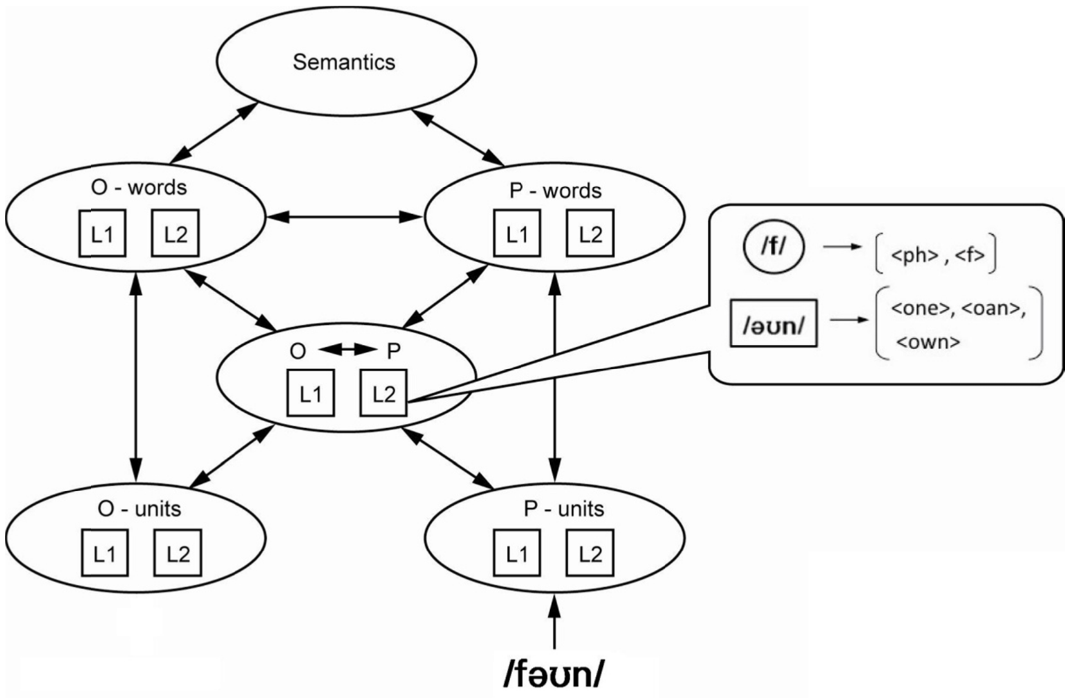

Figure 6.6. Auditory language processing in Danish non-native speakers of English. Segmentation of the phonological English word *phone* in phonological units of small and large grain size and corresponding orthographic representations.

The results of the present investigation suggest that once a preferred strategy of small- and/or large-unit processing has been adjusted during literacy acquisition in L1, it is transferred to orthographic processing in L2. It remains to be seen whether this mechanism can be adjusted to the orthographic characteristics of the L2 writing system, especially if the L2 writing system requires a more efficient processing strategy. The present data suggest that this is not the case. More research is definitely needed to verify the assumption of this grain size mechanism. Concerning the present study, the grain size mechanism seems to offer a promising approach to the finding of different degrees of orthographic activation during auditory word recognition across two non-native groups.

Taken together, the empirical data provided further evidence for the architecture of the working model. The data support the existence of connections from the phonological to the orthographic system for L2 auditory word processing. Furthermore, the empirical findings suggest that the working model has to be sensitive to language-specific characteristics in order to account for the observed cross-linguistic differences. In the previous section, I have argued that these cross-linguistic differences are due to the transparency of the participants' first language. As shown above, both explanations introduced in the previous section can be incorporated in the working model. Thus, the working model is able to account for the cross-linguistic differences between L2 speakers from shallow and deep L1 orthographic backgrounds as found in Experiment 1 and 3.

6.5 Implications for L2 learning and teaching

The finding that the L1 writing system seems to influence orthographic activation in L2 spoken word recognition poses the question of whether young L2 learners should acquire reading and spelling in two languages at the same time. Recall that all non-native participants involved in the present study acquired full literacy in their first language before they started to learn English as a second language. Nowadays, though, children tend to learn an L2 at a very early age, e.g. children receive English lessons at German primary schools from grade 1. In other words, children start to learn a second language before they have reached literacy in their first language. It is beyond the scope of this thesis to provide recommendations for L2 learning and teaching. Nevertheless, I will provide some food for thought with reference to the current discussion of whether primary school teachers should introduce reading and writing in L2 from the very beginning or introduce the orthographic form of L2 words at a later stage.

In the literature on second and foreign language learning, various arguments have been proposed for and against simultaneous literacy instruction in L1 and L2 (see Piske, 2010, for a recent review). Some researchers have argued that L2 lessons at primary school should exclusively focus on speaking and listening during the first two years of L2 instruction since children learn to listen and speak many years before they learn to read and write in their L1 (e.g. Bleyhl, 2007). Moreover it has been suggested that early exposure to the written form of L2 words would make L2 learners at primary school level more prone to mispronunciations of new words (e.g. Bleyhl, 2007; Kahl & Knebler, 1996; Young-Scholten, 2002). However, the majority of researchers has argued that young learners even benefit from simultaneous L1 and L2 literacy acquisition, especially when the orthographic systems differ in terms of orthographic transparency (e.g. Dlugosz, 2000; Edelenbos, Johnstone & Kubanek, 2009; Mertens, 2003; Rymarczyk, 2008a, b; Zaunbauer, 2007). For example, Rymarczyk (2008a, b) demonstrated that young learners of English who had been exclusively exposed to spoken English at German primary schools during grade 1 and 2 made a number of spelling errors that were based on the spelling rules of German orthography (e.g. *bee* was spelt <Bie>). It was argued that young L2 learners are more likely to overcome the incorrect English spellings within a short period of time if reading and writing in English is introduced simultaneously with literacy acquisition in German.

Given that the findings of the present experiments demonstrate that the role of orthography is not restricted to the visual modality but appears to have fundamental effects on the way spoken language is processed in L1 and L2, simultaneous literacy acquisition in both languages is likely to provide a processing advantage. It has been shown in the present study that speech processing was slowed down for German participants when auditory L2 stimuli activated conflicting orthographic information. In contrast, Danish participants demonstrated a slowdown of speech processing to a much smaller extent. I have explained these processing differences by means of different processing strategies that have been developed during literacy acquisition in the participants' first language. Danish participants, who were raised in an inconsistent orthography, relied on a more efficient processing strategy for inconsistently spelled English words compared to German participants. It is likely that German participants would have developed a more flexible and efficient processing mechanism for English words during simultaneous literacy acquisition in the shallow orthography of German and the deep orthography of English.

According to the PGST, readers exposed to the German orthography develop a processing mechanism which is primarily based on small-unit processing of consistent sound-spelling mappings whereas the opaque orthographic system of English requires both small- and large-unit processing. Consequently, during simultaneous exposure to the writing system of German and English, German children may acquire processing strategies both for transparent and opaque orthographies, which would reduce the slowdown of speech processing when exposed to orthographically inconsistent English stimuli, not only in visual word recognition but also in spoken word recognition, as shown in the present study. However, it takes longer to develop sensitivity to units of various grain sizes than to units of small grain size only (as shown in a number of cross-linguistic studies on reading acquisition). Moreover, the PGST was developed to explain cross-linguistic differences in reading acquisition, skilled reading and developmental dyslexia but does not explicitly address the field of biliteracy acquisition or literacy acquisition in L2. Future research has to address the question of whether simultaneous literacy acquisition in a shallow and deep orthography affects the way orthographic units of various grain size are processed.

To conclude, numerous studies on early second language learning suggest that simultaneous literacy instruction in L1 and L2 is considered to provide a processing advantage. Given that orthographic transparency affects both visual and auditory speech processing, children would benefit – at least in the long run – from the establishment of an efficient processing mechanism which is able to process words from consistent and inconsistent orthographies. The results of the present study reveal that the orthographic system of the L1 appears to influence language processing of an L2 which has been learned after L1 literacy acquisition. In order to develop a more flexible and efficient processing system, simultaneous acquisition of literacy in L1 and L2 would provide an advantage for young learners. Thus, foreign language teachers should introduce reading and writing in the L2 at a very early stage.

7 Conclusion

The present study has demonstrated that the widely observed orthographic effects in auditory word recognition are not restricted to monolingual language processing but can be also observed in non-native language processing. One of the major strengths of the present investigation was that orthographic influences on non-native language processing were compared to *two* groups of non-native speakers of English. This way, a more comprehensive picture about spelling interactions during L2 speech processing was established. Interestingly, the two non-native groups demonstrated different degrees of orthographic activations. As a consequence, it cannot be generally concluded that orthographic representations are activated more strongly in non-native compared to native language processing. Rather, it appears that the orthographic transparency of the speakers' native language affects the degree of orthographic recruitment in L2. In the present study, German participants, who were used to consistent mappings between sound and spelling in their L1, demonstrated stronger orthographic effects in two out of three experiments whereas Danish participants, who were familiar with an opaque L1 orthography of a similar consistency than English, demonstrated a smaller size of orthographic recruitment, which was comparable in size to the effect obtained for the English native speakers.

As previously noted, the assumption that the transparency of L1 affects the strength of orthographic activation in L2 has to be treated with some caution as it cannot be completely excluded that other factors, such as L2 proficiency and experience, contributed to the differences observed between Danish and German participants. Nevertheless, the present findings provide strong evidence for the hypothesis that L1 orthography shapes the way phonological and orthographic information is accessed in L2. Similar to a transfer of L1 speech sounds to L2 in non-native speech perception (e.g. Flege, 1987; 1995), it appears that fundamental patterns of phonological and orthographic processing, such as sensitivity to units of different grain size, are transferred from L1 to L2 during non-native auditory speech processing.

The working model of bilingual word recognition, which has been developed in the first part of this thesis, is considered a good starting point for further explorations of the role of orthographic effects on non-native auditory word recognition. Due to its bidirectional connections between orthographic and phonological units, the working model is the only model of L2 auditory word recognition, at present, which is able to explain orthographic influences during L2 spoken word processing. Moreover, the working model is able to account for the finding that the transparency of the L1 writing system shapes the way phonological and orthographic information is processed in a second language. More evidence for the transfer of an L1 processing mechanism to L2 would provide further support for the assumption that the language you were raised in has fundamental effects on language processing and cognition.

Over the last years, several studies have demonstrated that differences in language appear to create differences in the speaker's fundamental processes of cognition and experience, such as thinking about colours (e.g. Roberson & Hanley, 2007; Winawer, Witthoft, Frank, Wu, Wade & Boroditsky, 2007), space (e.g. Levinson, Kita, Haun & Rasch, 2002), time (e.g. Boroditsky & Gaby, 2010) and event structure (e.g. Fausey, Long, Inamori & Boroditsky, 2010; Papafragou, Hulbert & Trueswell, 2008). The present findings demonstrate that it is also the transparency of a language's writing system that seems to have fundamental and permanent effects on the cognitive structures of the brain.

Frith (1998) compared the acquisition of an alphabetic code with the infection of a virus: "This virus infects all speech processing (…). Language is never the same again." (Frith, 1998: 1011). Research over the last three decades has shown impressively that this virus is not restricted to the visual modality, which is usually concerned with orthographic processing, but also affects the auditory modality. It should be noted, though, that the large number of studies which reported orthographic effects on spoken language has primarily focused on receptive auditory tasks. This means, interactions of orthography have been almost exclusively investigated in studies on auditory word recognition. In contrast, the role of orthography during speech production is less clear. By and large, the small number of studies which addressed this topic so far did not provide evidence for orthographic effects during speech production (e.g. Alario, Perre, Castel & Ziegler, 2007; Damian & Bowers, 2009a; Lölfing, 2008; Roelofs, 2006; but see Damian & Bowers, 2003).

Moreover, as also noted by Dich (2011), the majority of studies which have reported orthographic effects on auditory speech processing involved university students as participants. This is particularly true for research on the orthographic consistency effect.

It may be argued that the reported findings cannot be generalized over all literate people given that university students have a more extensive exposure to written texts than people who are less involved in reading and writing in their everyday lives. As a consequence, further research is necessary to disentangle the influences of quantitative exposure to written texts for the establishment of strong links between orthographic and phonological representations.

Another question which is hotly debated addresses the question of why orthography is activated at all during auditory language processing. As demonstrated in previous research, the positive effects of orthographic influences on auditory speech processing are limited. While recruitment of orthographic representations appears to help performance in auditory tasks that focus on the phoneme level (e.g. Morais, Cary, Alegria & Bertelson, 1979), performance is impaired in other auditory tasks, such as rhyme judgement or lexical decision. At present, the existence of orthographic effects on auditory speech processing suggests that the phonological and orthographic systems appear to interact even if an advantage is not at hand. Most likely this is the case because orthographic co-activation occurs automatically. Due to the bidirectional links between orthography and phonology in the working model, I have argued that the same mechanism that explains phonological effects in visual word recognition is able to account for orthographic effects in auditory word recognition. Therefore, the co-activation of orthography during auditory speech processing may be regarded as a “side effect” of literacy acquisition and visual word recognition.

The present results provide an empirical basis for further investigations on the interactions of spoken and written language in non-native speech processing. The findings illustrate fundamental influences of written language on the cognitive structures that were evolutionary determined for spoken language processing. Primacy of spoken language over written language, as shaped through evolution, no longer exists once literacy has been acquired. Previous research on this field of study as well as the present findings demonstrate that written language appears to dominate the phonological system.

8 German summary

Eine zunehmende Zahl von Studien zeigt, dass der Erwerb schriftsprachlichen Wissens grundlegende Auswirkungen auf die auditive Sprachverarbeitung hat. Diese Befunde sind auf den ersten Blick erstaunlich, da auditive Sprachverarbeitung sehr gut ohne orthographische Informationen funktioniert. Während eine Vielzahl von Studien die Auswirkungen der Orthographie auf die auditive Sprachverarbeitung monolingualer (L1) Sprecher untersucht hat, sind die orthographischen Einflüsse auf die Sprachverarbeitung in einer Fremdsprache (L2) weitestgehend unerforscht. Die vorliegende Dissertation beschäftigt sich daher mit den Einflüssen schriftsprachlichen Wissens auf die auditive Sprachverarbeitung in einer Fremdsprache. Ziel dieser Arbeit ist es zum einen, ein Arbeitsmodell zur bilingualen Sprachverarbeitung zu entwickeln, welches orthographische Einflüsse auf die auditive Sprachverarbeitung erklären kann. Zum anderen sollen im empirischen Teil der Arbeit die bisherigen Erkenntnisse zu orthographischen Effekten während der monolingualen auditiven Wortverarbeitung auf die Verarbeitung in einer Fremdsprache erweitert werden.

In Kapitel 2 dieser Arbeit diskutiere ich Modelle und grundlegende Befunde der monolingualen Wortverarbeitung, die für die Erstellung des Arbeitsmodells relevant sind. Diese Befunde umfassen sowohl die auditive als auch visuelle Wortverarbeitung. Ich zeige, dass aktuelle Modelle der monolingualen auditiven Wortverarbeitung (wie z.B. das Kohortenmodell, TRACE, Shortlist) ausschließlich auf auditiven Informationen basieren und keine orthographischen Informationen verarbeiten können. Bisherige Studien zur visuellen Wortverarbeitung diskutiere ich vor allem mit Bezug auf die Rolle der Phonologie sowie der orthographischen Transparenz. Es wird gezeigt, dass phonologische Informationen eine essentielle Rolle bei der visuellen Wortverarbeitung spielen – auch dann, wenn die Aufgabe kein explizites lautes Lesen erfordert. Das *bimodal interactive activation model* (BIAM) (Grainger & Ferrand, 1994, 1996; Grainger, Muneaux, Farioli & Ziegler, 2005) bietet im Gegensatz zum *dual-route cascaded model* (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001) einen hoch interaktiven Mechanismus, welcher in der Lage ist, die zentrale Rolle der Phonologie zu simulieren. Durch die bidirektionalen Verbindungen zwischen Orthographie und Phonologie ist das BIAM das einzige Modell der (auditiven) Sprachverarbeitung, welches orthographische Einflüsse auf die auditive Wortverarbeitung erklären kann. Es spielt deshalb eine zentrale Rolle für die Entwicklung des Arbeitsmodells. Desweiteren diskutiere ich den Einfluss der orthographischen Transparenz hinsichtlich cross-linguistischer Unterschiede bei Leseanfängern und geübten Lesern. In diesem Zusammenhang bietet die *psycholinguistic grain size theory* (Ziegler & Goswami, 2005) einen Erklärungsansatz, der die beobachteten cross-linguistischen Unterschiede in der visuellen Wortverarbeitung im Hinblick auf eine unterschiedlich ausgebildete Sensibilität bezüglich phonologischer und orthographischer Einheiten erklärt.

In Kapitel 3 der Dissertation diskutiere ich relevante Befunde und Modelle der bilingualen Wortverarbeitung. Bisherige Studien zur bilingualen auditiven und visuellen Sprachverarbeitung lassen vermuten, dass bei der bilingualen Sprachverarbeitung der Zugriff auf ein integriertes Lexikon von beiden Sprachen sprachunspezifisch geschieht, d.h. sowohl Repräsentationen der L1 als auch der L2 aktiviert werden. Desweiteren wurden in zahlreichen Studien Einflüsse der Phonologie auf die visuelle L2 Wortverarbeitung nachgewiesen. Erste Studien belegen außerdem Einflüsse schriftsprachlichen Wissens auf die auditive Wortverarbeitung in einer Fremdsprache. Während das BIA+ Modell (Dijkstra & van Heuven, 2002) zur visuellen Wortverarbeitung die Einflüsse der Phonologie auf die Verarbeitung geschriebener Sprache erklären kann, gibt es kein Modell zur auditiven L2 Sprachverarbeitung, welches eine Erklärung für die andere Richtung, nämlich die orthographischen Einflüsse auf die auditive Wortverarbeitung liefert.

Auf der Grundlage dieser Erkenntnisse wird in Kapitel 4 ein Arbeitsmodell zur bilingualen Wortverarbeitung entwickelt. Dieses Modell ist eine bilinguale Version des *bimodal interactive activation model* (Grainger & Ferrand, 1994, 1996; Grainger, Muneaux, Farioli & Ziegler, 2005) und ist somit in der Lage sowohl phonologische Effekte in der visuellen Wortverarbeitung als auch orthographische Effekte in der auditiven Wortverarbeitung zu erklären. In der vorliegenden Dissertation beschränke ich mich jedoch auf orthographische Einflüsse auf die auditive Wortverarbeitung. Das Modell basiert auf der Annahme, dass die grundlegende Architektur der Sprachverarbeitung, die sich in der Erstsprache entwickelt hat, auf die Zweitsprache übertragen wird. Darüber hinaus beinhaltet es ein integratives Lexikon von Erst- und Zweitsprache mit einem parallelen Zugriff auf beide Sprachen.

In der empirischen Untersuchung in Kapitel 5 werden die Annahmen des Modells überprüft. Zum einen wird untersucht, ob nichtmuttersprachliche Sprecher orthographische Informationen während der auditiven Wortverarbeitung in einer Fremdsprache aktivieren (Forschungsfrage 1). Zum anderen untersuche ich, welche Unterschiede hinsichtlich der Aktivierung orthographischen Wissens einerseits zwischen muttersprachlichen und nichtmuttersprachlichen Sprechern (Forschungsfrage 2) sowie andererseits zwischen zwei Gruppen von nichtmuttersprachlichen Sprechern, die sich in Hinblick auf die orthographische Transparenz der Muttersprache unterscheiden (Forschungsfrage 3), bestehen.

Zur Untersuchung dieser Fragestellungen nahmen deutsche und dänische Probanden mit sehr guten Englischkenntnissen sowie eine Kontrollgruppe von englischen Muttersprachlern an drei auditiven Experimenten teil. Die dänische Sprache ist geprägt von einer hohen Inkonsistenz zwischen Phonologie und Orthographie, wohingegen die deutsche Sprache eine relativ hohe orthographische Transparenz aufweist. Somit stellten dänische und deutsche Sprecher eine geeignete Wahl dar, um die Einflüsse einer konsistenten bzw. inkonsistenten Orthographie auf die Aktivierung schriftsprachlichen Wissens während der auditiven Wortverarbeitung in einer Fremdsprache zu untersuchen.

Experiment 1 bestand aus einer auditiven rhyme judgement-Aufgabe mit englischen Wortpaaren, die einen orthographisch kongruenten (z.B. *turn* - *burn*) bzw. inkongruenten (z.B. *turn* - *learn*) phonologischen Reim enthielten. Alle drei Probandengruppen zeigten schnellere Reaktionszeiten bei orthographisch kongruenten im Vergleich zu inkongruenten Reimen, wobei der orthographische Effekt bei den deutschen Probanden am stärksten ausgeprägt war.

Experiment 2 umfasste eine phoneme deletion-Aufgabe, bei der die Probanden das erste Phonem eines auditiv dargebotenen englischen Wortes weglassen sollten während sie das Wort aussprachen. Die Stimuli bestanden aus orthographisch kongruenten Wörtern (*gold* - *old*) und inkongruenten Wörtern (*worth* - *earth*). Alle drei Sprachgruppen zeigten starke orthographische Effekte, welche sich folgendermaßen differenzieren lassen: Die orthographischen Effekte waren bei den deutschen und dänischen Sprechern am stärksten ausgeprägt, während die englischen Muttersprachler einen kleineren orthographischen Einfluss zeigten. Die hohen Fehlerraten und schnellen

Reaktionszeiten der englischen Probanden lassen jedoch einen *speed-accuracy trade-off* vermuten, so dass die Ergebnisse dieser Sprechergruppe weniger geeignet sind, um Vergleiche zu den nichtmuttersprachlichen Sprechern zu ziehen.

Während Experiment 1 und Experiment 2 explizite metaphonologische Komponenten beinhalteten, enthielt Experiment 3 keinen expliziten Fokus auf phonologische Einheiten bzw. korrespondierende orthographische Repräsentationen. Experiment 3 bestand aus einer lexikalischen Entscheidungsaufgabe mit orthographisch inkonsistenten Wörtern, d.h. Wörtern, bei denen der Reim auf verschiedene Arten geschrieben werden kann (z.B. /i:p/ kann *-eap* oder *-eep* geschrieben werden), und orthographisch konsistenten Wörtern, bei denen der Reim auf nur eine Art buchstabiert werden kann (z.B. /ʌk/ kann nur *-uck* geschrieben werden). Alle Probandengruppen zeigten längere Reaktionszeiten bei orthographisch inkonsistenten Wörtern verglichen mit konsistenten Wörtern. Ähnlich wie in Experiment 1 war der orthographische Effekt jedoch bei den deutschen Sprechern am stärksten ausgeprägt.

In Hinblick auf die Forschungsfragen zeigten die Ergebnisse der empirischen Untersuchung, dass schriftsprachliches Wissen während der auditiven Wortverarbeitung in einer Fremdsprache aktiviert wird (Forschungsfrage 1). Nichtmuttersprachliche und muttersprachliche Probanden zeigten lediglich in Experiment 2 eine unterschiedliche Stärke an orthographischer Aktivierung. In Experiment 1 und 3 wurden jedoch keine Unterschiede hinsichtlich der orthographischen Effekte zwischen L1 und L2 Sprechern gefunden. Insgesamt deuten die Ergebnisse darauf hin, dass keine verallgemeinerbaren Unterschiede zwischen L1 und L2 Sprechern vorliegen (Forschungsfrage 2). Vielmehr lassen die unterschiedlich starken Effekte zwischen deutschen und dänischen Sprechern darauf schließen, dass unterschiedliche Voraussetzungen zwischen den beiden nichtmuttersprachlichen Gruppen zu diesen Befunden geführt haben. Diese Unterschiede lassen sich vermutlich *nicht* auf unterschiedliche L2-Kompetenzen bzw. L2-Erfahrungen mit der englischen Sprache zwischen den deutschen und dänischen Sprechern zurückführen. Es scheint vielmehr, dass die orthographische Transparenz der Muttersprache, d.h. ob die Probanden in einer konsistenten oder inkonsistenten Sprache sozialisiert wurden, Einfluss auf die Stärke der orthographischen Aktivierung während der auditiven Wortverarbeitung in einer Fremdsprache hat (Forschungsfrage 3).

Zwei verschiedene Erklärungen für den Einfluss der orthographischen Konsistenz der Muttersprache werden mit Bezug auf das Arbeitsmodell zur bilingualen Sprachverarbeitung in Kapitel 6 diskutiert.

Die erste Erklärung stützt sich auf die Nutzung von zwei verschiedenen Routen innerhalb des Modells. So lassen sich die cross-linguistischen Unterschiede damit erklären, dass die dänischen Sprecher aufgrund ihrer Erfahrungen mit der inkonsistenten Orthographie des Dänischen eine direkte phonologische Route für die Verarbeitung gesprochener Sprache in einer Fremdsprache bevorzugen, die in einer schwächeren Co-Aktivierung der orthographischen Repräsentationen resultiert. Im Gegensatz dazu nutzen die deutschen Sprecher, welche mit einer transparenten Schriftsprache vertraut sind, innerhalb des Modells eine Route, die korrespondierende orthographische Repräsentationen während der auditiven Sprachverarbeitung co-aktiviert.

Eine alternative Erklärung bezieht sich auf die unterschiedliche Größe (*grain size*) der phonologischen und orthographischen Repräsentationen, welche zu einer unterschiedlichen Anzahl von aktivierten schriftsprachlichen Repräsentationen zwischen den deutschen und dänischen Sprechern führt. Mit Bezug auf die *psycholinguistic grain size theory* (Ziegler & Goswami, 2005) zeige ich, dass die deutschen Sprecher aufgrund der transparenten Orthographie der deutschen Sprache eine Verarbeitungsstrategie entwickelt haben, die sich auf kleine Einheiten, d.h. Phonem-Graphem-Korrespondenzen stützt. Diese Strategie wenden sie auch auf die Verarbeitung der englischen Wörter an. Dies bedeutet, dass die phonologischen Wörter in einzelne Phoneme segmentiert werden, die eine Vielzahl von korrespondierenden Graphemen aktivieren. Die dänischen Sprecher haben hingegen aufgrund der inkonsistenten Orthographie des Dänischen eine Verarbeitungsstrategie entwickelt, die eine Segmentierung in kleine und große phonologische Einheiten mit korrespondierenden orthographischen Repräsentationen beinhaltet. Diese Strategie transferieren die dänischen Sprecher auf die Sprachverarbeitung in einer Fremdsprache. Da die inkonsistente Orthographie des Englischen eine höhere Konsistenz für die Korrespondenz von größeren im Vergleich zu kleineren phonologisch-orthographischen Einheiten aufweist, führt diese Verarbeitungsstrategie zur Aktivierung einer geringeren Anzahl an orthographischen Einheiten im Vergleich zur Verarbeitungsstrategie der deutschen Sprecher. Auf diese

Weise lassen sich die unterschiedlich starken orthographischen Effekte zwischen den deutschen und dänischen Sprechern in Experiment 1 und 3 erklären.

Zusammenfassend ist festzustellen, dass die Ergebnisse der empirischen Untersuchung die Annahmen des entwickelten Arbeitsmodells stützen. Verbindungen zwischen phonologischen und orthographischen Repräsentationen bestehen nicht nur für die Wortverarbeitung in der Erstsprache – wie in einer Vielzahl von Studien bereits gezeigt wurde – sondern auch für die Verarbeitung in einer Fremdsprache. Desweiteren zeigen die Ergebnisse, dass das Arbeitsmodell sprachspezifische Besonderheiten bezüglich der Transparenz des orthographischen Systems der L1 berücksichtigen muss, welche sich auf die Verarbeitung in der L2 auswirken.

Die vorliegende empirische Untersuchung zeigt, dass die Schriftsprache fundamentale Auswirkungen auf die L2-Wortverarbeitung hat. Diese Befunde diskutiere ich abschließend in Hinblick auf den frühen Schriftspracherwerb in einer Fremdsprache, wie er beispielsweise seit einigen Jahren in Grundschulen in Deutschland praktiziert wird. Darüber hinaus bilden die Ergebnisse der vorliegenden Untersuchung eine empirische Basis für weitergehende Untersuchungen von phonologisch-orthographischen Interaktionen während der Wortverarbeitung in einer Fremdsprache. Durch die bimodale Struktur des Arbeitsmodells eignet es sich für die Untersuchung sowohl auditiver als auch visueller Wortverarbeitung in einer Fremdsprache. Weitergehende Untersuchungen sind notwendig, um die genauen Prozesse zu entschlüsseln, welche die Interaktion von orthographischen und phonologischen Informationen während der bilingualen Wortverarbeitung erklären können.

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Appendix A

A.1 Stimuli used in Experiment 1 (Rhyme judgement task)

Targets, orthographically similar (OS) and orthographically different (OD) cues in rhyme and non-rhyme condition.

rhymes			*nonrhymes*		
target	cues (OS)	cues (OD)	target	cues (OS)	cues (OD)
fate	mate	eight	beat	wet	sweat
fox	box	rocks	bomb	room	tomb
glue	clue	crew	cash	gosh	wash
goal	coal	soul	cough	stuff	tough
joke	stroke	soak	done	John	gone
june	tune	moon	foot	fruit	boot
knee	tree	key	hood	rude	mood
nail	fail	scale	howl	pole	bowl
name	blame	claim	leaf	chef	deaf
ride	side	guide	lord	bird	word
roast	toast	ghost	love	groove	move
spend	send	friend	read	bed	dead
start	part	heart	swear	beer	clear
tie	pie	guy	toe	blue	shoe
turn	burn	learn	town	phone	blown

A.2 Stimuli used in Experiment 2 (Phoneme deletion task)

Stimuli and response words in orthographically congruent and orthographically incongruent condition.

congruent		*incongruent*	
stimulus	reponse	stimulus	response
blast	last	beg	egg
bill	ill	burn	earn
fear	ear	phone	own
fact	act	fail	ale
farm	arm	folk	oak
cash	ash	curl	earl
cloud	loud	claim	lame
crush	rush	crane	rain
scar	car	school	cool
spend	end	sheet	eat
slip	lip	sleep	leap
slow	low	slam	lamb
soil	oil	same	aim
spin	pin	spy	pie
still	till	street	treat
swing	wing	sweat	wet
chart	art	cheese	ease
wage	age	worth	earth

A.3 Stimuli used in Experiment 3 (Lexical decision task)

Orthographically consistent and orthographically inconsistent word stimuli.

consistent	*inconsistent*
bag	boat
bell	buy
book	cheap
choice	claim
coach	crowd
dish	dealt
fact	doubt
faith	fault
field	fence
gang	guide
help	meal
job	meant
judge	myth
jump	priest
king	rule
knife	scale
left	soak
lunch	soap
milk	speech
pig	staff
pub	style
safe	taught
soft	theme
song	tongue
wealth	type

Appendix B

B.1 Participants' questionnaire

Questionnaire given to the participants prior to the experiments. German and Danish participants completed sections A and B whereas English participants completed section A only.

Section A: Personal details

1 Participant no. ______

2 Gender: ☐ female ☐ male

3 Age: _______ years

4 Year of study: ______ years

5 My mother tongue is: ☐ German ☐ Danish ☐ English ☐ other: ________

6 I have more than one mother tongue ☐ yes ☐ no
If yes, please specify: ________________________

7 I speak ☐ British English
☐ American English
☐ I don't know

Section B: Information about your non-native language proficiency and experience

8 Which foreign languages do you speak? Please try to describe your proficiency level.

	zero	beginner			intermediate			advanced			superior
		low	mid	high	low	mid	high	low	mid	high	
English	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
French	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Spanish	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Italian	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

9 When did you start to learn English?
- ☐ in kindergarten
- ☐ in primary school
- ☐ in secondary school
- ☐ ____

10 For how many years did you attend English lessons at school?
______ years

11 Have you ever been in an English-speaking country? How long?
- ☐ never
- ☐ one or two weeks
- ☐ a month at least
- ☐ a few months
- ☐ more than 6 months

12 How often do you watch English films with <u>English</u> subtitles?

never	rarely	sometimes	often	very often
☐	☐	☐	☐	☐

13 How often do you watch English films with <u>German/Danish</u> subtitles?

never	rarely	sometimes	often	very often
☐	☐	☐	☐	☐

The following questions refer to a typical week during the semester:

14 How many hours do you spend each week <u>reading</u> English texts (books, magazines, etc.)?
approximately ______ hour(s)

15 How many hours do you spend each week <u>listening</u> to English native speakers (on radio / TV /
internet or in personal communication)?
approximately _______ hour(s)

16 How many hours do you <u>speak</u> English each week?
approximately _______ hour(s)

B.2 Results of the participants' questionnaire (section A)

			German	*Danish*	*English*
1	*Number of participants*		60.00	60.00	60.00
2	*Gender [%]*	male	15.00	26,70	25.00
		female	85.00	73,30	75.00
3	*Age [years]*	mean	22,68	24,57	20,73
		SD	2.74	4.16	2.64
4	*Year of study [year]*	mean	2.43	2.95	2.23
		SD	1.25	2.02	1.37
5	*My mother tongue is… [%]*	German	100.00	.00	.00
		Danish	.00	100.00	.00
		English	.00	.00	100.00
6	*I have more than one mother tongue [%]*		.00	.00	.00
7	*I speak… [%]*	British English	50.00	36.67	100.00
		American English	13.30	31.67	.00
		I don't know	36.70	31.67	.00

B.3 Results of the participants' questionnaire (section B)

			German	*Danish*
8	*Describe your proficiency level of English (0 zero, 10 = superior)*	mean	7.67	8.15
		SD	.90	1.19
9	*When did you start to learn English? [%]*	kindergrarten	1.70	5.00
		primary school	6.70	86.67
		secondary school	91.70	8.33
10	*For how many years did you attend English lessons at school? [%]*	mean	9.22	9.25
		SD	1.24	1.45
11	*For how long have you been in an English-speaking country? [%]*	never	5.00	1.67
		1-2 weeks	35.00	48.33
		1 month	25.00	8.33
		> 1 month	8.30	13.33
		> 6 months	26.70	28.33
12	*How often do you watch English films with English subtitles? [%]*	never	61.67	1.67
		rarely	26.67	13.33
		sometimes	8.33	38.33
		often	1.67	23.33
		very often	1.67	23.33
13	*How often do you watch English films with German/ Danish subtitles? [%]*	never	61.67	1.67
		rarely	26.67	13.33
		sometimes	8.33	38.33
		often	1.67	23.33
		very often	1.67	23.33

14	*How many hours do you spend each week reading English texts? [hours]*	mean SD	8.20 6.34	15.42 9.03
15	*How many hours do you spend each week listening to English native speakers? [hours]*	mean SD	6.47 8.02	14.59 14.66
16	*How many hours do you speak English each week? [hours]*	mean SD	5.08 6.40	5.29 5.71