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„ Lexical-semantic processing in bilingual children
A cross-linguistic priming study "

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Zusammenfassung:

Neue elektrophysiologische und bildgebende Messmethoden haben in den vergangenen Jahrzehnten neue Erkenntnisse über die neurofunktionalen Strukturen, die bilingualer Sprachverarbeitung zugrunde liegen, geliefert. Vor allem die Schnittstelle von Lexikon und Semantik lässt in der neurolinguistischen Forschung noch viele Fragen offen. Ziel der vorliegenden experimentellen Studie war es, die funktionalen Verarbeitungspfade und kortikalen Strukturen zu erkunden, die der lexikalischen und semantischen Analyse sprachlichen Inputs zugrundeliegen, sowie zu untersuchen, ob es gemeinsame Repräsentationen oder funktionale Interaktion in der Verarbeitung der beiden Sprachen im bilingualen Gehirn gibt.

Dazu wurde eine experimentelle Studie mit 6- bis 7-jährigen Kindern durchgeführt: Mittels funktionaler Nahinfrarot-Spektroskopie wurde die kortikale Aktivierung während der Verarbeitung auditiv präsentierter deutscher und englischer Wörter gemessen. Die Abfolge der Stimuli folgte einem Priming-Design, wobei sowohl exakte Wiederholungen einzelner Wörter in einer Sprache, als auch Übersetzungen vom Englischen ins Deutsche und umgekehrt in der listenartigen Präsentationsabfolge der Wörter vorkamen. Die statistische Auswertung zeigte erhöhte Aktivierung für die Verarbeitung deutscher Wörter in linker temporaler Messposition, einen Priming-Effekt bei der Wiederholung von englischen Stimuli in temporalen Positionen bilateral, sowie Priming bei der Übersetzung Wörtern vom Englischen ins Deutsche in rechts-temporaler Position. Diese Ergebnisse werden im Bezug auf psycholinguistische Modelle interpretiert, und im Zusammenhang mit aktuellen Ergebnissen neurolinguistischer Studien diskutiert.

Abstract:

During the last decades the continuously improving neuroimaging methods have shed some light on the neurofunctional architecture of the bilingual brain. Especially the organization of the bilingual lexicon and semantic system remains a major question in neurocognitive research. The aim of this study was to analyze the functional pathways and anatomical structures underlying lexical and semantic processing in the respective languages, and to test whether there are functional interconnections or common mental representations between the two languages in the bilingual brain.

The experimental study with 6 to 7 year old German-English bilingual children used a repetition and translation priming design: The single words were presented auditorily in blocks of German and English. The presentation sequence contained exact repetitions of words in both languages respectively, as well as translated word pairs. The cortical activation was measured with near infrared spectroscopy (NIRS). The statistical analysis revealed greater activation for German words in left temporal position, a within-language priming effect for English in temporal positions bilaterally, and a cross-language priming effect from English to German items in right temporal position. The results are discussed in the light of psycholinguistic models of lexical-semantic processing and with respect to current neurophysiological research.

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1. Introduction

What happens in our brain when we hear speech in a language that we know? As any human can, from pure introspection, confirm: we understand it. But what does it mean to understand a word?

When we hear a word in a language we know, our brain starts off a sequence of complex cognitive mechanisms, which pick up the acoustic signal, identify it as a word – thus, an arbitrary, meaningful phonetic code –, decompose it into morphological components – the smallest linguistic units carrying semantic meaning – and, considering the way these morphemes are assembled, retrieve the meaning of the perceived word, thus, the semantic concept which the word stands for in our mind.

But the internal functioning of these processing steps is not unambiguous: Obviously, we do not only associate different meanings to the same word form, when used in different contexts, but we can also have several words at our disposal representing, mainly, one and the same concept.

And this referential plurality becomes even more drastic and complex in the case of bilingualism: If an individual masters more than one language, their lexical entries virtually double up; also, these lexemes can apparently be distinguished in a mutually exclusive manner by the context of their usage, or rather respective compositional incompatibility. This observation gave rise to further debate on the organisation of this mapping process between a lexical entity and its semantic meaning, or in general, the crossroads between the so called lexicon – our mental vocabulary store –, and the semantic memory – the network storing the concepts we have established in our mind to represent entities in the real world.

Thus arises the general question of this thesis, which aims to investigate, if and in what way the processing of the different languages in the bilingual brain differ from each other, and to which extent these respective linguistic systems interact.

In order to investigate the neurofunctional organisation of this lexical-semantic interface, we will specifically try to explore the cortical basis of its processing steps and pathways, and track possible qualitative or quantitative, developmental or structural

differences of the cortical substrate responsible for the processing of different languages in the bilingual brain.
As a means for contributing to these questions an experimental study with six to seven year old German-English bilingual kids was conducted, monitored by near infrared spectroscopy (NIRS), a brain imaging method working with near infrared light; the findings from this study will be presented and discussed.

In order to sketch out the theoretical background of the subject, we will first give a brief introduction on linguistic symbols and their meanings, and present models accounting for the functional components of language processing; after restricting our point of view on the lexical-semantic mapping process in bilingual language processing, a description of the empirical experimental study will prepare the final discussion of the obtained results.

To preliminarily clarify the discussed variables, the next chapter will be dedicated to a thorough look at different attempts to classify bi- and multilingualism.

2. THEORETICAL PART

2.1. Defining Bilingualism

The first terminological issue that needs to be discussed in the context of this thesis is a working definition of bilingualism. The term '*bilingual*' with its prefix '*bi-*' clearly refers to someone speaking exactly two languages. Obviously, the models and mechanisms discussed here could refer just as well to the case of *multi*lingual speakers, or *polyglots*. Since the below discussed experimental study has been conducted with German-English bilingual children, I will continue to use the term *bilinguals,* with the implication, that the findings of the study could also be applied to multilingual cases, an assumption I will, however, not explore further.

In a conservative understanding of the term *bilingualism*, a true bilingual was a person having been raised with two languages simultaneously, for example because the parents had two different mother tongues, or because of the family language being different from the one spoken in their home country. Also, these kinds of bilinguals were, and are still being seen as exceptional, as a minority compared to the amount of monolinguals in our societies.

Taking a less euro-centric and more current look at the language situation worldwide, it is clearly noticeable that multilingualism is not an exception, but reality for probably more that 50% of the worlds population (Grosjean 1982; Tucker 1999): Many post-colonial countries have one official, administrative language, being spoken in all schools and official institutions or in bigger cities, and many different local languages and dialects spoken in the families, on markets and streets, in informal everyday-life situations – a fact making it necessary for the population to be fluent in at least two languages, simply in order to participate in their country's social life. On the other hand, in the "western", or "first" worlds countries, in spite of them being organised as nation-states, and sharing one main language and culture, as a result of globalisation and internationalisation nearly every child starts learning a second language at a very early age in school, and a majority of the people ameliorate their second language competence travelling abroad, thus making pure monolingualism a decreasing phenomenon.

All these cases, in spite of them subsuming people speaking more than one language in their everyday life, differ from each other in several factors, which have been used by scientists to classify types of bilingualism:
Concerning the manner of acquisition, bilinguals have been classified as *compact*, *coordinated*, and *subordinate bilinguals*. Following this distinction, a *compact bilingual* has learned both languages before an age of more or less 6 years, in his immediate environment. A person will be classified as *coordinated bilingual* if he or she learned a second language before puberty, mostly due to changes in the family or place of residence. Finally, a *subordinate bilingual* has learned an additional language after puberty, and uses his second language to translate concepts and utterances structured in his mother tongue (Fabbro 1999).
Weinreich 1953 (as cited in Appel et al. 2006) used the same terminology to characterize the mental representation of the two languages, as well as their functional interaction: According to his definition, in a *compound* bilingual the two languages would function autonomously, each having established their own connection to semantic memory, and working independently of each other. For a *coordinate* bilingual, the semantic concepts of his two languages are shared, and some domains of the second language are mediated by L1 structures. In a *subordinate* bilingual system the L2 was acquired - and thus is also processed - through the mediation of the L1, which has been learned earlier and is typically spoken with higher fluency.
A common, though very imprecise terminology, based on age of acquisition of the two languages, differentiates between *early* bilingualism, thus acquisition of both languages at a very early age, *late* bilingualism to refer to the case of a second language being learned significantly later than the mother tongue, and *adult learning of a second language*.
Finally, a classification emphasizing the proficiency of the two languages in a bilingual person defines a *balanced* bilingual as the ideal case of equally high native competence in two languages, while a *dominant* bilingual has superior competence in one, his first language.

All of these classifications have proven to be useful to interpret some scientific questions or explain some empirical results, but none of them could have ubiquitous validity.

Returning to the quest of a definition of bilingualism, it becomes clear, that we can only try to trace out the range of the possible cases, in order to get an overview over the phenomenon of bilingualism: While the 'maximal' definition represents a bilingual, also called *ambilingual* (Halliday et al. 1964), with "native-like control of two languages" (Bloomfield, 1933 p.56, as cited in Bhatia 2008 p.114), a 'minimal' definition, describing the very beginning of bilingualism in an individual, would define a person as bilingual from the point where he or she "can first produce complete meaningful utterances in the other language" (Haugen, 1953 p.7, as cited in Bhatia 2008 p.114).

Most bilinguals cases are, obviously, situated somewhere in between these two extremes.

2.2. The lexical-semantic interface

Umberto Eco (1990) points out the importance of semiotics, the science of signs and symbols, by proposing, that the entirety of cultural acts and entities can be ascribed to acts of signification and communication. Following this definition and taking a closer look at what Eco called acts of communication and signification, we clearly see the implication for *langage*, which is by far our strongest tool for both of these acts: We use words, just like semiotic units or symbols, to refer to entities in the real, or any imagined world – thus, objects, situations, ideas, acts, or other issues –, and to convey these topics to an eventual listener, independently of a deictic origo.

But how does this mapping process, this encoding of semantic information to arbitrary linguistic codes, function on a cognitive level? We need to establish mental concepts, acting as *references* (see figure 1) of the concrete or abstract entities, which we want to refer to in the world (see *referent*, figure 1); these references, or mental concepts, constitute our semantic memory. Each mental concept is then mapped to one or more corresponding lexemes (or, in general, *symbols*). And this cognitive crossroads will be referred to as the lexical-semantic interface.

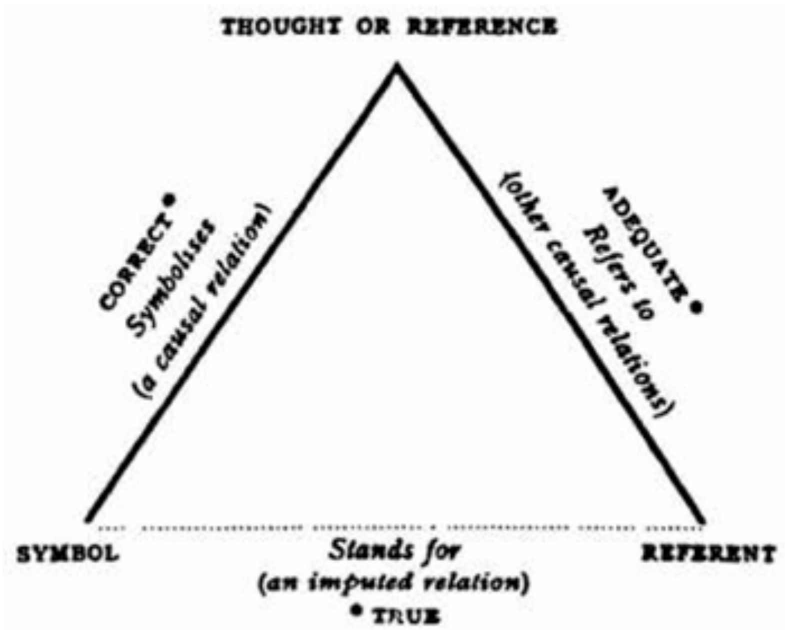


Figure 1: The so-called Semiotic Triangle, also called Semantic Triangle.
From "The Meaning of Meaning. A Study of the Influence of Language upon Thought and of the Science of Symbolism" by Ogden (Ogden et al. 1927, p.11)

Now, if attempting to draw a neurofunctional model of this interface, we need to know what the interaction between items from the lexicon and from semantic memory could look like. Clearly, the tempting image of a dictionary-like one-to-one relationship from each concept to one single lexeme, unambiguous and complete, does not reflect what experience and empiricism show: Firstly, a single concept can often be verbalised in more than one way; the subtle difference between the competing expression equivalents can reflect the speakers age (youth language), social context (sociolect), emotional relation to the subject (e.g. vulgar expressions, etc.), and so on. Secondly, one word can often represent more than one concept – depending on the context of usage, prosody, or position in the sentence.

The bilingual brain shows this referential ambiguity to an even bigger extent, but assumingly with one additional feature: The huge amount of lexemes is organised in such a manner, that lexemes from one language are usually not used in syntagmatic combination with lexemes from another language. Even though several questions concerning the comparability of the bilingual and monolingual brain are still unanswered (Are different sociolects or registers, just like different languages, not mutually exclusive concerning their usage, and thus syntagmatically incompatible, too? Is the difference between the realisations of one concept in two languages really ‘bigger’ than the divergence of its expressions in different situational registers? Does being bilingual totally alter the neurofunctional setup, or can bilingual language use be managed by an extended form of the normal language processing structures?), studies on bilingual language processing are often used to shed some light not only on the structure of the bilingual lexicon, but possibly on the functional and neurophysiological organisation of the lexical-semantic interface in general.

After sketching out this basic semiotic model, the next chapter will present different functional models of lexical-semantic processing.

2.3. Modelling the lexical-semantic interface

2.3.1. Models of monolingual language processing

Before discussing the neurofunctional mechanisms of bilingual speech processing, a brief description of the research on monolingual lexical-semantic processing shall be given.
Many models have been proposed to account for the sometimes very divergent empirical results on speech processing in healthy or aphasic subjects. Two of the most influential models from the last three decades, each representing a different neurofunctional architecture, shall be presented here.

2.3.1.1. Logogen Model

The Logogen model was first proposed by John Morton (1969). Morton originally designed it to account specifically for the phonological or graphemic word recognition process, thus constituting a passive system, responding to provided input. He introduces a basic processing unit in his model and calls it *logogen* – from Greek *logos* (“word”) and *genus* (“birth”). This unit is a device which accepts information from the *sensory analysis mechanisms*, concerning the properties of linguistic stimuli, and from another mechanism, called the *context system*, concerning the probability of occurrence of a word in a specific context. Each logogen is thus defined through the kind of information it can accept, and by the response it makes available. When the amount of linguistic and contextual properties of the input matching a certain logogen exceed its *threshold level*, its specific response is made available.

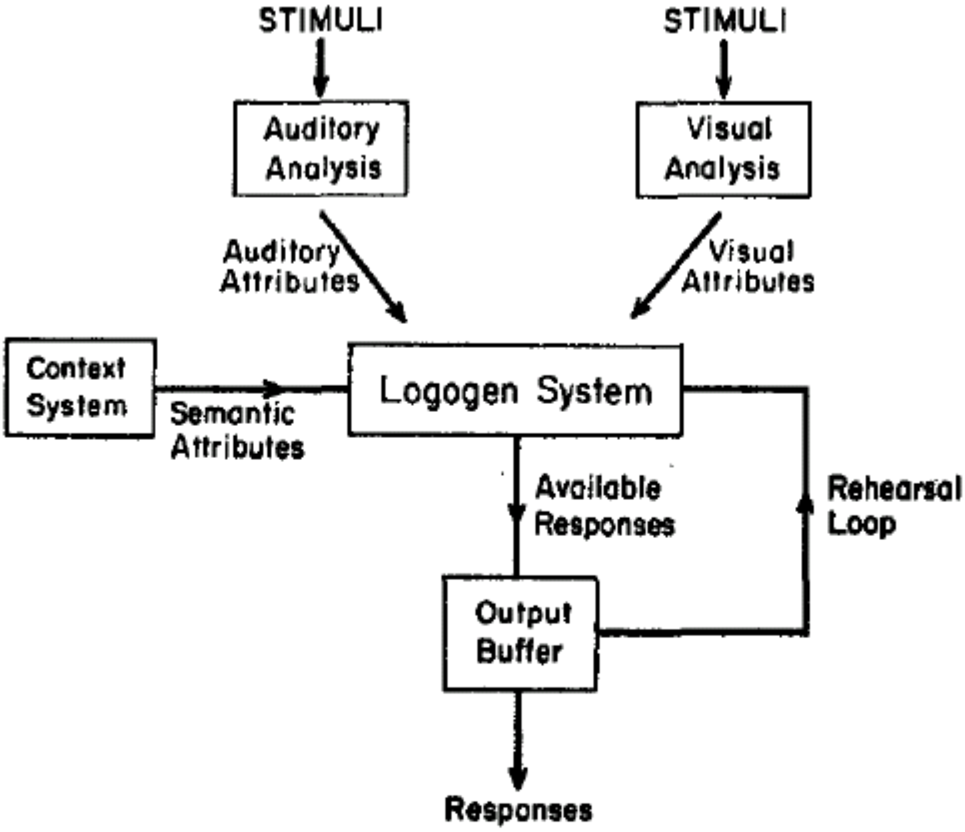


Figure 2: Flow-diagram for the Logogen Model.
(From Morton 1969, p.166, fig.1)

This flow diagram provided by Morton 1969 shows the basic components of the system: The language input is first processed by either an auditory or a visual analysis mechanism, which dissects the information in its phonological or graphemic properties and passes this information on to the logogen system. Additionally, the context system can increase or decrease the logogen's activation level by processing information about the language context created by the arriving stimuli and matching it with contextual properties of the specific logogen. This new device was introduced by Morton to account for the effect of context on word recognition, as will be explained further on.

Another strength of the model is, that word frequency effects can be explained using the above-mentioned notion of threshold levels of activation: Through continuous language input the activation levels of the different logogens rise and fall. The activation level of logogens, whose properties occur frequently in the received input, will frequently reach threshold level, and make their response available. Thus, the resting level of these frequently needed logogens will be lastingly raised, as a result of an adjustment process of the system affected by the processed input, which makes less additional activation necessary in order to reach threshold level. This explains the empirically proven shorter reaction times in the processing of highly frequent words in comparison to less frequent words.

Note, that in the original model in figure 2 no separate semantic system as such is provided – information concerning semantic properties of words is said to be stored in the logogens, just as information on phonetic or graphemic properties.

An important limitation of the logogen model, however, lies in the fact that, since one logogen is presupposed to store information about one single linguistic unit, only the recognition of monomorphemic words can be explained. Morton’s model provides no morphological composition mechanism for logogens.

In subsequent research, the logogen model has been extended to account for more cognitive linguistic tasks such as reading aloud, auditory word repetition, or writing and picture naming, thus also for active speech or writing processes. A developed form of the logogen model, as designed by De Bleser and colleagues (1997) is depicted in figure 3:

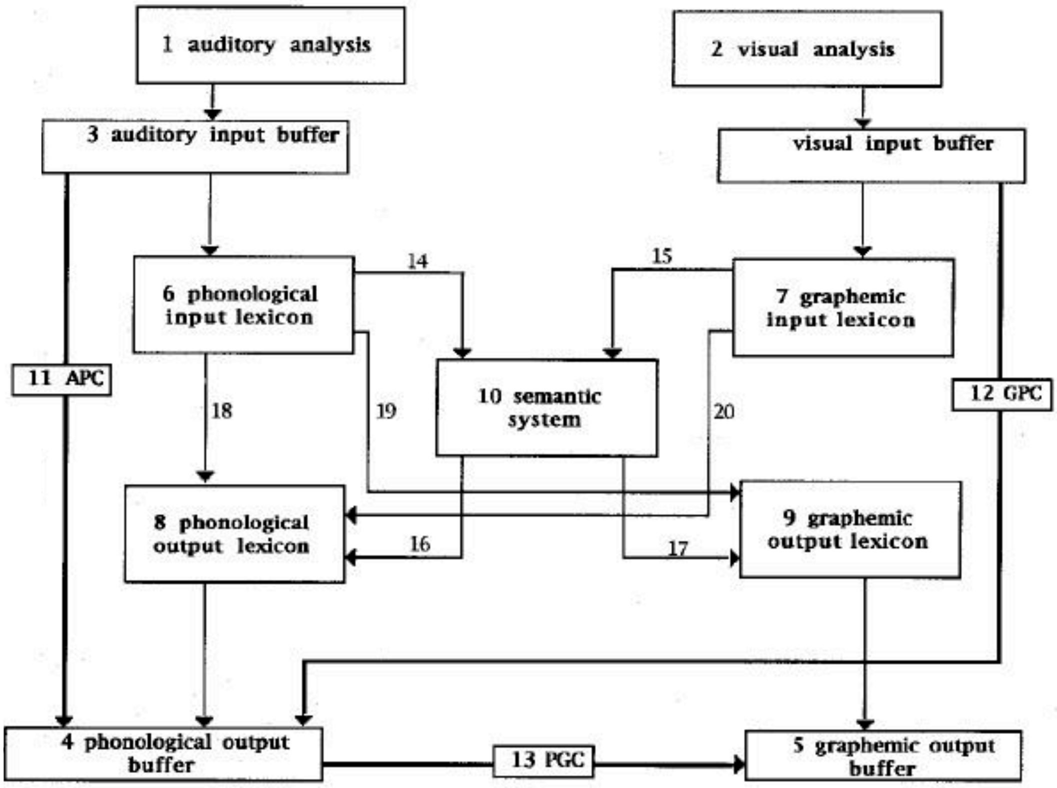


Figure 3: Logogen model for the processing of monomorphemic words (after Patterson, 1988) APC = auditory-phonological conversion; GPC = grapheme-phoneme-correspondence; PGC = phoneme-grapheme-correspondence.
(From De Bleser et al. 1997, p344, fig.1)

Here the different information stored in the logogens has been split up into different functional units: In the middle of the graph, we now see a semantic system, which stores word meanings, while phonetic, graphemic, syntactic or word form information is stored in the respective lexicons. The functional dissociation between phonological input, phonological output, graphemic input and graphemic output lexicon, like many other implications on functional processing in this model, has been proven mostly by double dissociations in studies with aphasic patients, showing language deficits in one isolated processing unit or pathway only.

Since this thesis is especially interested in phonological word recognition processes, figure 4 shows a close up on the mechanisms responsible for this cognitive process in the logogen model.

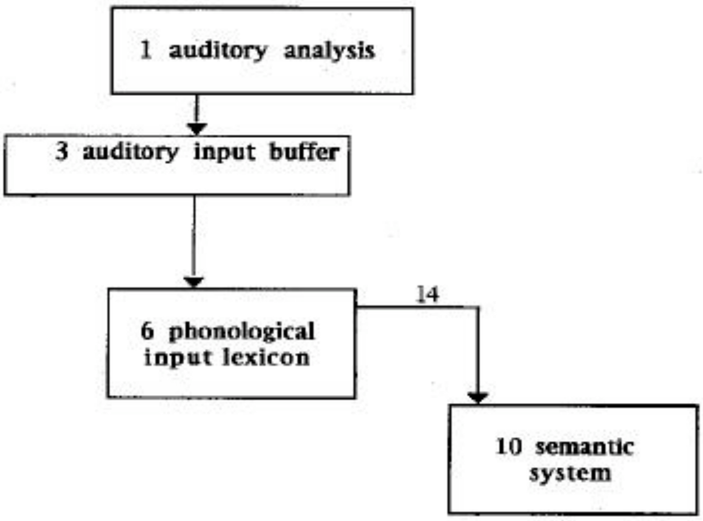


Figure 4: Detail from the Logogen model for the processing of monomorphemic words (after Patterson, 1988): Components responsible for phonological word recognition.
(From De Bleser et al. 1997, p344, fig.1)

Another interesting expansion of the logogen model, especially describing the phonological input lexicon, has also been proposed by De Bleser et al. (1990) on the basis of some earlier models in the framework of lexical morphology theories, e.g. by Kiparsky (1982). To account for the processing of polymorphemic words they described the phonological input lexicon as a set hierarchically, modularly organised units, processing lexemes on the basis of their word class and can deal with processes of inflection, derivation and compounding.

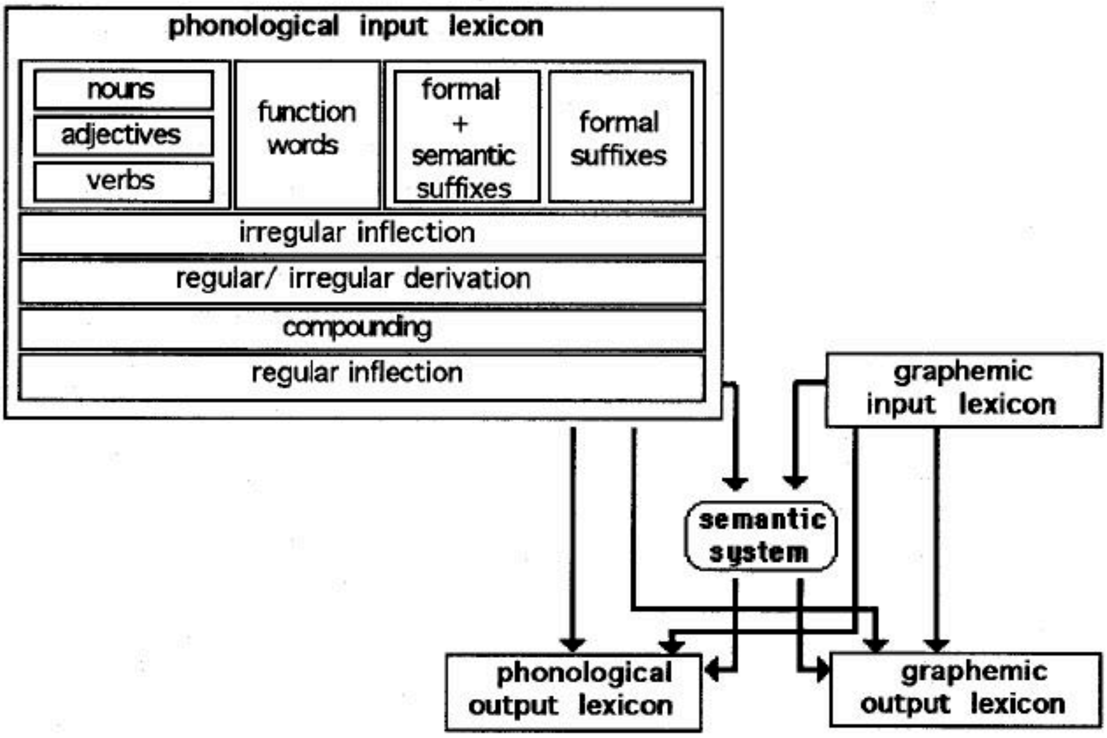


Figure 5: Expanded lexical system for the processing of polymorphemic words in the logogen model (after De Bleser & Bayer, 1988)
(From De Bleser et al. 1997, p.353, fig.2)

But since the stimuli used in the experimental study as part of this thesis were generally monomorphemic words, we will not describe the morphological processes proposed by this expanded model.

2.3.1.2. Interactive activation model

The interactive activation model (IAM) by McClelland and Rumelhart (McClelland et al. 1981; Rumelhart et al. 1982) adopts a totally different approach to the modelling of language processing: The logogen model, as described above, is composed of modular processing units, where information is stored as a whole, and can be passed on hierarchically. Interactive network models, on the contrary, try to model cognitive processes as the complex interaction of many computationally primitive elements in a parallel network. Firstly, this approach seems to account better for the actual neurophysiological structure of the human brain: the functioning of the primary elements of an interactive network, also called nodes, is similar to that of neurons, as each one can receive a certain type of information – thus, neurologically speaking, receive activation from other neurons – and will pass this information in the form of activation on to other elements of the network. Secondly, the functioning of these network models, assuming a vast number of elements governed by relatively simple rules, can be well simulated by computational programs, thus producing quantitative assumptions about the impact of different input or about the malleability of the system through learning processes.

While network models were originally adopted to explain human memory processes in general, they were soon found very suitable to explain perception and linguistic processes: In the early eighties, McClelland and Rumelhart (McClelland et al. 1981; Rumelhart et al. 1982) present an interactive activation model for the reading process; in 1983 (Elman et al.) and 1986 (McClelland et al.) an equivalent model for the speech perception process is proposed.

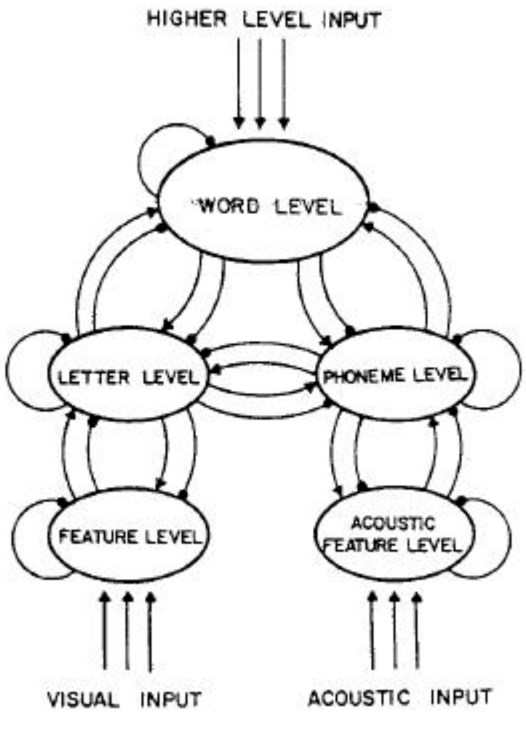


Figure 6: The four main processing levels of the interactive activation model, accounting for visual and auditory word recognition.
(From McClelland et al. 1981, p. 378, fig.1)

As sketched in the graph in figure 6, four processing levels, each forming a representation of the presented input at a different level of abstraction, are assumed to account for visual and auditory word perception: on the "lowest" level, basic visual (e.g. vertical, horizontal, or diagonal lines) or acoustic features (sounds of different frequencies, containing specific formants, etc.) of the perceived input are being detected; this information is being passed on to the subsequent level, which recognises letters or phonemes; finally words are being identified on one common level, fed also with so-called *higher level* "top down" *input* of conceptual nature.

Within each one of these levels, every relevant informational unit of the system, thus every word we know, or every letter in its specific position, etc., is represented by an element called a *node*. Every node is connected to other nodes on his own and on neighbouring levels by a two-way connection, which is either of *excitatory* or *inhibitory* nature: When a unit, for example the word *the*, suggests the existence of another unit, for example the initial letter *t*, on its neighbouring level, and vice versa, the nodes representing these two features are connected by an excitatory connection – when two units cannot be involved in the processing of the same input, for example in the case of the nodes of two different words, they will inhibit each other.

This network, constituted of *nodes* and *excitatory* or *inhibitory* connections, works in a parallel way, that is, different levels can operate at the same time. Additionally, so called "top-down", or "conceptually driven" processes, transmitting activation from higher to lower levels of the model, and "bottom-up" or "data driven process", passing on information from lower to higher levels, both contribute to the processing of a stimulus and thus determine what we perceive. This kind of network interaction, where activation from one level is spreading to neighbouring levels, is called *spreading activation mechanism*.

Concerning word frequency and context effects, the IA design describes a functional pattern similar to that proposed by Morton (see Logogen model, above), in that the frequency of processing of specific input, and thus the frequency of activation of specific nodes, can enhance the processing of familiar input, relative to unfamiliar input, resulting in reduced reaction times, or lower processing effort necessary. The difference between the logogen model's predictions and the IA framework include the idea, that according to McClelland and Rumelhart not only the *logogen*, thus, in the IA model, the lexical node of a word itself, can obtain a higher resting level activation through frequent activation, making it easier for that node to reach recognition threshold (or, in other interpretations, obtain a lower threshold level, resulting in the same processing advantage through less activation needed to make the node “fire”), but all higher-level or lower-level nodes connected to that specific word node and making up its context – established through formal similarities as well as experienced context of usage etc. – develop stronger or weaker excitatory or inhibitory connections to that specific word node, through the influence of the specific contexts in which the word was used before! This functional architecture is capable of accounting not only for priming effects in simple repetition paradigms, but can explain also semantic-, context-, or translation-priming, because the direct pre-activation of the specific word node itself is not the only factor of processing efficiency.

However, in the further description of processing details, occurring effects and empirical support of the model, McClelland 1981 concentrate on the interaction between a (*visual* or *acoustic*) *feature level*, a *letter* or *phoneme level*, and a so-called *word level*, and gives only a sketchy description of the organisation of semantic memory or conceptual feature nodes, under the vague term *higher level input*, thus giving no clear answer to our questions on the lexicon-semantic interface.

Still the interactive activation model remains very influential in research on visual and auditory language perception, and has been further developed and tested.

2.3.2. Models of bilingual language processing

A further challenge to the investigations on the neurofunctional mapping of form to meaning is the question, how this mapping process takes place in bilinguals. Considering performance, L1 and L2 representations seem to be functionally separate – most people can choose to speak only one language. But if one hears speech in two languages, which are both known to him, he will still be able to understand both – thus, to switch from one to the other language during the perception process. Research has been trying to show, whether word form and semantic meaning in two different languages are represented independently, or stored in a shared system. Two different approaches, one modular hierarchical model and one connectionist model, will be discussed in this chapter.

2.3.2.1. *(Re-)revised hierarchical model*

Potter and colleagues (1984) hypothesized two alternative models of bilingual lexical-semantic processing and tested them in a study with more or less fluent bilinguals. Both models assume a lexical level, which contains information about word form and syntactical features of words, and a concept level, containing real world knowledge about the objects and issues that words refer to. Also, in both models the concept level is shared by the L1 and the L2 language.

In the so-called *concept-mediation* mode*l*, the lexical levels of both languages have no direct connection, but both access the same concept level.

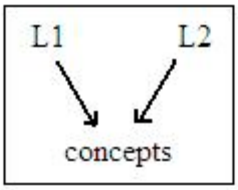


Figure 7: The concept mediation model, as proposed by Potter et al. 1984

The tasks carried out in the empirical experiments in order to test this model were picture naming and translation; if both of these should be accomplished via concept mediation, they would take more or less equally long to perform.

On the contrary, the *word association* model assumes that L2 words can access conceptual information only through their L1 translation equivalents. In this case, translation tasks could be accomplished through the direct link between the two lexicons, and should thus take significantly less time than picture naming in L2, which would need to take the longer route over the L1 lexicon.

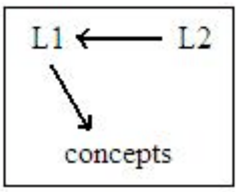


Figure 8: The word association model, as proposed by Potter et al. 1984

Subsequent research has shown, that it is not possible to prove only one of these models to be right for all kinds of bilinguals: Chen & Leung (1989) and Kroll & Curley (1988) found, that less fluent bilinguals in an early stage of their L2 acquisition process performed translation tasks faster than picture naming, in accordance with the word association model, while more proficient bilinguals performed equal reaction times, in accord with the predictions of the concept mediation model.

These findings lead to a developmental hypothesis, suggesting that there is a shift from a lexical to a conceptual mapping strategy, entailed by the factor of second language proficiency: At an early stage of L2 acquisition, L2 word meanings are accessed via the L1 lexicon, and as the speaker becomes more fluent, L2 words gradually strengthen their direct conceptual mediation route.

This new hypothesis, incorporating the two originally alternative models, has been described by Kroll & Stewart (1994) under the name *revised hierarchical* model: While both L1 and L2 lexicons have a conceptual link to the semantic system, and are also interconnected by a lexical link, the L1's lexical link is stronger than the L2's, and the lexical link from L2 to L1 lexicon is stronger than the opposite one.

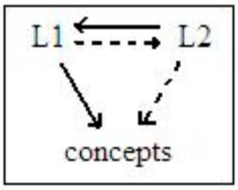


Figure 9: The revised hierarchical model, as proposed by Kroll and Stewart 1994

First and second language in the model depicted above are commonly defined on the basis of age of acquisition. But experimental findings from the mid 90s (e.g. De Groot et al. 1994; Heredia 1997; La Heij et al. 1996) reported no translation time differences for concrete words in different proficiency groups, suggesting both translation directions to be sensitive to semantic processing, or even reversed translation times (L1 to L2 translation faster than L2 to L1 translation) for abstract words! These findings started calling into question some basic assumptions about the revised hierarchical model's components. Heredia (1996; 1997) proposed a modification of Kroll & Stewards revised hierarchical model: Instead of L1 and L2, the *re-revised hierarchical model* labels the two languages of a bilingual "most dominant language" and "least dominant language", assuming that the dominance between them is not a stable relationship based on the age of acquisition but can change throughout a lifetime: The dominance of a languages is seen as a function defined by individual word frequency, which is dependant on the intensity of usage.

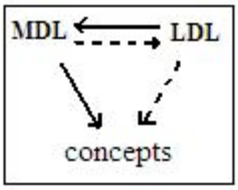


Figure 10: The re-revised hierarchical model, as proposed by Heredia 1996; 1997

2.3.2.2. Bilingual interactive activation (plus) model

In the nineties, Dijkstra and Van Heuven (1998) extended the interactive activation framework to account for bilingual language processing. Based on the interactive activation model for visual word recognition, they proposed the bilingual interactive activation (BIA) model, originally also only for the visual processing modality. The model maintains the IA model's concept of *feature*, *letter*, and *word* level, all of which contain units representing both L1 and L2 features, letters or words. Additionally the BIA assumes a fourth, the *language node* level, which contains a single node for each language, to which all word items from the lower level are connected, thus specifying the language context of the processed input. The shared letter level assumes that the specific letters and positions, activated by visual input, will pass on their activation to both L1 and L2 words, a phenomenon in the bilingual literature usually referred to as *unselective access*. But, since all items on the word level are also interconnected, they mutually inhibit each other's activation, a phenomenon referred to as *lateral inhibition*.

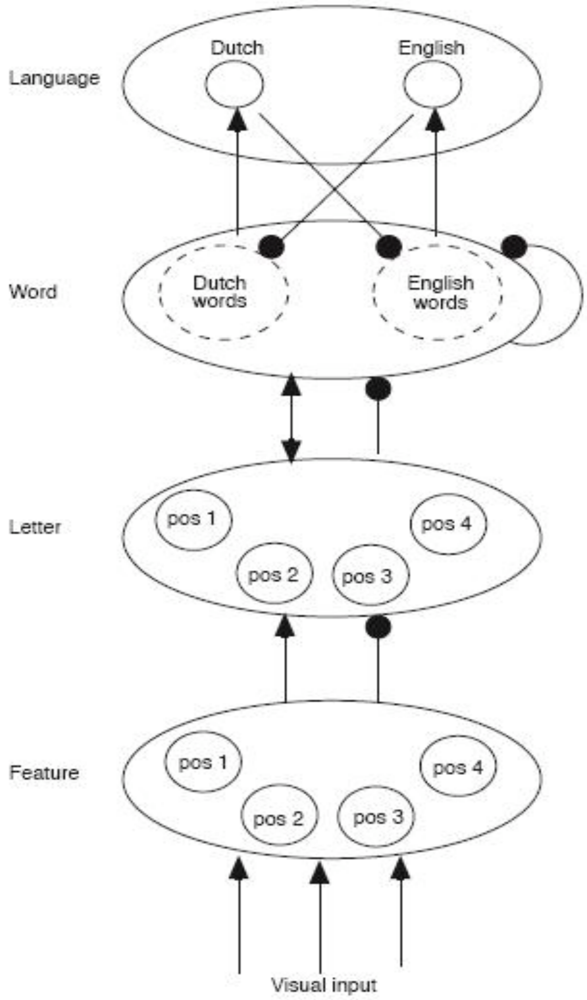


Figure 11: The bilingual interactive activation (BIA) model word recognition. The arrow heads indicate excitatory connections, the black circle heads indicate inhibitory connections.
(From Dijkstra et al. 2002, p.117, fig.1)

Four years after their first paper on the BIA model, Dijkstra and Van Heuven (2002) presented a new model, the BIA+ model, extending the ideas of the BIA model to orthographic and phonological recognition; its functioning is also adapted to new findings by Green (1998) and his idea of an additional task/decision system, but these aspects of the model will not be explained here.

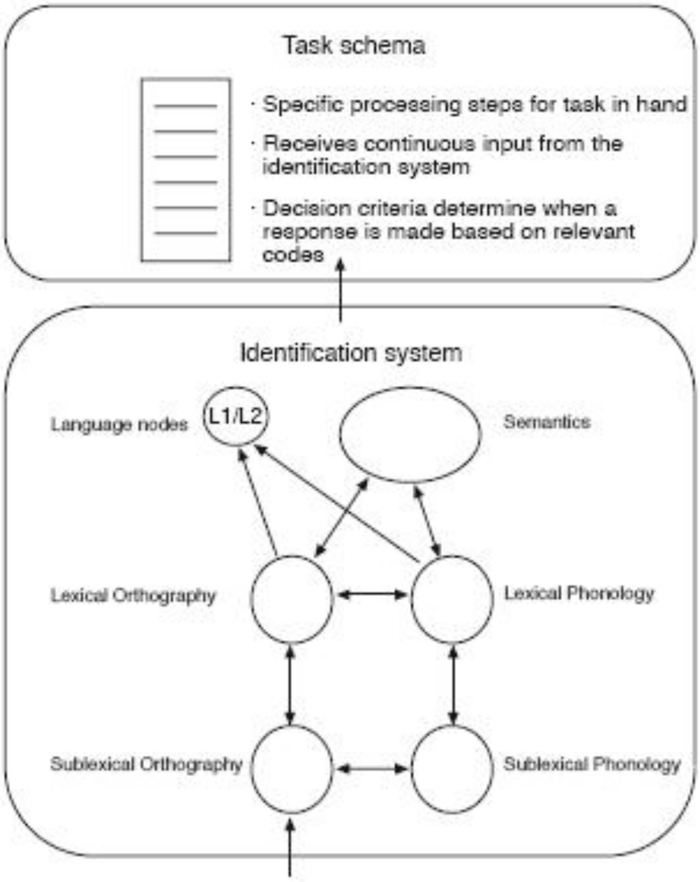


Figure 12: The BIA+ model for phonological and orthographical word recognition. Lexical level processing is divided in a sublexical and a lexical level.
(From Dijkstra et al. 2002, p.182, fig.2)

In order to account for the context-sensibility effect in some languages' mapping process between graphemes and phonemes, the authors introduce a sublexical and a lexical level of each orthography and phonology (see fig. 12), segmenting the input first in clusters, then in syllables, and finally into words.

2.4. Neurofunctional basis of language processing

The different models presented in the last chapter try to explain the functional architecture of language processing. But what do the neuroanatomical structures underlying language processing look like?

2.4.1. Monolingual Language Processing

2.4.1.1. Anatomical Structure of the Cortex

Most areas responsible for language processing, but also most structures important for memory, perception or consciousness are situated in the cerebral cortex, the outermost part of the brain, a 2 to 4 mm thick layer of neurons. Four regions have been defined to describe the neurofunctional architecture of the cortex: The frontal, temporal, parietal and occipital lobe.

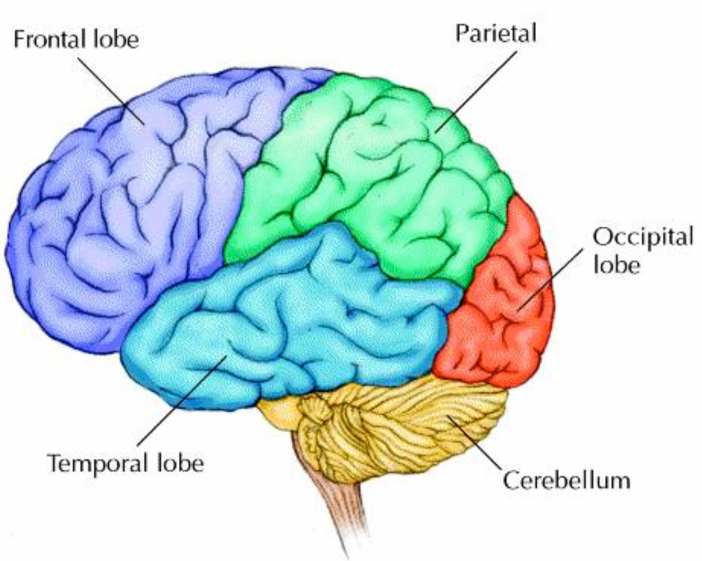


Figure 13: The five main regions of the cortex.
From http://www.deryckthake.com/psychimages/cerebral_cortex.jpg, on 20.8.2010.

Most of these gross areas can be further divided into superior, middle and inferior cortex, gyrus (the ridges on the cortical surface) or sulcus (the fissures on the cortical surface, surrounding the gyri).

To further classify smaller regions of the cerebral cortex, Korbinian Brodmann, a German neurologist, elaborated a numbered map, dividing the cortical surface into so-called Brodmann areas (BA) based on each site's specific cytoarchitecture, thus the organisation of neural cells in the tissue.

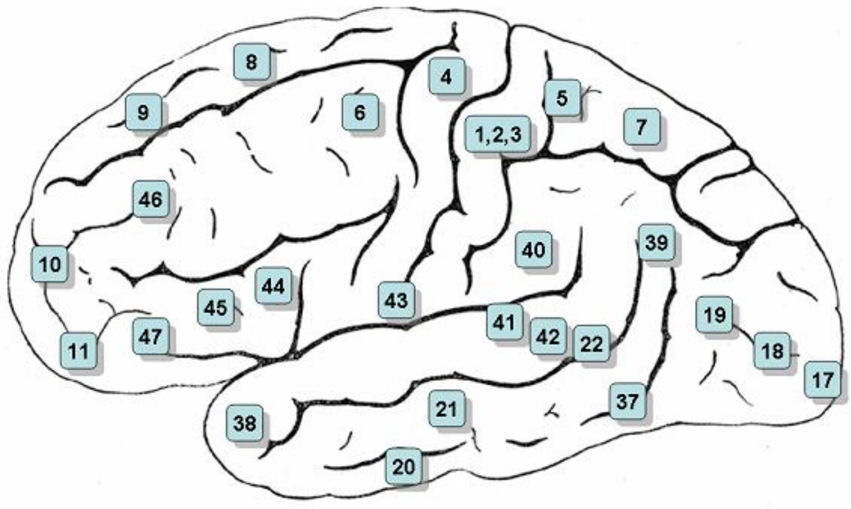


Figure 14: The Brodmann areas, a numbered categorization of brain regions by K. Brodmann. From http://en.wikipedia.org/wiki/File:Gray726-Brodman.png, on 20.08.2010.

These maps will serve to unambiguously describe different language areas in the course of the following chapters.

2.4.1.2. Language processing in the adult brain

2.4.1.2.1. Evidence from the study of lesions and behaviour

The earliest contributions to the question of localization of language functions have been published by Paul Broca and Carl Wernicke, who studied the brains of patients with brain lesions post mortem, in the 19th century.

Broca's patient suffered of severe speech impairment, being able to utter only one syllable. The brain region injured in this patient, the left inferior frontal gyrus, was thus hypothesized to play a major role in speech production, and has become known as Broca's area (BA 44 and 45).

The patients studied by Wernicke had preserved relatively intact and natural sounding speech production, but were unable to understand spoken or written language; as a result of their lexical-semantic impairment, their utterances were syntactically correct, but semantically meaningless. Wernicke thus described the region injured in these patients, the posterior section of the superior temporal gyrus of the left (or dominant) hemisphere (mainly BA 22), as responsible for spoken and written language perception – a view which has been more or less maintained for a long time, but seriously challenged in the course of the last decades by neurophysiological studies showing the involvement of much more widespread areas in the temporal lobe as well as parts of Broca's area around the inferior frontal cortex in language perception.

2.4.1.2.2. Evidence from neuroimaging- and electrophysiological studies

Since the development of neuroimaging methods like fMRI or NIRS new studies have further specified the localization of language functions. These new measuring methods can be applied on the intact, healthy brain, and are capable of differentiating the loci of different stages of language processing.

Generally, the left hemisphere is said to play a major role for most language related cognitive functions. According to Friederici (2006b), *syntactic* processing takes place mainly in the left inferior frontal cortex and the anterior portion of the temporal cortex. Different neuroimaging studies have reported specific activation in Brodmann areas 44 and 45, as well as in the frontal operculum adjacent to inferior portion of BA 44 (Caplan et al. 1998; Friederici et al. 2000a; Inui et al. 1998) upon processing of local phrase structure and sentence structure.

Also in the processing of *phonological* information mainly increased activation in the left hemisphere, specifically in BA 44, thus Broca's area, has been observed.

Lexical-semantic processing has been generally associated with the left temporal as well as inferior frontal cortex: Specific involvement of the superior and middle temporal as well as the inferior frontal gyrus has been repeatedly reported (Fiez 1997; Poldrack et al. 1999; Price et al. 1997).

Processes relying mainly on right hemispheric cortical structures are emotional, and partly lexical *prosody*: For the processing of pitch information at the segmental, for example syllable level, and at the suprasegmental, for example syntactic level, recent studies found increased activation in the right prefrontal, right superior temporal and the right fronto-opercular cortex (Meyer et al. 2002; Wildgruber et al. 2002). On the other hand, when prosodic features were relevant parameters for the discrimination between different lexical items, like in tonal languages, also left hemispheric activation, for example in the left frontal operculum (adjacent to Broca's area) has been reported (Gandour et al. 2000).

Since the subjects of the experimental study for this thesis were children, the next chapter will take a closer look on the neuroanatomic development of language functions and on eventual differences in the lateralization of language functions in the not yet mature brain.

2.4.1.3. Language processing in children

Observing the language behaviour of babies and young infants might convey the impression that children start to process language only after more or less one year of life, when they start to utter their first words and phrases. But in fact, already new-born babies process certain basic structures of their mother tongue, and gain more and more competence about linguistic structures long before they actively start to speak. Many recent studies have attempted to take a look at the neurofunctional architecture of the infant brain. Obviously, to measure cortical activity in babies requires very gentle and non-invasive methods: While functional magnetic resonance imaging (fMRI) or magnetoencephalography (MEG) for example cannot be applied on very young children, electroencephalography (EEG) and near infrared spectroscopy (NIRS) are methods approved and established for studies with children. These methods have been successfully used, and the respective studies have shed some light on the functional lateralization of cognitive functions in infants:

2.4.1.3.1. Phonology

Already new born babies show activation patterns specific to language processing upon hearing speech, in contrast to music or speech played backwards, thus non language sounds. These *phonological* abilities serve as a first clue to language learning. Few months old babies are able to distinguish between different phonemes, and seem to specifically pay attention to syllable structure typical for their mother tongue. Processing of syllables differing in the first consonant showed increased cortical activation in the temporal and frontal lobes, thus areas specific for language processing, already in three-month-old infants (Dehaene-Lambertz et al. 1994). Also the recognition of word-stress is a phonological competence crucial for example for the segmentation of continuous speech, in order to extract single words and thus be able to build up a vocabulary. Indeed this ability is developed early and elicits left-hemispheric activation already in 10-month-old children (Kooijman et al. 2005).

2.4.1.3.2. Lexicon and semantics

After the phonological analysis of continuous speech input, children begin to understand and eventually produce first single words. Studies testing the electrophysiological reaction to known versus unknown words in infants between age one and two found bigger amplitudes for the processing of known words, with local distribution in bilateral hemispheres till the age of 13 months, but shifting to predominant processing in the left hemisphere at the age of 20 months. The discrimination of familiar from unfamiliar words indicates a clear processing of lexical information, but implications on beginning of adult-like processing of semantic properties of words remain uncertain for children of less than two years.

In a series of studies Friedrich and Friederici (2004; 2005a; 2005b) tested a design differentiating between lexical and semantic processing of single words on children between 12 and 19 months. While the 12-month-olds showed increased fronto-central activity indicating a lexical familiarity effect, the 14- and 19-month-old group showed specifically semantic processing, in addition to the lexical familiarity effect. The fact that the effects in these infants peaked slightly later and lasted longer than in the adult brain reflects slower semantic processing; the more widespread local distribution of activation in semantic processing tasks, especially the involvement of additional frontal areas, has been interpreted as an involvement of increased attention processes due to not yet developed automaticity and routine in this modality.

Studies with five to fifteen year old kids, requiring semantic judgement on auditorily presented words, found activation in bilateral temporal, left middle temporal, and in bilateral inferior frontal gyri, with decreasing local distribution, especially in right frontal regions, with the factor of age (Balsamo et al. 2006; Chou et al. 2006). These studies generally indicate that semantic processing in children is lateralized in the left hemisphere in similar regions as in the adult brain from an age of approximately 5 years.

2.4.1.3.3. Syntax

So far very few studies on early syntactic processing in children are available, and most of them used EEG, a method which has a very precise resolution of electrophysiological activation changes over time, but a rather poor resolution of spatial localization of the measured activation. The electrophysiological studies reviewed by Friederici (2006a) all found a rather adult-like neurophysiological signature of mapping of syntactic and thematic structure, processing of temporally syntactic ambiguities and syntactic complexity in general in children from an age of two years. The so-called early left anterior negativity (ELAN), a specific electrophysiological syntactic processing component, occurring in adult processing of language stimuli later after stimulus onset, and mostly responsible for automatic initial structure building, was not found in early stages of language development till the age of two years, but occurred in a delayed but adult-like form in children from the age of two and a half years. These findings indicate that while highly automatic processes of syntactic analysis develop in children from the age of two and a half years, more controlled processes of syntactic and thematic integration are established in an adult-like manner from the age of two years.

2.4.1.3.4. Prosody

A NIRS study from 2006 (Homae et al.) measured the haemodynamic response to normal speech versus speech with flattened intonational contours in three-months-old infants, and found activation in bilateral fronto-parietal and frontal lobes for both conditions, and specific right temporo-parietal activation for the normal speech condition, containing prosodic information. These and other results investigating the neuroanatomical basis of prosodic processing in infants (e.g. Pannekamp et al. 2006) indicate, that already in infants of less than one year of age processing of prosody of speech is lateralized to the right hemisphere.

In general, taking into account the current state of research, we can conclude that the processing systems underlying language processing change quantitatively but not qualitatively during early development, and the underlying neuroanatomical structures are established in a rather adult-like manner already in infants.

2.4.2. Bilingual language processing

2.4.2.1. Evidence from clinical and behavioural studies

Throughout the history of studies of bilingual language processing different models of neurofunctional organisation of two languages in one brain have been proposed, some on the basis of anatomical evidence drawn from post mortem examinations of lesioned brains, some on the base of mere psycholinguistic speculations. Still, the different models have remained influential for the further experimental research over the 20th century, and will therefore be described here in a short overview, in a classification taken from Paradis and Libben (1987).

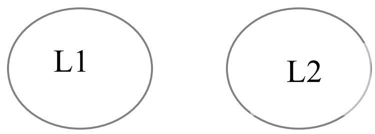


Figure 15:
The dual system hypothesis

According to the *dual-system hypothesis*, the two languages of a bilingual are stored in two different subsystems, and processed independently of each other. Since, especially if the two languages have a similar linguistic structure, some grammatical information or lexical items might be equal in both language systems, a certain proportion of linguistic information is encoded twice, thus constituting a redundancy of the system. Most studies which seem to confirm this kind of neurofunctional organisation report the cases of aphasic patients which lost their competence in one language, but have preserved linguistic abilities in the other one. The first patient with this selective recovery pattern has been reported in 1867 by Scoresby-Jackson, who therefore proposed differential localization for the two languages, but nearly without anatomical knowledge. Rapport, Tan and Whitaker (1983) used two invasive methods on a group of Chinese-English bilingual stroke patients requiring awake craniotomy: With Wada-testing, a method where an anaesthetic substance is injected in one hemisphere, it is possible to test cognitive functions of the single hemispheres differentially; intraoperative electrocortical stimulation (stimulation of language relevant regions on the open brain with electrodes with biphasic electrical current) was performed on very small cortical areas known to be crucial for language processing, while the patients were subjected to do object naming and reading tasks, and lead to specific language inhibition and switching effects. From the results of these invasive methods, and from observations on language loss and recovery patterns of the patients after the stroke the authors found, that both languages were lateralized in the left hemisphere, but in different areas, thus supporting the dual-system hypothesis of differential localization of the two languages.

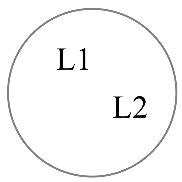


Figure 16: Extended system hypothesis

The counterpart to the proposed differential localization has been formulated as the *extended-system hypothesis*, claiming that there is no qualitative difference between a bilingual language processing system and the monolingual neurofunctional setup, except for the bilingual system having more elements – more different phonemes, morphemes, or syntactic rules – which are organized complementarily and are used in a mutually exclusive manner, just like different terminology, dialects or registers in a monolingual. This model is often referred to by studies reporting non-language-specific access, or other cross-linguistic effects. Minkowski, a Swiss neurologist at the beginning of the 20th century, claimed that it is not necessary to assume differential localization for the different languages in order to explain the different recovery patterns from aphasia: ‘‘If we assume no spatially separate centers or areas in the cortex for the different languages, but instead assume that within the same area, the same elements are active, though in different combinations and interacting with a differential linguistic constellation, it is easy to explain the phenomena occurring in polyglot aphasia in terms of the interaction of such a large set of factors’’(Minkowski 1927 p.229).

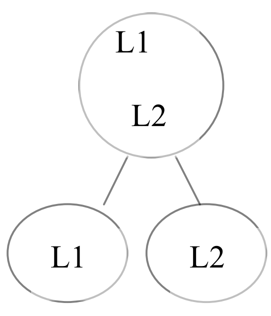


Figure 17: The tripartite system hypothesis

The *tripartite system hypothesis* attempts to meet the criticism of redundancy in the dual system hypothesis by suggesting three different subsystems, one of which is storing the common items and rules of the two languages, while the language-specific information of L1 and L2 are again stored individually.

The *subset* or *subsystems hypothesis* implies that extended and dual system hypothesis are not mutually exclusive: While there are stronger links between items from one respective language, both are included in one superordinate system, and can thus have also direct cross-linguistic links. This model can explain most of the reported recovery patterns from bilingual aphasia, since the respective languages can be activated or inhibited differentially, but also the superordinate system can be disturbed, thus causing disorders in all languages.

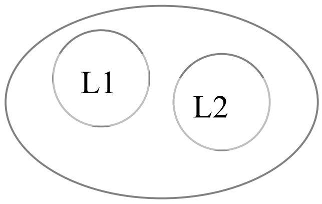


Figure 18: The subsystem hypothesis

Another approach, first proposed by Pötzl 1925 based on observations of involuntary language switching in aphasic patients, claims the existence of a so-called *switch-mechanism*, which functions independently of the two languages' memory representations, and controls their respective activation and inhibition. This model has also been used to account for the longer reaction time in the so-called bilingual stroop test, where a colour name is visually presented, written with ink of a different colour then the one denotated by the written word, and the subject is asked to name the ink colour in his other language, which leads to extended reaction times, because the language of the visually presented item is first activated by the input, and the voluntary inhibition of one language leads to very extended reaction times. This „switch-time" has been interpreted as an additional activation of the switch mechanism.

Fabbro and colleagues (2000) reported another bilingual patient showing pathological language switching, in the absence of language mixing (thus, the use of two languages within a single utterance) or any other linguistic impairment. Since the lesion in this patient was situated in the left anterior cingulate, a region adjacent to the corpus callosum, and in the frontal lobe, Fabbro et al. suggested, that language switching should be considered as a discrete mechanism, neuroanatomically situated in the frontal lobe.

Evidence from intraoperative cortical stimulation has lately renewed the discussion about a possible language-independent switch-mechanism: Kho et al. (2007) reported selective inhibition of one language or involuntary language switching of a French-Chinese bilingual patient during stimulation of the pars opercularis, in the inferior frontal gyrus. From the fact, that the language switching occurred immediately upon stimulation, and that the switching effect was reversible, the authors concluded that this cortical region might be the locus of the switch-mechanism. Holtzheimer et al. (2005) reported spontaneous language switching in two depressive multilingual patients upon non-invasive transcranial magnetic stimulation of the dorsolateral prefrontal cortex.

While these described clinical and behavioural studies mostly aim at analyzing anatomical differences in bilingual aphasics, studies using electrophysiological and neuroimaging methods can monitor language processing in the healthy brain, and are thus capable of addressing the more general question whether there are qualitative or quantitative differences in the functional processes and underlying cerebral structures between a bilingual's different languages, and between the bilingual and the monolingual brain. Electrophysiological methods, like EEG, have a very high temporal resolution, and can, when applied in studies with specific stimulus designs, discriminate between the cortical activation elicited during processing of different levels of the linguistic input, like phonological, lexical, syntactic or semantic analysis; but, since non-invasive EEG measures electrical activation changes through electrodes placed on the outside of the skull and skin, and the measured signal is highly scattered during transition of these tissues, EEG cannot identify the exact cortical areas from which the received signal originates. Neuroimaging methods like fMRI and PET, on the other hand, also have their specific limitations: While their spatial resolution is generally very high, they can monitor neurological activation changes over time only in a rate of seconds, but the specific processing steps of linguistic analysis proceed in milliseconds.

Still, due to their strength in spatial resolution neuroimaging studies deliver stronger evidence for answering the question of differential or analogue localization of languages in the bilingual brain.

2.4.2.2. Evidence from neuroimaging studies

Most neuroimaging studies on bilinguals showed very similar patterns of activation for the respective languages, but some found single areas of differential activation, but with rather heterogeneous intensity and interpretation.

In one of the first neuroimaging studies on bilinguals, Klein et al. (1995) found higher activation for the less dominant language in the left putamen. In a subsequent study in 1999 (Klein et al.), however, the authors did not find the previously reported difference between the languages, in spite of the subjects being late bilinguals. Numerous other studies found no significant differences upon processing of two languages in bilingual subjects (Chee et al. 1999; Illes et al. 1999).

Kim et al. (1997) found similar cortical activation around Wernicke's and Broca's area for an early bilingual group of subjects; in late bilingual subjects they found similar activation in Wernicke's area, but two distinct regions in the left Broca's area, separated from each other by approximately 8mm, one active only for L1 stimuli, and the other only during processing of stimuli in the L2. The authors attributed these differences in the neurofunctional architecture to the factor of *age of acquisition*, which varied over the two subject groups. However it needs to be noted, that the authors give no detailed description of the specific phonetic and syntactic competence of the late learners in their L2, and thus the influence of the factor of proficiency could not be correctly evaluated.

Several other studies, like Perani et al. (1996) and Dehaene et al. (1997), also found strong and discrete activation for the subjects' dominant language, with considerably reduced active volume, and high inter-individual variability of activated regions (varying from predominant right to standard left hemispheric lateralization), upon processing of the less dominant language of bilingual test groups. Perani et al. (1998) compared the activation patterns of two groups of subjects, one with early acquisition onset (L2 acquisition before the age of 4 years), the other with late age of acquisition (L2 acquisition after the age of 10 years) for the second language, but both highly proficient in both languages. Interestingly, for the high proficiency late acquisition group no significant difference of activated brain areas was found over the two languages, but the high proficiency early acquisition group showed significant differences in the processing of L1 versus L2 in the right hemisphere, with a region in the right middle temporal gyrus being active specifically during L1 processing, and right superior parietal areas responding to L2 processing only. By comparing the results of this study, especially the activation patterns found in the high proficiency late acquisition group, with the results found by the same authors in 1996 in subjects with late age of acquisition and low proficiency, the authors found that the neurofunctional architecture of the bilingual brain seems to be influenced stronger by the actual *proficiency* level in the respective languages, than by the relative age of acquisition.

Especially the last two decades of research, using highly developed neuroimaging methods, started to shed some light on the anatomical and neurofunctional structures underlying bilingual language processing. In most studies very similar areas were active for processing of the dominant and a less dominant language. Since every bilingual is different in many factors concerning his language history and communicative behaviour, the eventual differences in neurofunctional representation of L1 and L2 should be further examined with respect to the influencing factors of language exposure, proficiency and age of acquisition.

2.5. Priming

Priming is an implicit memory effect, used extensively in experimental settings to investigate the architecture of the neural networks underlying perception and memory. It describes the facilitated processing of a perceived stimulus, when preceded by perception of another stimulus working as a prime. The influence of the prime item on the second item, also called target, results in reduced intensity or distribution of cerebral activity, which can be measured by electrophysiological (e.g. reduced amplitudes in signal measured by EEG) or imaging methods (e.g. reduced local cerebral blood flow measured by fMRI), or in shorter reaction times for execution of control tasks.

From the many different types of priming **repetition priming** is the most direct form of priming. If the same stimulus is presented twice, because its perceptual as well as conceptual properties are activated upon processing of the first presentation, processing of the stimulus upon the second presentation will be faster or elicit less neural activity, than upon the first time it was processed.

Perceptual priming subsumes different types of experimental designs, in which the prime – the stimulus presented earlier, which will influence the processing of the later stimulus – and the so-called target stimulus – the stimulus who's processing is facilitated by the prime stimulus – share certain form features, like, in the case of

linguistic stimuli, phonemic or graphemic similarities. For example, after visual perception of a word list containing the word *table*, subjects confronted with a word completion task (complete a given syllable to form the first word, that comes to your mind) are more probable to name the word *table*, than if not primed by the word list, and will complete the syllable *tab* more quickly than unprimed syllables.
Perceptual priming effects are shown to be sensitive to the modality of presentation, thus even if a word pair is phonetically and graphemically similar, priming will be higher if the prime and the target are presented in the same modality.

The processing of a word can also be primed through prior presentation of a semantically related word: For example, the word *pear* will prime the processing of the word *apple*, because they are both from the same semantic category. This type of priming design is called **semantic** or **conceptual priming**. Control tasks used frequently to monitor this kind of priming are the semantic categorization task, as well as the lexical decision task: When previously visually primed through a word list containing the word *pear*, subjects asked to decide, whether a string of letters is a word of a given language or not will respond more quickly to, for example, to the word *apple*, than to semantically unrelated words or non-words.
This kind of semantic or conceptual priming has been explained by spreading activation in neural networks: When we think of a word, not only the neurons representing the word itself become active, but we activate also other words from the same semantic category, or similar semantic contexts.

A similar effect was found when processing of a target item was primed by words or sentences which are frequently encountered together with the target item, thus when the stimuli used as prime constitute a context predicting the target with a high probability. This so-called **associative** or **context priming** is also involved in normal processes of reading sentences: Each words in a sentence acts as a contextual cue for the next words, and the more a given sentence is typical, the faster the processing of, for example, the last word in the sentence, which might act as target in a priming experiment, will be, in comparison to a single presentation of that word.

Finally, **translation priming** is a specific form of priming developed for studies on bilingual language processing. It is being used to investigate the neural pathways involved in the processing of two different languages, and on the possible interconnections between the semantic, lexical or perceptual levels of representations of items from the different languages. When an item from one language is primed by its translation equivalent from another language known to the subject, its processing is facilitated.

In the stimulus design of the experimental study carried out in the course of this thesis repetition priming and translation priming have been used to monitor processing of German and English individually as well as the interaction of the two language systems. A further description of the stimulus sequences will be given in the empirical part of the study (chapter 3.3.2.).

3. EMPIRICAL PART

3.1. Questions and hypotheses

To shed light on the processing of two languages in the bilingual brain has been the aim of many studies during the last decades. This study has concentrated on the neural processes during language perception, and thus applied an experimental design with a passive listening task.

To monitor neural activity in the cortex the study used near infrared spectroscopy (NIRS), an imaging method measuring cortical activity through the correlated oxygenation changes. Neural activation in the cortex, for example during the processing of a word in a passive listening task, results in an increase in oxygenated haemoglobin and a decrease in deoxygenated haemoglobin in the blood of the responsible cortical areas. This metabolic dynamics can be measured by NIRS and are expected to be found in this study after every stimulus, be it English or German, prime or target, primarily in left hemispheric temporal cortical regions (see e.g. Bortfeld et al. 2007).

The functional differences in the processing of words in the subject's first versus second language were measured using a so-called priming paradigm. Semantic or repetition-priming effects – a facilitation in the processing of a target stimulus preceded by a conceptually similar or identical stimulus (see chapter 2.5.) – have been found frequently in monolingual experiments (e.g. Dehaene et al. 1998); in this study's experimental design monolingual repetition priming in English and German respectively is thus expected to produce reduced oxygenation levels for prime items. Further analysis will show if the intensity of the priming effect differs between repeated English word pairs and repeated German word pairs.

Moreover this study used cross-linguistic translation priming in order to investigate the functional differences in the processing of the bilingual's two languages. Translation priming effects have been reported reliably for example by Alvarez et al. (2003); the results will show if, in spite of the comparatively big lags between the prime items and the translated targets in the stimulus design of this study, cross-linguistic priming effects were elicited. Furthermore, if cross-linguistic priming effects reach significance, it is of major significance for the evaluation of functional differences and interaction between the two languages, if the intensity or localisation of the measured cross-linguistic priming effects differs according to the direction of cross-linguistic priming from L1-L2 or L2-L1.

Finally, activation during processing of English versus German words in general will be compared, to track processing differences between a bilingual's languages, independently of a priming paradigm.

Following the considerations discussed above, the following hypotheses and explorative questions for the experimental study shall be deduced:

3.1.1. Hypotheses tested

- During the acoustic presentation of a stimulus, in contrast to phases of silence, a haemodynamic response (resulting in a measured increase in [oxy-Hb] and decrease in [deoxy-Hb], see chapter 3.2.1.1.) is expected, primarily in left hemispheric temporal cortical regions (see e.g. Bortfeld et al. 2007).

- The signals measured during presentation of primes and of the repeated targets significantly differ from each other in respect of intensity of the elicited activation: Prime items elicit a stronger activation than target items in temporal regions (see e.g. Rissman et al. 2003).

3.1.2. Experimental questions

- Is there a difference between the intensity or localization of the priming effect in English within-language repetition word-pairs versus German within-language repetition word-pairs?

- Is there a difference concerning the intensity of the priming effect between cross-linguistic priming from L1-L2 and cross-linguistic priming from L2-L1?

- Is there a difference in the intensity or localisation of the elicited activation during the processing of German versus English items?

3.2. Methods

3.2.1. Near infrared spectroscopy (NIRS)

Brain Imaging Methods aim to depict neuronal activity during the processing of a stimulus. An active neuron processes information by transmitting electrical impulses – it "fires". The most direct and immediate way to record neuronal activity would thus be to measure these electrical activation changes in single neurons. This procedure has been carried out directly on the open brain in animal experiments, but, for obvious ethical reasons, cannot be carried out on healthy humans. Besides, considering the huge amount of neurons constituting the cortex, only a very small area of it can be measured by this procedure.

Electroencephalography (EEG) is a method which is being mostly applied in a non-invasive manner, measuring electrical activation changes through the skull, with electrodes being placed on the outside of the head. Electroencephalography provides very good temporal resolution: Even in the non-invasive setup, the Electrodes can record activation changes within a range of milliseconds. But the skull, skin, meninges and other tissue, separating the cortex from the electrodes, scatters the signal, so that the localisation of the origins of the measured signal is pretty inaccurate.

During the last decades, another approach to measuring brain activity has been developed, based not on the neuronal firing itself, but on the vascular and metabolic response, that it elicits. Near infrared spectroscopy (NIRS), which was used to obtain the data for this study, is a non-invasive imaging method, which measures changes in the oxygenation level of the haemoglobin, caused by changes in the regional blood flow.

3.2.1.1. *Physiological basis of NIRS*

Activated neurons, like any other active cells in our body, need more resources than in resting state. Therefore neuronal firing is associated with a regional increase of blood flow, to supply neurons with glucose and oxygen, which is carried by the haemoglobin. Fox et al. (1986) measured the regional cerebral blood flow (rCBF) and the rate of cerebral oxygen metabolism - which is the parameter measured with NIRS - during neuronal activation evoked by somatosensory stimulation in the form of a simple finger tapping task. In resting state the cerebral blood flow volume and the rate of oxygen uptake by the cerebral cells were well balanced. During activation, though rCBF increased by 29% on average in the activated cortical areas, oxygen metabolism increased only by an average of 5%. This uncoupling leads to a focal increase in oxygenated haemoglobin ([oxy-Hb]) and a simultaneous decrease in deoxygenated haemoglobin ([deoxy-Hb]), altogether resulting in a locally increased concentration of oxygen in the blood ([tot-Hb]), thus a temporary hyperoxygenation. This correlation between neuronal activity, blood flow, and blood oxygenation level is called the neurovascular coupling. It has first been described in 1890 (Roy et al.), and today there is no doubt about its existence. Still, it should be noted, that its exact functioning and all influencing factors could not yet be explained.

The amount of [oxy-Hb] and [deoxy-Hb] in the blood, measured with near infrared spectroscopy as one feature of the complex process of neurovascular coupling, is an indirect measure of cortical activation: The temporary regional increase in blood flow, also called haemodynamics, and its focal hyperoxygenation, occur as a physiological response to neuronal firing, and, being a much slower process than the latter, with a notable ‘delay’. Still, because of their temporal correlation, it is possible to model this latency and calculate time, location and strength of the eliciting activation from the oxygenation data with good precision, with a function called the haemodynamic response function (HRF).

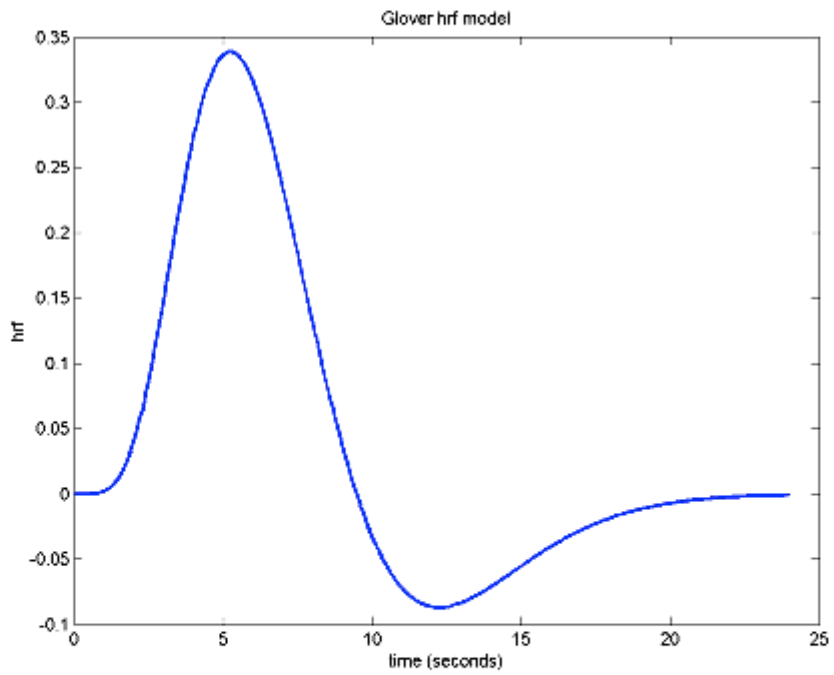


Figure 19: Model of the haemodynamic response function (HRF)
From http://www.math.mcgill.ca/keith/BICstat/fighrf0.jpg, 27.02.2010.

The haemodynamic response starts rising about 2 s after stimulus onset, reaches its climax between second 5 and 7, and falls back to its initial intensity circa 16 seconds after stimulus onset (see figure 19). Zhang et al. (2005) showed, that this function can also be used to model the concentration changes of oxygen in the blood, measured by NIRS: They imaged the motor cortex of subjects performing a simple finger tapping exercise over a period of 1-2 seconds (red bar), and found that both the concentration changes of [oxy-Hb] (black curve) and of [deoxy-Hb] (grey curve) can be modelled by the HRF.

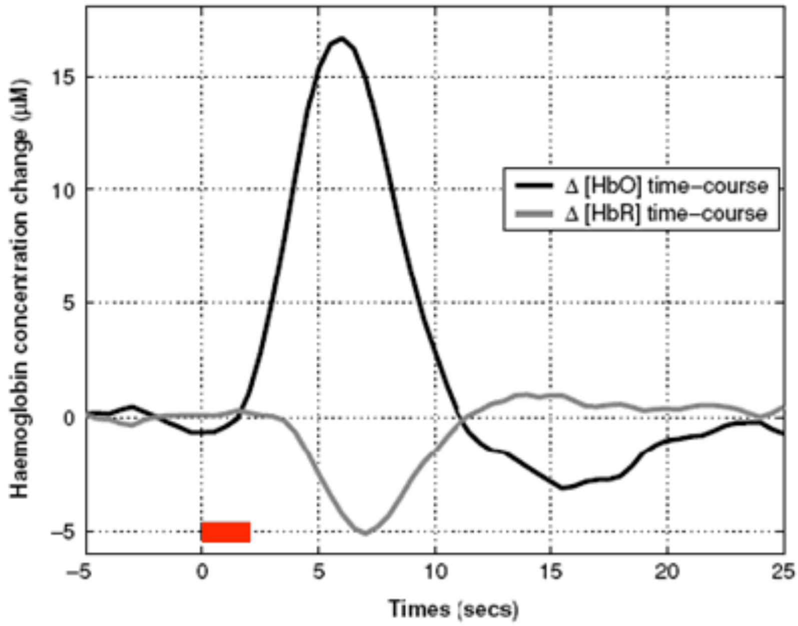


Figure 20: Time course of concentration changes in [oxy-Hb] and [deoxy-Hb] throughout a fingertapping task (duration 2 seconds, see red bar).
(From Zhang et al. 2005, p.4634, fig.2)

Thus, an increase in oxygenated haemoglobin and simultaneous decrease in deoxygenated haemoglobin can be seen as an indicator for neuronal activity.

3.2.1.2. Methodology of NIRS

So the aim of NIRS is to measure the changes of concentration of oxygenated and deoxygenated haemoglobin in the blood of activated brain areas – with light.
Even a simple flashlight pointed at the finger will, to a certain extend, penetrate the skin, muscles etcetera and illuminate the tissue. In invasive experiments, when the cortex is laid bare, even photons from a light bulb can penetrate its upper layers and illuminate the cells. So the idea of optical imaging methods, working with light, is to investigate the properties of a tissue by pointing a ray of light into the texture to be examined, and detecting the scattered and reflected photons, altered by their travel through the tissue. The quantity and quality of the reflected light measured by a detector would give information about the matter it has traversed.

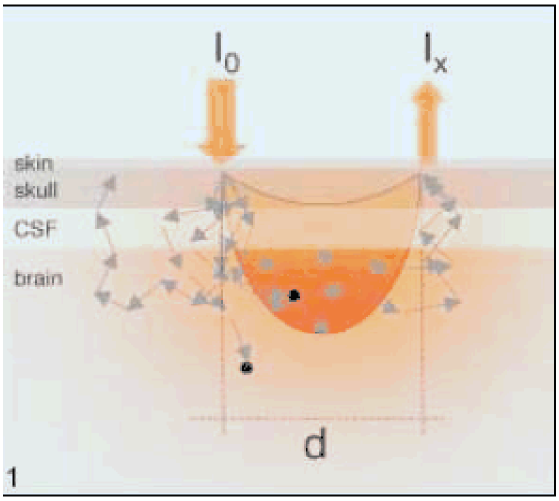


Figure 21: Light with an intensity I0 is being emitted into the tissue, scattered and absorbed by the skin, skull, etc., and eventually detected by the detector with an intensity Ix**.** d stands for the so called inter-optode distance, which is at the same time the assumed maximal depth of the travelling photons.
(From Obrig et al. 2003, p.9, fig.5)

The difficulty of non-invasive experiments lies in the fact, that the tissue of interest is covered by a solid layer of 1-2 cm of skin, bone, meninges etc. Jöbsis (1977) was the first one to prove the possibility of illuminating cortical tissue through the intact head. In this case, the light beam, on its way from the light source to the cortical cells, is obstructed by numeral layers of tissue. In order for the light to reach cortical tissue, NIRS uses near infrared light, which is capable of penetrating the biological tissue. In brain imaging studies with humans, the wavelengths used lie between 650 and 950 nm. Light from a shorter-waved spectre, lying under 650 nm, would be too strongly absorbed by the haemoglobin. For long-wave light over 950 nm the absorption rate of water is too high. Therefore, the spectre between 650 and 950 nm is in this context also referred to as the "optical window".

Pairs of optodes emitting the near infrared light and detectors taking in the reflected light are placed on the skull in a distance of few centimetres: The bigger the inter-optode distance, the longer the travelled distance of the photons detected by the detector, and the deeper their assumed route (see figure 22). Therefore an ideal inter-optode distance to detect photons that have passed deep enough to transit the cortex, but not so deep as to get totally absorbed by the deeper neuronal layers, lies between 2-3cm.

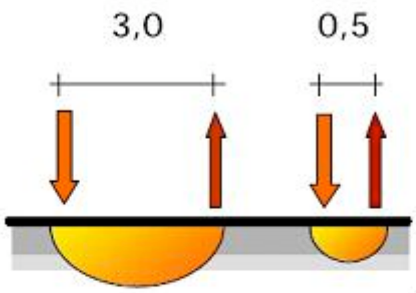


Figure 22: The inter-optode distance corresponds to the depth of the travel route of the detected photons: The bigger the inter-optode distance, the deeper the assumed course of the photons. (left: 3 cm; right: 0,5 cm)
(From Obrig 2002, p.18, fig.6b)

So near infrared light is being sent into the cortex, and the amount and wavelength of the reflected photons gives information about the illuminated cortical area of neurons. But how is it possible to differentiate between signal changes caused by the haemoglobin and other components of the tissue, or even between [oxy-Hb] and [deoxy-Hb]?

The part of a substance, more precisely of its molecules, which is responsible for its light absorbing or scattering properties, is called the chromophore. When a substance absorbs certain wavelengths of light and reflects or transmits others, it has a colour. As we can observe also in other parts of our body, our blood changes its colour according to the concentration of the containing oxygen: When straining ones body, the skins turns red, due to the high concentration of [oxy-Hb], which has a reddish colour. When the blood circulation in our fingers or lips is slow or blocked, the skin turns blue, due to the bluish colour of the deoxygenated haemoglobin. These ‘colour’ properties, or rather their equivalents in the near infrared, thus invisible spectre, of [oxy-Hb] and [deoxy-Hb] are also used for NIRS:

Haemoglobin, or rather its chromophore, changes its specific absorption pattern for different wavelengths according to its concentration rate of oxygen. Thus NIRS uses two wavelengths, one of which is absorbed characteristically by [oxy-Hb], the other by [deoxy-Hb]. Through the changes in absorption of these two wavelengths of 690 nm and 830 nm the concentration of [oxy-Hb] and [deoxy-Hb] in the haemoglobin can be calculated: The Beer-Lambert law calculates the concentration of a substance as being proportional to the weakening of the intensity of light, which passed through the examined substance, for a certain wave length. Some modifications of the formula are necessary to account for the non-invasive setting: The scatter caused by the skull, skin,

etc. diminishes the quantity of photons, which can be registered by the detector. But since this scattering factor is steady for all detecting optodes, it can be added to the Beer-Lambert law as a constant factor G.
Many studies investigating oxygen metabolism and its temporal and local functioning as part of the haemodynamic response have convincingly proven that focal oxygenation changes of haemoglobin can be seen as a reliable indicator for neural activity.

In comparison to other methods like fMRI, which is also based on vascular processes, NIRS has both advantages and disadvantages: The spatial resolution of NIRS is comparatively vague, allowing differentiations only within a range of centimetres. Further, only cortical issue within a depth of 2-3 cm maximum can be illuminated with NIRS, while fMRI can depict activation throughout the brain. A clear advantage of NIRS is its undemanding setup, which provides a relaxed and unpretentious measuring situation even for very small kids or patients confined to bed, who cannot be measured in the narrow and intimidating fMRI scanner. Available even in wireless form, and less susceptible to movement artefacts, NIRS can also be of great use in studies needing a mobile and flexible setting, providing free movement possibility for the subject. Finally, studies with a research interest in auditory processing (for example language studies with children, like the one carried out in the course of this thesis, where the use of visual, orthographic stimuli would result in data possibly influenced by differences in reading competence as an additional confounding factor) might prefer to use NIRS due to its totally silent functioning.

3.3. Experimental study

3.3.1. Participants

Twenty-eight early German-English bilingual children, aged between five and eight years (mean 6.71; SD (standard deviation) 0.71), all of them right handed (assessed by means of the Edinburgh Handedness Inventory, Oldfield 1971), took part in the study. Due to technical problems during the measurements three of them had to be excluded from further analysis.
The remaining sample of 25 children - 17 boys and 8 girls - had a mean age of 6.72 years (range 5 to 8 years, SD 0.74) at the time of the measurement. None of them had

any hearing disorder (assessed with a self report of the parents). All of the children had started learning both languages (i.e. German and English) from a very early age on (mean 0.8; SD 1.61) and lived in Germany at the time of the study.
Their proficiency in German and English was first rated by the parents on a scale from 1 to 5 (1= native, 2= very good, 3= good, 4= moderate, 5= not good) (see appendix), revealing a main proficiency of 1.15 for German (SD 0.35), and 1.72 in English (SD 0.92). Second, a picture-naming test in English carried out with all participants after the measuring session resulted in a mean of 82 percent of correct answers (SD 0.14).
All participants attended one of Berlin's English-German bilingual schools at the time of the study.

3.3.2. Stimuli and experimental design

During the experiment, participants passively listened to German and English words, recorded by a female English-German bilingual person. These items were arranged in a design combining repetition priming and cross-linguistic priming: The stimulus material consisted of 120 different concrete, mainly monomorphemic, nouns (Woodcock Language Proficiency Battery-Revised (WLPB-R)), each in German and in English. The 120 German nouns were translation equivalents of the 120 English nouns; these translation word pairs were matched for frequency according to the CELEX database (http://celex.mpi.nl/), and cognate word pairs were excluded.
To obtain priming within one language, 48 nouns from each language were presented twice – the first presentation serving as a prime, the second as target item – with one to three filler words from the same language in between the two presentations. Due to this repeated presentation the total number of presented stimulus tokens per language was 160.
All stimuli were grouped into 8 German and 8 English monolingual blocks, containing 20 words each; these blocks were presented in an alternating manner, each English block being followed by a German one, being followed by an English one, and so on. Within each block there were pairs of prime and target, in German or English respectively, forming the repetition priming design.
Distributed over the whole presentation, each prime and target pair occurred twice, in German and in English, thus providing a cross-linguistic priming design. Additionally,

each filler item's translation equivalent reoccurred in another block, providing a further opportunity for cross-linguistic priming.

Altogether, half of these cross-linguistic repetitions had the German item(s) presented first, in the other half of the cases German followed English.

German block 1		**English block 1**		**German block 2**		**English block 2**	
glocke	schiff	leaf	thumb	blatt	hase	**coat**	can
nagel	zitrone	church	bread	dose	spiegel	ant	sink
hexe	hund	pumpkin	thumb	degen	esel	bridge	rope
ameise	**mantel**	leaf	goat	blatt	hase	**coat**	can
glocke	schiff	sock	sword	strumpf	maedchen	dog	bell
ameise	**mantel**	donkey	bread	dose	spiegel	ant	sink
spuele	brot	boat	rabbit	ast	daumen	mirror	witch
fenster	seil	sock	potato	strumpf	kartoffel	lemon	kite
ziege	drachen	***window***	branch	kirche	kuerbis	mirror	bell
spuele	brot	boat	rabbit	bruecke	daumen	nail	girl

Table 1: The first 4 blocks (80 items) from randomisation 1 of the experiment, to be read vertically, column by column, starting from the left. Two exemplary pairs of prime and target in cross-linguistic repetition 1 and 2 are printed in green; two exemplary filler words in German and English translation are printed in blue colour in italics.

The stimuli were presented in a pseudo-randomised manner, with an inter-stimulus-interval (ISI) varying between 2 and 4 seconds, and an inter-block-interval of 10 seconds.

3.3.3. Realization of the NIRS measurement

The experimental study and the realization of the measurement were approved by the local ethics committee. The NIRS measurement has been accomplished with the NIRS System Omniat Tissue Oxymeter (ISS Inc., Champaign, IL, U.S.A.). To monitor oxygenation changes in the cortical areas relevant for semantic and lexical processing, 2 detecting optodes and 4 emitting optodes were placed each on both hemispheres over frontal, temporal and parietal areas, with a distance of 2.5 cm between each emitter and detector.

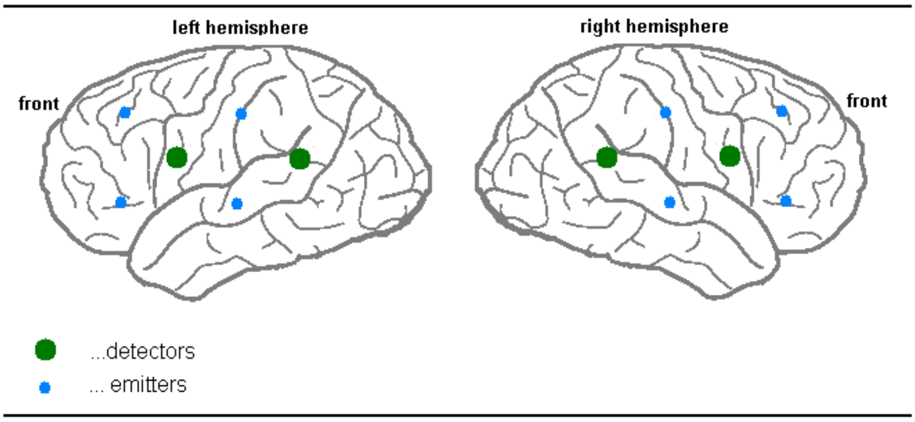


Figure 23: Positions of emitting and detecting optodes for the NIRS measurement.

Due to the NIRS methodology and optodes setup, which has been explained above, the de facto measured positions lie each between an emitter and a detector.

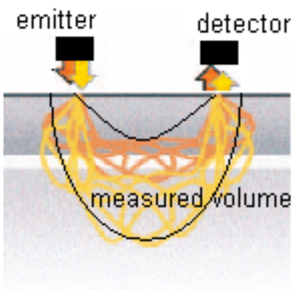


Figure 24: Model of the NIRS optodes setup: The measured volume of tissue lies approximately crescent-shaped between the emitter and the detector.
(Adapted from Obrig et al. 2003, p.9, fig.5)

The used optodes configuration results in 12 measured positions, 6 over each hemisphere, covering fronto-temporal (positions 1 and 2), temporal (positions 3 and 4) and temporo-parietal (positions 5 and 6) areas.

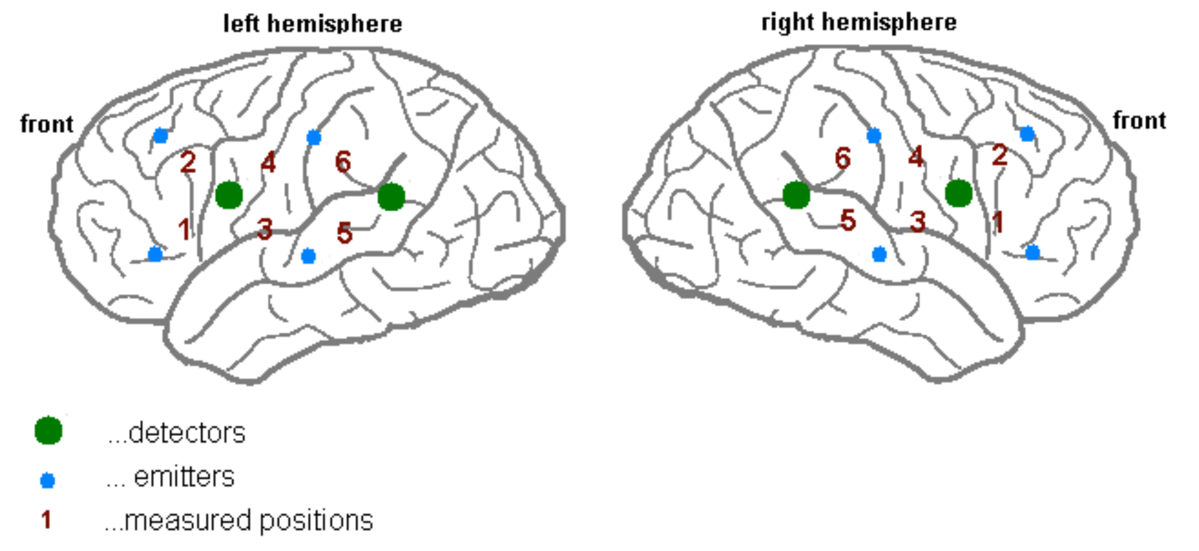


Figure 25: The 12 measured positions, in fronto-temporal, temporal and temporo-parietal regions.

Each emitter consisted of a bundle of fibre optic cables, with two ends of 1 mm diameter each, one of which was sending light at a wavelength of 690nm, the other one at a wavelength of 830nm onto the participants head and into the tissue. The detectors, consisting of one 3mm fibre optic cable, measured the reflected photons continuously at a rate of 10 Hz.

Simultaneously to the NIRS measurement we measured also the EEG response; but the electrophysiological measurement, analysis and resulting data will not be discussed in this thesis (see Hernandez et al., in preparation).

The NIRS optodes were fixed in a soft cloth cap (www.easycap.de), which held also the EEG electrodes. The cap had ready-made plastic attachments for the electrodes placed according to the 10-20 System (Jasper 1958). The NIRS detector fibres were placed into plastic rings, which were sewn into the cap to hold the annular electrodes. For the emitting optodes new holes were cut into the easycap in a distance of 2.5 cm from each detector (for exact configuration see figure 23).

3.3.4. Situation and procedure of the experimental session

All children were recruited from one of Berlin's English-German bilingual primary schools. The measurements took place in the Charité Berlin, Campus Virchow.

Each session lasted approximately 2 hours, of which the measurement itself took about 30 minutes.
Parents gave their informed consent prior to the measurements. At the beginning of each session the subject's parent(s) or legal guardian(s) were once more informed about the methods used, possible risks and how they were prevented. While the team started to prepare the cap and electrodes, parents were asked to fill out a questionnaire enquiring handedness, behavioural data concerning the development of the child, basic health issues, and communicational habits in the social sphere of the family (see appendix).
To provide a comforting measuring situation, the child was placed in an armchair, and given a book or paper and pencils during the preparations of the cap. The cloth cap for EEG and NIRS was adjusted to the head circumference. To assure comparable electrode and optode positions over all participants, the positioning of the cap on the child's head was determined by the 10-20 System (Jasper 1958) by adjusting the cap relatively to nasion[1] and inion[2], and preventing it from getting out of place by an additional chest strap. In order to diminish the obstacles in the way of the travelling near infrared light, the hair on the small spots designated as optode positions was gently pushed apart with cotton buds, and eventually the skin was prepared with electrode gel (consisting of sodium chloride, hydroxyethyl cellulose, propanediol, and distilled water). Optodes and electrodes were additionally fixed by an elastic net.
Before starting the measurement, the child was told, that there was nothing special it needed to do, just try to keep as still and relaxed as possible. If the child was confident and calm, the measurement was started.
While the participants listened to the stimuli, which were played through small speakers set up in front to the left and right of the subject, they were shown a relaxing silent nature film, to prevent eye motion. After half of the experiment, they were given the possibility to make a small pause.
After the NIRS recording, a member of the staff carried out a vocabulary test, containing the previously acoustically presented items, as well as a picture naming test, to examine the participants' proficiency in English (see appendix).
Participants were given an expense allowance in the amount of 30€ for the participation in the study.

[1] Intersection of the frontal bone with the nasal bones of the human skull. Visible in the face as a distinctly depressed area directly between the eyes, just superior to the bridge of the nose.
[2] Most prominent protrusion of the occipital bone, at the posterioinferior, thus lower rear, part of the skull.

3.3.5. Data analysis

3.3.5.1. Artefact correction

Artefacts are undesired alterations in the signal; they are undesired, because they did not occur due to the physiological processes that one wants to measure, but because of accompanying physiological reactions, movement, or technical interferences. The amount of these artefacts in the measured data is also called noise.

In the case of NIRS, artefacts arise due to the heartbeat, breath, and movement of the subject during the measurement.

Of course, an ideal setup, study design and measurement procedure can minimize artefacts to a certain extent. Preventive steps taken in our study were, as described above, technical aids like the chest strap and the elastic net, and precaution in the procedure like a relaxing position of the participants, the instruction to hold still, a silent measuring environment and the silent movie which served to prevent eye movement (see chapter 3.3.4.). But, especially in studies with children, artefacts are still inevitable. So it is necessary to get rid of the disturbing artefacts in the signal, or in other words, to improve "signal-to-noise ratio".

Signal changes induced by the concentration changes of haemoglobin after the presentation of a word, and thus really depicting an activation change that happened due to the processing of a stimulus, are known to fluctuate only within a range of few percent of intensity. Thus, signal changes outside this assumed relevant frequency window were removed: By filtering the data with both a "high-pass filter" and a "low-pass filter", only oscillations faster than 0.04 Hz and slower than 0.3 Hz were included in further analysis. This step improves the "signal-to-noise ratio".

Furthermore, the signal recorded during the break in the experiment, which in most cases lasted a few minutes, was cut out, since in that time no stimuli were presented.

As described before, changes in both oxygenated and deoxygenated haemoglobin have been measured by NIRS. Theoretically, their simultaneous occurrence, and the resulting focal hyperoxygenation, constitute the oxygenation response typically expected over an activated cortical area. Still, the decrease in [deoxy-Hb] and the increase in [oxy-Hb] are measured separately by means of the two different wavelengths, so that certain dissociations can occur. Other vascular-based methods, for example in fMRI, a method better explored and longer in use than NIRS, use the [deoxy-Hb] signal, whose deactivation is correlated with BOLD-contrast[3], as an indicator for cortical activation. So in accordance with others, like Obrig et al. (2003), also for NIRS the [deoxy-Hb] signal was chosen as a more reliable measure for cortical activation, and thus only [deoxy-Hb] data were subjected to further analysis.

3.3.5.2. Statistic analysis

Statistical analysis of the received data consisted of different analyses and calculations. The aim was to determine the influence of the stimulus factors 'language' (German vs. English), 'repetition' (1st vs. 2nd cross-linguistic repetition) or 'condition' (prime vs. target) on the elicited neural activation level, measured in concentration changes of [deoxy-Hb], which here constitute the dependent variable.

By convolving the actual signals for different stimulus conditions with the theoretical model of the haemodynamic response function (see chapter 3.2.1.1.), independent predictors for the time courses of the signal for the different conditions were determined. These show the theoretically expected time course for every condition. Beta-values are estimates for the accordance of the measured signal with the modelled predictor; for each condition they are thus proportional to the concentration changes of [deoxy-Hb] (Goebel et al. 2005).

To assess the influence of the stimulus factors on the cortical activation, a repeated measures 2*2*2 ANOVA (Analysis of Variance) with the factors 'language' (German vs. English), 'repetition' (1st vs. 2nd cross-linguistic repetition) and 'condition' (prime vs. target) was conducted for all positions for [deoxy-Hb] separately.
Significance values (p-value) were computed with Greenhouse-Geisser correction.

[3] Blood-oxygenation-level-dependent (BOLD), a measure used in magnetic resonance studies, measuring neural activity.

In case the ANOVA showed a significant main effect or a significant two-way or three-way interaction ($p \leq 0.05$), paired t-tests for the relevant single optode positions were computed, comparing the relevant conditions.

For the two-levelled factor 'condition' there is a clear assumption, that items characterized as targets should elicit a lower activation than prime items. As described above, this expected difference in processing is due to the so-called priming effect. Therefore in evaluating the factor condition a directional hypothesis was used, resulting in the application of a one-tailed t-Test for effects affected by the factor condition. All other T-statistics were analyzed using two-tailed t-Test.

By pronouncing a directional hypothesis, the research question, addressed to measured data with the factor 'condition', is restricted to the question, if prime items elicit a *bigger* activation than target items. Data showing other effects, are considered not relevant for the research question. Since all four rear positions of NIRS (temporo-parietal positions 5 and 6 for both hemispheres) showed inverse main effects of condition, and no other significant effects or interactions, these positions will not be displayed in the results.

4. Results

Figure 25 shows the actual location of the measured positions. In the diagrams depicting the results, the time courses or beta values of the signal at the 12 measured positions will be arranged in a simplified grid (see figure 26).

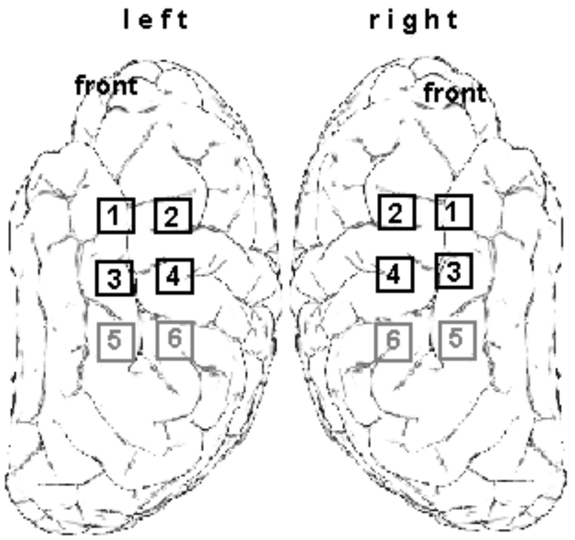


Figure 26 : The approximate, simplified measured positions, numbered and arranged in a grid, as they will appear in the following figures, displaying the obtained effects. The bilateral temporo-parietal position 5 and 6, coloured in grey, will not be included into further analysis.

4.1. Stimulation vs. silence

The mean time courses of the NIRS signal of all subjects during all stimuli were compared to the NIRS signal during phases of silence, for each position. As expected, the time courses of concentration changes show a typical haemodynamic response pattern: While the concentration of [oxy-Hb] increases shortly after stimulus onset (time 0 on the x-axis in fig. 20), [deoxy-Hb] shows a simultaneous decrease in concentration. This indicates the typical physiological response rooted in the cortical processing of the presented stimuli.

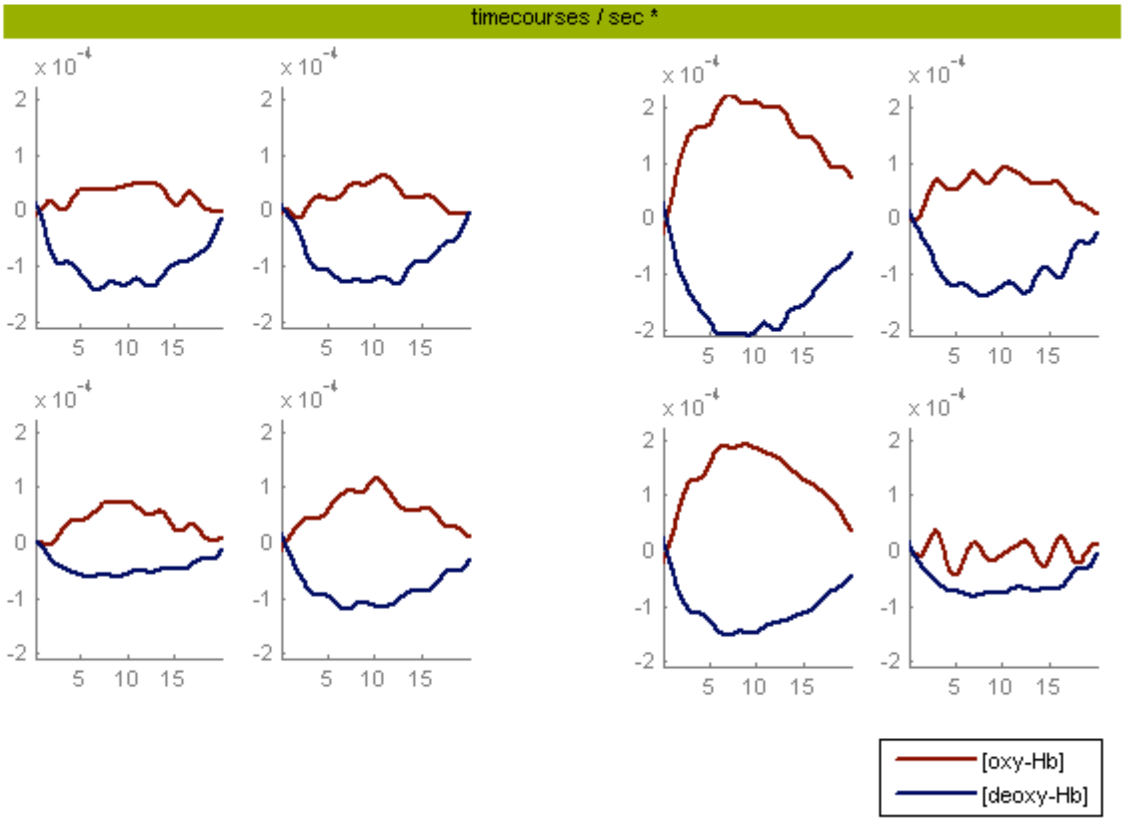


Figure 27: Grand Average plot of the time courses for mean of all stimuli versus rest, in [oxy-Hb] and [deoxy-Hb].

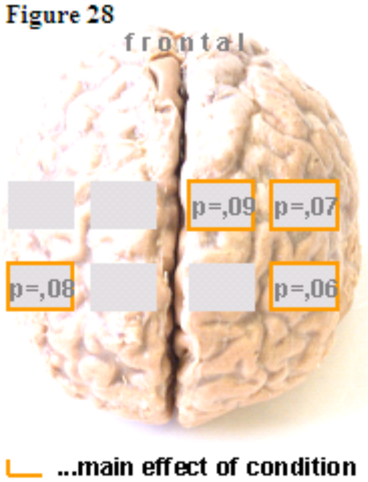
4.2. ANOVA and t-test analyses

The three-factorial ANOVA, with the factors language, repetition and condition, with repeated measures verifies, if the variance of the dependent variable – thus, the concentration changes of haemoglobin – can be ascribed to main effects of one single factor, or of an interaction between the factors. Paired t-tests calculate the specific orientation of the significant contrasts, found before in the ANOVA.

4.2.1. Main effect of condition (prime vs. target)

The ANOVA with the beta values of the [deoxy-Hb] signal revealed a marginally significant ($p \leq 0.1$) main effect of condition in the temporal position DL3 for the left hemisphere; for the right hemisphere the ANOVA became marginally significant in fronto-temporal positions DR1 and DR2, and in temporal position DR3 (for F-values and p-values see table 4).

Figure 28



The t-tests, comparing the means of the conditions prime and target, should verify the hypothesis, if the processing of target items elicits less activation than the processing of prime items. Indeed, paired t-tests revealed a significantly higher activation for prime than for target items over all tested positions (for T-values and significance values see table 2).

hemisphere	position	prime vs. target			df
		T-value	p-value	orientation	
left	DL3	-1.81	**0.04 ***	prime > target	1 (24)
right	DR1	-1.89	**0.04 ***	prime > target	1 (24)
	DR2	-1.78	**0.04 ***	prime > target	1 (24)
	DR3	-2.01	**0.03 ***	prime > target	1 (24)

* ... p ≤0.05 = significant

° … p ≤0.10 = marginally significant

Table 2: Paired t-tests comparing the means of the conditions prime and target.

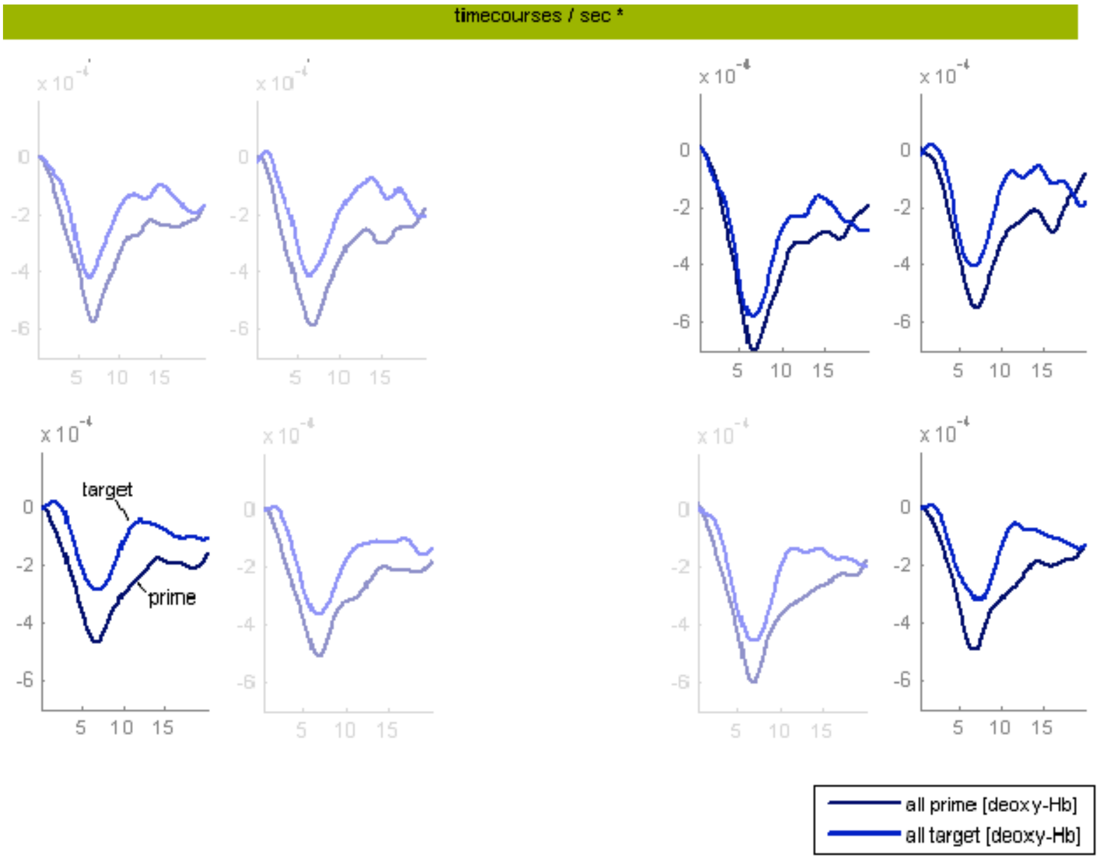
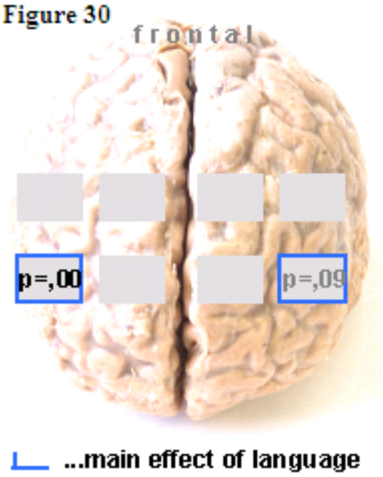


Figure 29: Time courses for fronto-temporal(1, 2) and temporal(3, 4) positions: prime versus target.

4.2.2. Main effect of language (German vs. English)

Figure 30



Interestingly, a highly significant main effect of language (German vs. English) (p=0.001) was found for temporal position DL3 in the left hemisphere, accompanied by a marginally significant main effect of language for the same position in the right hemisphere. This effect indicates, that the processing of German versus English items differed concerning the required activation level. To find out, which language elicited higher activation intensity, progressive t-tests for positions DL3 and DR3 were computed.

The t-test computed bilaterally for the temporal positions DL3 and DR3 showed a higher activation for German than for English stimuli (for T-values and significance values see table 3).

hemisphere	position	German vs. English			df
		T-value	p-value	orientation	
left	DL3	-3.84	**0.00 ***	German > English	1 (24)
right	DR3	-1.74	0.09 °	German > English	1 (24)

* ... $p \leq 0.05$ = significant
° ... $p \leq 0.10$ = marginally significant

Table 3: Paired t-tests comparing the means of the conditions German and English.

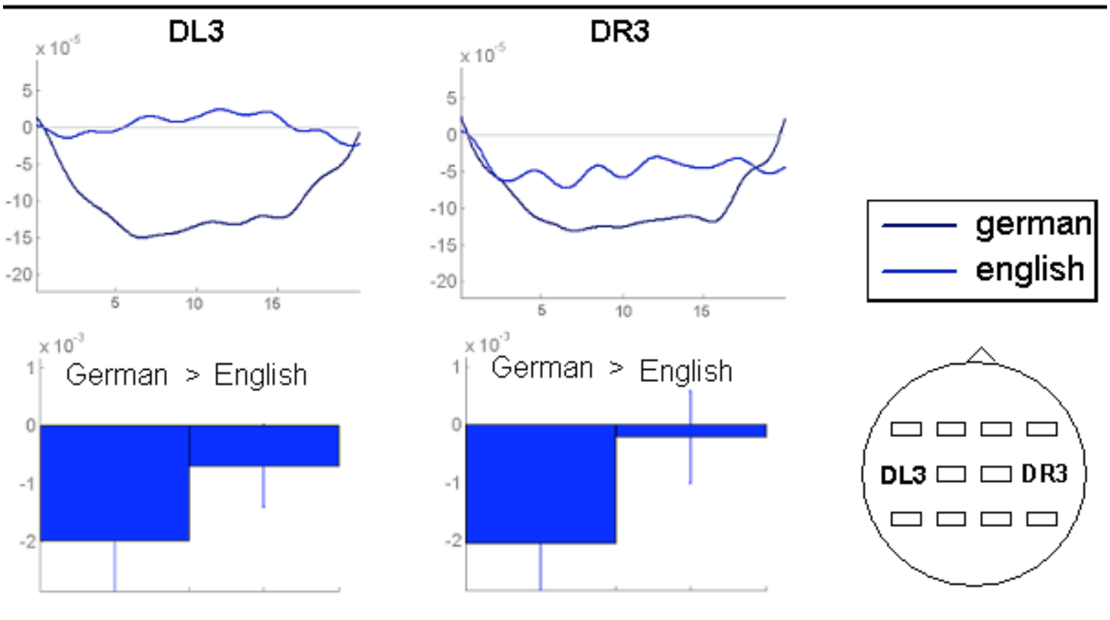
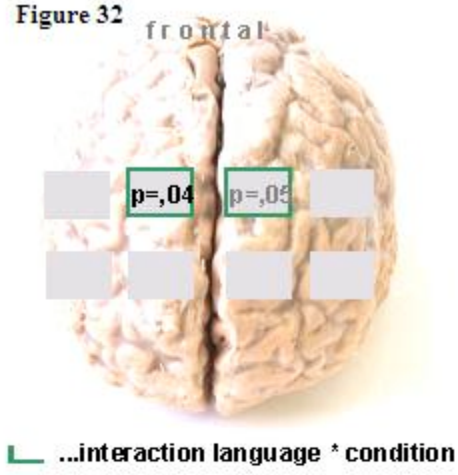


Figure 31: Time courses and beta-values for positions DL3 and DR3: German vs. English.

4.2.3. Interaction of language and condition

Significant differences could also detected for the interaction of the factors language (German vs. English) and condition (prime vs. target): bilateral activation in fronto-temporal positions DL2 and DR2 showed significance. Again, the specific meaning of this interaction was subsequently resolved using paired t-tests.

Figure 32



hemis-phere	position	main effect of condition		main effect of language		interaction lang.*cond.		df
		F-value	p-value	F-value	p-value	F-value	p-value	
left	DL1	0.97	0.34	0.08	0.78	2.64	0.12	1 (24)
	DL2	1.15	0.30	0.01	0.91	4.93	**0.04 ***	1 (24)
	DL3	3.28	0.08 °	14.75	**0.00 ***	0.16	0.69	1 (24)
	DL4	1.87	0.18	1.89	0.18	0.38	0.54	1 (24)
right	DR1	3.58	0.07 °	0.21	0.65	2.36	0.14	1 (24)
	DR2	3.16	0.09 °	0.61	0.44	4.12	**0.05 ***	1 (24)
	DR3	4.04	0.06 °	3.04	0.09 °	1.23	0.28	1 (24)
	DR4	0.04	0.85	0.32	0.57	0.49	0.49	1 (24)

* ... $p \leq 0.05$ = significant

° … $p \leq 0.10$ = marginally significant

Table 4: ANOVA calculating the main effect of the factor condition (prime vs. target), the main effect of the factor language (German vs. English), and the interaction of the two factors language and condition.

To test the interaction of the factors language and condition in positions DL2 and DR2, four paired t-tests were calculated (see table 5): The first compared German to English items within the condition prime, the second did the same within the condition target. Furthermore, prime versus target was tested for all English items, and for all German items.

The t-test comparing German with English target items, thus the influence of the factor language on the condition target, showed a marginally significantly higher activation for German targets than for English targets in position DL2. This result supports the idea suggested by the effect in positions DL3 and DR3, showing significantly higher activation for German items in general than for English ones.

More importantly, the t-test calculating English prime versus target items showed a strong significance for both tested positions, revealing a stronger difference between prime and target items for the English language, thus a stronger priming effect in English! The implications and possible explanations for this interesting result will be discussed in the next chapter.

hemisphere	position	Germ. prime vs. Engl. prime		Germ. target vs. Engl. target		Engl. prime vs. Engl. target		Germ. prime vs. Germ. target		df
		T-value	p-value	T-value	p-value	T-value	p-value	T-value	p-value	
left	DL2	0.85	0.20	0.66	0.26	-1.98	**0.03 ***	0.65	0.26	1 (24)
right	DR2	0.18	0.43	-1.56	0.07 °	-2.29	**0.02 ***	0.38	0.35	1 (24)

* ... p ≤0.05 = significant
° … p ≤0.10 = marginally significant

Table 5: Paired t-tests calculating the interaction of the factors language and condition.

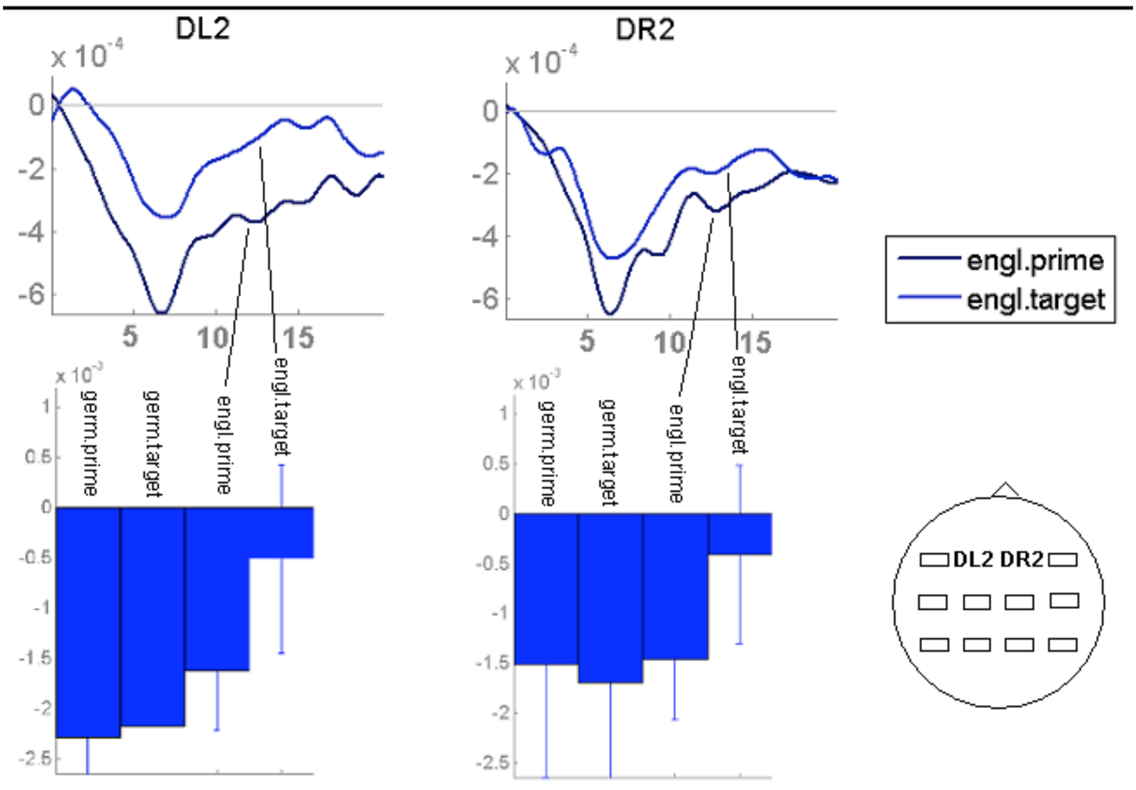
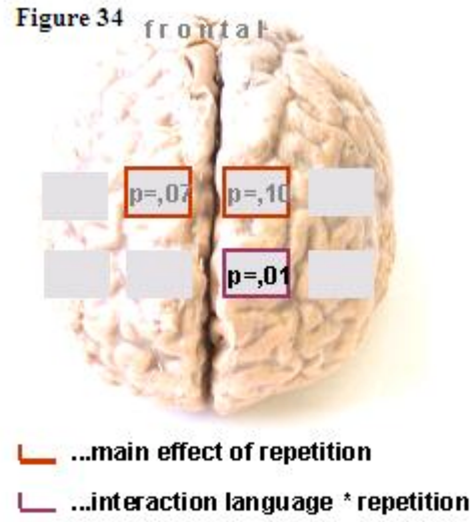


Figure 33: Time courses and beta-values for positions DL2 and DR2: Engl. prime vs. Engl. target.

4.2.4. Main effect of repetition

A marginally significant main effect of repetition (repetition 1 vs. repetition 2) was found bilaterally in fronto-temporal position DL2 for the left and DR2 for the right hemisphere.

Figure 34



The t-test comparing the means of all items presented as cross-linguistic repetition 1 versus all items presented as cross-linguistic repetition 2 revealed a marginally significantly higher activation for repetition 1 items, in fronto-temporal positions; this data possibly suggests, that, even though the amount of filler words between the corresponding repetition 1 and repetition 2 items was much bigger than the lags between prime and target (which were 1 to 3 filler words), the experimental design could have elicited a certain cross linguistic priming effect.

hemisphere	position	repetition 1 vs. repetition 2			df
		T-value	p-value	orientation	
left	DL2	-1.936	0.07 °	repetition 1 > repetition 2	1 (24)
right	DR2	-1.713	0.10 °	repetition 1 > repetition 2	1 (24)

* ... p ≤0.05 = significant
° … p ≤0.10 = marginally significant

Table 6: t-test comparing the means of all items presented as cross-linguistic repetition 1 versus all items presented as cross-linguistic repetition 2.

4.2.5. Interaction of language and repetition

Finally, the interaction of language (German vs. English) and repetition (repetition 1 vs. repetition 2) gained significance only in right-hemispheric position DR4.

hemisphere	position	main effect of repetition		interaction language * repetition		df
		F-value	p-value	F-value	p-value	
left	DL1	2.14	0.16	0.87	0.36	1 (24)
	DL2	3.75	**0.07 °**	2.16	0.15	1 (24)
	DL3	0.07	0.79	0.01	0.94	1 (24)
	DL4	0.50	0.49	1.97	0.17	1 (24)
right	DR1	1.98	0.17	0.02	0.90	1 (24)
	DR2	2.94	**0.10 °**	0.66	0.43	1 (24)
	DR3	0.03	0.87	1.69	0.21	1 (24)
	DR4	1.21	0.28	9.35	**0.01 ***	1 (24)

* ... p ≤0.05 = significant
° … p ≤0.10 = marginally significant

Table 7: ANOVA calculating the main effect of the factor repetition (cross-linguistic repetition 1 versus cross-linguistic repetition 2), and the interaction of the factors language (German vs. English) and repetition.

Of the four paired t-tests conducted to specify the interaction language - condition, only one gained significance: In right-hemispheric temporal position DR4 significantly higher activation for German repetition 1 items in comparison to German repetition 2 items also seems to support a possible cross-linguistic priming effect in the L2-L1 direction.

hemisphere	position	germ.1 vs. germ.2		engl.1 vs. engl.2		germ.1 vs. engl.1		germ.2 vs. engl2		df
		T-value	p-value	T-value	p-value	T-value	p-value	T-value	p-value	
right	DR4	-2.59	**0.02 ***	1.73	**0.10 °**	-1.51	0.14	0.73	0.47	1 (24)

* ... p ≤0.05 = significant
° … p ≤0.10 = marginally significant

Table 8: Paired t-tests calculating the interaction of the factors language and repetition.

5. Discussion

5.1. Critique of the stimulus material

The choice of stimulus material as part of the experimental design has a major influence on the results of an experimental study, and thus it is important to review the influence of certain characteristics or weaknesses of the stimulus design on the discussed findings. While the repetition priming word-pairs were presented with a controlled lag of one to three filler words between prime and target item, the cross-linguistic priming word-pairs were presented with strongly variable and partly very long lags, which moreover were randomised but not encoded differentially according to their length, and thus cross-linguistic priming over different lag sizes could not be evaluated separately. In some studies cross-linguistic priming was found also in priming designs containing comparatively long lags, but in other studies cross-linguistic priming reached significance only in a design condition presenting the prime immediately before the target item. Thus it cannot be excluded, that, had we used smaller lags for the cross-linguistic prime-target word-pairs, cross-linguistic priming would have reached significance also in the forward-priming condition. Nevertheless, backward cross-linguistic priming obviously proved to be the stronger and more robust effect in the experiment.

Another critical point in the interpretation of the processing of our stimuli in general, and the cross-linguistic priming design in particular, is that the experimental design did not demand any specific behavioural response task from the subjects upon hearing the stimuli. As described in chapter 3.3.4., the subjects were told they would hear words from speakers, and were instructed to sit comfortably and watch the screen. This choice of experimental setting was taken due to our subjects' young age (mean age of 6,72 years): A linguistic decision task requiring explicit knowledge of a linguistic meta-level, like a lexical decision or semantic categorisation task, would have been not only emotionally intimidating for the children, but would probably have overstrained their attentional and intellectual capacities. But the lack of on-line behavioural instruction controlling the processing depth of the stimuli leaves us with speculations on which levels of information were actually activated – Did the subjects access lexical level information (as would be granted for in the case of the subjects performing a lexical decision task)? Did they activate semantic information from their conceptual level (as would be requested in a semantic categorisation task)? The typical haemodynamic responses found in all measured positions, and the widely distributed main effect of condition (priming effect irrespectively of the language) clearly show, that some specific word information has been retrieved. What the other results of the study suggest concerning the processing depth and pathways will be discussed below.

5.2. Evaluation of the hypotheses

The overall mean of measured oxygenation changes, thus cortical activation, during stimulus presentation versus phases of silence showed the typical haemodynamic response pattern with [oxy-Hb] increasing shortly after stimulus onset and [deoxy-Hb] showing a simultaneous decrease in concentration in all fronto-temporal and temporal positions. According to the hypothesis, this shows, that the presented words have indeed been processed by the subjects.

The t-tests contrasting the activity during processing of prime versus target items, regardless of the specific language, shows a clear tendency towards reduced activity for target items in two bilateral temporal positions as well as in right-hemispheric fronto-temporal positions; thus the hypothesized within-language repetition priming effect occurred faintly but steadily for all stimuli.

5.3. Discussion of explorative questions

5.3.1. Higher activation for German than for English items in left temporal position

As described in chapter 3.3.1., all subjects were early bilinguals, thus they started learning both language at an early age. Nevertheless, the fact that all of them lived in Berlin at the time of the study – and most of them had been doing so for all or the majority of their lifetime – results in a clearly higher amount of exposure to the German language in comparison to English, especially in the modality of passive listening. This difference between the languages is reflected also by the behavioural data on language proficiency: While, in the parents' ratings, the children's proficiency in German scored 1.15 (on a scale from 1=native till 5=not good) (SD 0.35), their proficiency in English reached only a mean of 1.72 (SD 0.92). Thus, in spite of the subjects being early bilinguals, German should be considered as the dominant language, and English as the less dominant one.

On this basis the main effect of language, showing significantly higher activation for German items in comparison to English items (highly significant effect in left temporal, marginally significant effect in right temporal position), means a higher activation during the processing of the dominant language, mainly in left temporal position. These findings coincide with the results of several studies on lexical-semantic processing in bilinguals, reporting a highly distinct area in the left hemisphere specialized on L1 processing: Perani et al. (1996) assessed bilinguals' cortical activation during passive listening to words and sentences in Italian (the subjects' L1) and English (L2), and found significantly more activation for Italian language items over a large set of areas, including the left and right temporal poles. In an imaging study Dehaene et al. (1997) measured French-English bilinguals' cortical activity, also during a passive listening task; their findings correspond closely with our results, showing an area in the left temporal lobe, clustering along the left superior temporal sulcus as well as superior and middle temporal gyri till the temporal pole, active specifically - and very consistently over all subjects - during processing of French, the subjects' dominant, native language.
The lack of a preferentially activated region for the less dominant language, gaining significance over all subjects, might be due to a higher inter-individual variability for the neurofunctional architecture of the less dominant language. Indeed, by evaluating activity observed in the single subjects, Dehaene et al. found that the less dominant language activated a highly variable network of areas, none of which gained significance over subjects. Such neurofunctional variability has often been attributed to the influence of age of acquisition; the measured physiological difference between processing of the two language in our study emphasizes the importance of relative language proficiency as a factor influencing the neurofunctional setup, even if age of

acquisition does not significantly differ across a bilingual's languages – a fact also emphasized by both above mentioned studies.

Furthermore, considering the position of the measured higher activation for German in left temporal position, a region repeatedly identified as crucial for semantic processing, suggests a qualitative analysis of the pathways underlying German and English item processing: As discussed at the beginning of this chapter, English acts as the less dominant language for our subjects, because they have been exposed to English language input less frequently in their lives than to German input. Speaking in terms of the (bilingual) interactive activation framework (see chapter 2.3.2.2.), English items have a lower (subjective) word frequency for our subjects, resulting in a lower resting-level activation, than German items; in this respect L2 words, in comparison to L1 words, in a bilingual, behave similarly to low-frequency words, in comparison to high-frequency words, within one language (Thomas et al. 2009), in that they need more excitatory resources in order to reach recognition threshold and fully process the associated information. This surplus of needed activation, especially for higher level information, for items from the less dominant language could be explained in terms of the re-revised hierarchical model (RRHM, see chapter 2.3.2.1.) by their access of conceptual information preferentially by an indirect, lexically mediated pathway, through the dominant language's lexicon. Keeping in mind the undemanding experimental context of the word processing, due to lack of a response task instruction controlling processing depth, discussed at the beginning of this chapter, the fact that English items elicited less activation in our experiment suggests that the English words could have been processed less deeply by our subjects, than the German ones. Considering that it needs more cortical activation for less dominant language words to process higher level information, the low amount of attention on the auditory stimuli in our experiment might not have recruited sufficient resources to retrieve all form, lexical and semantic information. It can be concluded, that while in the processing of German words information from lexical as well as conceptual level has been retrieved, in the processing of English words mainly lexical level information got activated, while significantly less conceptual information was recruited by the subjects, resulting in less measured activation for English items mainly in left temporal position. This interpretation gets support from studies investigating the neuroanatomical areas responsible for semantic processing: Demonet et al. (1992) conducted a study to isolate the functional anatomy of semantic processing in a passive listening task with semantic categorization, and found highly significant and differentiated activation in the left middle and inferior temporal gyri. Price et al. (1997) also identified the left middle temporal cortex specifically with semantic processing. It should also be mentioned, that both Perani et al. 1996 and Dehaene et al. 1997, who found a neurofunctional distribution for processing of dominant and less dominant language similar to our results, used passive listening tasks without requirement of an immediate response task, and hence a different processing depth for the two languages could have influenced their experimental data analogically to our experiment.

5.3.2. Within-language repetition priming in English items in fronto-temporal positions

The statistical analysis comparing German to English items within the conditions prime and target revealed a bigger within-language repetition priming effect for English, the less dominant language. This effect occurred with high significance in left and right superior fronto temporal positions. To account for this effect we will again refer to the (bilingual) interactive activation framework, which indeed predicts an interaction of word frequency and repetition priming effects: Low-frequency words, while initially needing more excitatory input to reach recognition threshold, gain a significantly higher processing advantage through repetition, than high-frequency words, having a higher resting-level activation anyway, do! Several ERP studies have confirmed this prediction for high- and low-frequency words of one language (Rugg 1990), but the paradigm has also been used to generate predictions for bilingual priming studies (e.g. Alvarez et al. 2003), and can thus explain the greater within-language priming effect, thus stronger benefit from repetition, in English items in our study.

We have to bear in mind, that, since we assume the English items in general to have activated mainly lower, lexical level information, the reduced activation through repetition priming can obviously concern only these processes. Taking into account the localisation of the within-language priming effect in bilateral fronto-temporal regions this is indeed probable: Several studies have found the inferior frontal cortex, more specifically the inferior frontal and inferior precentral sulcus, to play a role in lexical processing during presentation of word-lists (Friederici et al. 2000a), morphosyntactic processing of single words (Friederici et al. 2000b), or retrieval of segmental information (Hickok et al. 2000). In addition, some lower-level processing facilitation through priming could stem also from Broca's area, lying in the inferior frontal gyrus, and being known to be involved in phonological processing (Demonet et al. 1992; Price et al. 1997).

5.3.3. Backward cross-linguistic translation priming from L2 to L1 in right temporal position

The interaction of the factors language and repetition revealed a facilitation in the processing of German items, if they were preceded by their English translation. To interpret this cross-linguistic priming effect in the L2-L1 direction, also called backward translation priming effect, we will again draw upon the RRHM, an approach also applied by Alvarez et al. 2003 in formulating the hypotheses for their translation priming paradigm. According to the RRHM both the dominant and less dominant language have a shared conceptual store, but are represented separately on the lexical level. While both languages' lexical entries have a connection to the concepts as well as to the other language's lexical entries, the L1 lexicon has a stronger connection directly to the conceptual store, while the L2 lexicon has a stronger connection to the L1 lexicon, activating the respective L1 translation equivalents. The absence of forward translation priming and the strong measured backward translation priming effect in our study match the predictions of this configuration of functional interaction in bilingual language processing: Assuming that L2 words activated mainly lexical level information, in the case of forward translation priming, the concepts pre-activated by the L1 primes did not help the processing of the subsequent L2 translation equivalent, because the L2 word accessed only lexical information, and not the concept level. On the other hand, and independently of processing depth, if an L2 prime automatically activates its L1 translation equivalent, the observed priming effect in the processing of the subsequent L1 target item is similar to a within-language L1 repetition priming effect! In fact, a study conducted by Menenti et al. (2006) confirmed the strong lexical connection from L2 to L1 items, also in highly proficient bilinguals: The subjects were presented L2 word pairs, in which the L1 translation of the first presented L2 word rhymed with the second L2 word. Thus, only if the L2 prime item automatically activated its L1 translation equivalent, the phonological form priming effect could be observed. That a priming effect was in fact found by Menenti et al. suggests, that even high proficient bilinguals make use of their direct lexical connection to lexical representations of their dominant language when processing words in their less dominant language.

6. Conclusion

The thorough discussion of the obtained results, in the light of the many influencing factors of the study, has shown a responsible interpretation of the neurofunctional processes elicited by the experimental stimuli, and drawn implications for a general understanding of the bilingual lexical-semantic interface. The differential activation for German and English stimuli has shown, that different amount of exposure to the two languages, and the resulting different proficiency level, has an influence on the neurophysiological architecture of the bilingual brain, even for equal age of acquisition for both languages. Speaking of the physiology of the cortical substrate underlying language processing in the different languages, it seems that while the dominant language is represented in similar cortical regions over all tested subjects, the cortical regions activated by the less dominant language possibly displayed a high inter-individual variability, reflecting the differences in each subject's communication experience and behaviour in that less dominant language, which is not determined by society or other institutional factors common to all children. Speaking of the functional pathways underlying language processing, the obtained priming effects indicate that even early bilinguals rely more on a lexically mediated pathway in order to access meaning in their less dominant language, a conclusion which supports the qualitative prediction of the RRHM. Also, in order to access not only lexical level information, but also the semantic level of less dominant language items, more excitatory activation is needed; this effect matches the quantitative predictions of the BIA+ model (see chapter 2.3.2.2.) for less frequent words, like words from the less dominant language.

For further research on the lexical-semantic interface in bilingual children it might be useful to find an experimental setting which allows to distinguish more clearly between lexical and semantic neurofunctional processes. Speaking of methodological factors, it needs to be considered that near infrared spectroscopy is a very non-invasive and convenient measuring method for children, but, since the measured activation changes are calculated indirectly on the basis of haemodynamic concentration changes, which occur with a delay of several seconds after stimulus onset, it cannot distinguish between different levels of input processing, like phonological, lexical and semantic processes, which occur in a course of milliseconds. Speaking about the stimulus design, a more accurate distinction between lexical and semantic processes could also be achieved through the use of response tasks, like lexical decision or semantic categorization, controlling the depth of processing of the speech input.

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8. Indices

8.1. List of figures

8.2. List of tables

8.3. List of abbreviations

[deoxy-Hb]	deoxygenated haemoglobin
[oxy-Hb]	oxygenated haemoglobin
[tot-Hb]	total haemoglobin
ANOVA	analysis of variance
BA	Brodmann area
BIA	bilingual interactive activation
BIA+	bilingual interactive activation plus
BOLD	blood-oxygenation-level-dependent
cm	centimeter
EEG	electroencephalography
ELAN	early left anterior negativity
fig.	figure
fMRI	functional magnetic resonance imaging
HRF	haemodynamic response function
Hz	hertz
IAM	interactive activation model
ISI	inter-stimulus-interval
L1	first language
L2	second language
MEG	magnetoencephalography
mm	millimeter
NIRS	near infrared spectroscopy
nm	nanometer
PET	positron emission tomography
rCBF	regional cerebral blood flow
RRHM	re-revised hierarchical model
s	second
SD	standard deviation
vs.	versus
WLPB-R	Woodcock Language Proficiency Battery-Revised

9. Appendix

9.1. Declaration of consent

CHARITÉ – UNIVERSITÄTSMEDIZIN BERLIN

CHARITÉ • Schumannstr. 20/21 • D-10117 Berlin • Germany

BNIC

Berlin NeuroImaging Center

<u>Einverständniserklärung über Nahinfrarot-Spektroskopie-Untersuchungen (NIRS) und Elektroenzephalographische Untersuchungen (EEG) zu wissenschaftlichen Zwecken</u>

<u>Zweitsprachverarbeitung bei Kindern</u>

Messung der evozierten elektrophysiologischen und vaskulären Antwort bei Sprachstimuli durch Koregistrierung der evozierten Potentiale (ERP) und der Oxygenierungsantwort mittels cerebraler Nahinfrarot-Spektroskopie (fNIRS).

PD Dr. Hellmuth Obrig
Tel. +49-30- 450 560 010
Fax. +49-30-450 560 952
hellmuth.obrig@charite.de

____________________	____________________
Vor- und Nachname der Mutter	Vor- und Nachname des Kindes
____________________	____________________
Vor- und Nachname des Vater	Geburtsdatum des Kindes

Ich bin von Frau / Herrn ____________________ (ärztlicher bzw. wissenschaftlicher Mitarbeiter) über das experimentelle Vorhaben und das Verfahren der Nahinfrarot-Spektroskopie und Elektroenzephalographie aufgeklärt worden (siehe gesonderter Aufklärungsbogen "Elterninformationen für das Forschungsprojekt"). Mir ist bekannt, dass die Untersuchung ausschließlich zu wissenschaftlichen Zwecken durchgeführt wird und keine medizinisch-diagnostische Untersuchungsmaßnahme darstellt.

Ich erkläre mich mit der Durchführung der wissenschaftlichen Studie einverstanden. **Ich erkläre mich damit einverstanden, dass die im Rahmen dieser Studie erhobenen Daten/Angaben verschlüsselt und auf elektronischen Datenträgern aufgezeichnet, verarbeitet und die anonymisierten Studienergebnisse veröffentlicht werden.**
Mir ist bekannt, dass ich meine Einwilligung jederzeit ohne Angabe von Gründen und ohne nachteilige Folgen für mich oder mein Kind zurückziehen kann und einer Weiterverarbeitung der Daten jederzeit widersprechen und ihre Löschung bzw. Vernichtung verlangen kann.

____

Ort und Datum

______________ / ______________	____________________
Unterschrift der Erziehungsberechtigten	Unterschrift Versuchsleiter

9.2. *Authorization*

CHARITÉ – UNIVERSITÄTSMEDIZIN BERLIN

CAMPUS CHARITÉ-MITTE

CHARITÉ • Charitéplatz 17 • D-10117 Berlin • Germany

BNIC

Vollmacht

Berlin NeuroImaging Center

Dr. Isabell Wartenburger
Tel ++49-30- 450 560 194
Fax ++49-30- 450 560 952
Email isabell.wartenburger@charite.de

______________________ ______________________

Vorname, Name der Mutter | Vorname, Name des Vaters

______________________ ______________________

Vorname, Name des Kindes | Geburtsdatum des Kindes

Vollmacht

Hiermit bevollmächtige ich ________________________ in meinem Namen die Elterninformation für die Untersuchung meines Kindes ____________________ zu unterschreiben.

Berlin, den ________ ____________________ ____________________

Name (Druckbuchstaben) | Unterschrift

CHARITÉ – UNIVERSITÄTSMEDIZIN BERLIN
Gemeinsame Einrichtung von Freier Universität Berlin und Humboldt-Universität zu Berlin
Körperschaft des Öffentlichen Rechts
Schumannstr. 20/21 • D-10117 Berlin • Telefon: ++49-30-450 50 • Internet: www.charite.de

9.3. *Questionnaire*

VP____________

Liebe Eltern,

Wir möchten uns bei Ihnen bedanken, dass Ihr Kind an unserer Untersuchung teilnehmen kann.

Für die spätere Auswertung und Einordnung der Daten ist es für uns wichtig, noch einige weitere Informationen von Ihnen zu bekommen. Deshalb bitten wir Sie, diesen Fragebogen vollständig zu beantworten.

Wir möchten nochmals darauf hinweisen, dass alle von Ihnen gemachten Angaben streng vertraulich behandelt werden und ausschließlich wissenschaftlichen Zwecken dienen.

____

Vor- und Nachname des Kindes: ____________________________________

Tel:_________________________ email:___________________________

Geburtsdatum:____________________ Geschlecht: m w

Muttersprache(n):____

Schulklasse: ______________________

Zur Allgemeinen kognitiven Entwickling:

1. Mit welcher Hand führt Ihr Kind die nachfolgend aufgeführten Tätigkeiten am häufigsten aus?

	Links	rechts
Schreiben		
Malen		
Ball werfen		
Schneiden mit einer Schere		
Zahnbürste		
Schneiden mit dem Messer (beim Essen)		
Suppe löffeln		
Schachtel öffnen (Deckel)		

2. Gibt es in Ihrer Familie Linkshänder? Ja Nein

Wenn ja, wer? ____

3. Würden Sie Ihr Kind als „musikalisch" einschätzen? Ja Nein

4. Spielt Ihr Kind ein Instrument? Ja Nein Wenn ja, welches? ___________

Wenn ja, seit wann? ____

5. War/ist Ihr Kind in logopädischer Behandlung oder besucht(e) es eine sprachtherapeutische Einrichtung?

Ja Nein Wenn ja, warum?____

6. Besteht ein Verdacht auf eine Lese-Rechtschreibschwäche? Ja Nein

7. Leidet Ihr Kind an einer Hörstörung? Ja Nein

8. Hatte Ihr Kind jemals eine Schädigung des Gehirns bzw. des Kopfes (Unfall, Gerhirnerschütterung, o.ä.)?

Ja Nein Wenn ja, welche?____

9. Leidet Ihr Kind an einer Herz-Kreislauferkrankung?

Ja Nein Wenn ja, welche?____

10. Muss Ihr Kind irgendwelche Medikamente einnehmen?

Ja Nein Wenn ja, welche?____

11. Fällt Ihnen sonst noch irgendetwas ein, was für uns von Interesse sein könnte?

____

Zur Sprachentwicklung:

12. Spricht Ihr Kind noch andere Sprachen außer Deutsch und Englisch?

Ja Nein

Wenn ja, welche?____

13. Wie gut schätzen Sie die Kompetenz Ihres Kind in folgenden Sprachen zur Zeit ein?

	wie ein(e) MuttersprachlerIn	sehr gut	gut	mäßig/aus-reichend	nicht gut
Englisch					
Deutsch					
________					
________					

14. In welche/n Sprache/n würden Sie Ihre Kompetenz zur Zeit als „native“ einstufen?

Mutter: ___________________________________Vater:________________________________

15. Welche Sprache spricht Ihr Kind mit seinen Geschwistern?

____

16. Gibt es sonst noch irgendwelche Besonderheiten in der Familienkommunikation, die für uns von Interesse sein könnten?

____

____

____

	In welchem Umfeld spricht Ihr Kind .. ?			Mit welchen Bezugspersonen spricht Ihr Kind.. ?			Wieviel % spricht Ihr Kind pro Tag.. ?			Wieviel % hört Ihr Kind pro Tag.. ?		
	.. englisch	.. deutsch	.. ________	englisch	deutsch	__________	engl.	dt.	____	engl.	dt.	____
1. LJ							%	%	%	%	%	%
2. LJ							%	%	%	%	%	%
3. LJ							%	%	%	%	%	%
4. LJ							%	%	%	%	%	%
5. LJ							%	%	%	%	%	%
6. LJ							%	%	%	%	%	%
7. LJ							%	%	%	%	%	%
8. LJ							%	%	%	%	%	%
9. LJ							%	%	%	%	%	%
10.LJ							%	%	%	%	%	%

4

9.4. Language test

picture naming test VP:_______________

Item 8	telephone	
Item 9	fish	
Item 10	ball	
Item 11	scissors	
Item 12	banana	
Item 13	bike	
Item 14	star	
Item 15	shoe	
Item 16	spoon	
Item 17	key	
Item 18	carrot	
Item 19	helicopter	
Item 20	lock	
Item 21	grasshopper	
Item 22	octopus	
Item 23	doorknob	
Item 24	switch	
Item 25	waterfall	
Item 26	magnet	
Item 27	water faucet	
Item 28	globe	
Item 29	igloo	
Item 30	cinema	
Item 31	pyramid	
Item 32	washing gold	

vocabulary test

monkey		church		peanut		tie	
ant		cherry		donkey		sled	
branch		pillow		flag		key	
eye		dress		bicycle		snail	
car		bone		window		pig	
tree		button		bottle		rope	
leg		basket		wing		mirror	
mountain		pumpkin		airplane		sink	
picture		spoon		woman		city	
pear		lion		frog		rock	
leaf		girl		fork		boot	
pencil		coat		bell		sock	
flower		knife		belt		chair	
wood		moon		rooster		cup	
letter		trash		neck		plate	
bread		nail		rabbit		rug	
bridge		net		shirt		table	
castle		ear		heart		safe	
brush		pan		witch		door	
roof		whistle		deer		bag	
thumb		horse		pants		bird	
sword		peach		chicken		cloud	
can		doll		dog		desert	
kite		wheel		hat		fence	
egg		rain		boy		toe	
bucket		swing		potato		goat	
duck		boat		cheese		lemon	
strawberry		snake		cookie		train	

9.5. Picture naming test

9.6. *NIRS measurement record*

Ableitungsprotokoll L2 prime kids

Name: __________________________ **Vp-Nr: _____________**

Geburtsdatum	Alter	Geschlecht m w	Randomisierung	Tag der Durchführung
Kappengröße	Impedanzen vor Messung		Problematische Elektroden	

Zeit	EEG-Verlauf Block 1	EEG-Verlauf Block 2
0.00		
0.30		
1.00		
1.30		
2.00		
2.30		
3.00		
3.30		
4.00		
4.30		
5.00		
5.30		
6.00		
6.30		
7.00		
7.30		
8.00		
8.30		
9.00		
9.30		
10.00		
10.30		

Sonstiges:

A			**B**		
C			**D**		

9.7. *Receipt for expense allowance*

PROBANDENQUITTUNG

Probanden stehen in keinem Beschäftigungsverhältnis. Die „Entschädigung" ist nicht sozialversicherungspflichtig, jedoch als „sonstige Einkünfte" dem Finanzamt zu melden.

Name, Vorname des Probanden	**Privatanschrift**	**für welche/s Klinik/Institut**	**Tel. ggf. Dienst-Tel.**
	Steueranschrift (wenn abweichend von der Privatanschrift)		

Betrag: ____________________________ €

für (Zweck): ____

erstatten Sie mir auf das Konto:

Konto-Nr.:	**Geldinstitut**	**Bankleitzahl**

zu lasten des Innenauftrages (Drittmittelprojektes): __________________
(Bitte nur eine Kostenstelle!)

Ich versichere, dass ich den vorstehenden Betrag als steuerpflichtige Einnahme meinem Finanzamt mitteile.

für die sachliche Richtigkeit

____
Datum, Unterschrift des Probanden

____
Datum, Unterschrift des Zeichnungsberechtigten
(Stempel d. Klinik/Institut/Dienststelle)

9.8. Flyer

CHARITÉ UNIVERSITÄTSMEDIZIN BERLIN

The Charité seeks elementary school children

for a study on bilingualism

Alexander von Humboldt Stiftung / Foundation

Why do I learn foreign words faster than you?

How does language work?

How do I learn to understand what you are saying?

Dear parents,

We are conducting a study on the processing of a second language in children. We are looking for primary school children aged 6-7 years, who were raised bilingually with the languages German and English.
Our study is designed to uncover the brain processes which occur when listening to a second language. To achieve this we will present German and English words through speakers, while simultaneously measuring brain activity using two different neurophysiological methods. These methods include both Electroencephalography (EEG), which tracks the timing of neural responses, and near infrared spectroscopy (NIRS), which can localize where in the brain these processes occur. Both methods make use of a cloth cap.
Do not worry: All this is easier than it sounds! Both methods are completely painless, are NOT dangerous, and have been used for years to understand language processing.

So, if your child is…

- **6 to 7 years old**
- right-handed
- **bilingual**, speaking **English and German**

… we would be pleased if your child participates in our language study.

Subjects in this study will receive 30 euros for their participation.

For more information, contact us:

Prof. Dr. Arturo Hernandez
Prof. Dr. Isabell Wartenburger
Dipl. Psych. Manfred Gugler
Raina Gielge

030 - 450 560 283 or 0157 - 777 898 37

Email: gielge@uni-potsdam.de

The study will take place at the Virchow Hospital Charité (Augustenburger Platz 1, 13353 Berlin), within the campus at the Mittelallee 2, 4th floor on the right in the glass box.

Phone no. of the testing room: 030 - 450 560 304.

BVG Station: U9 Amrumer Strasse

9.9. *Informative handout*

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<u>Elterninformation für das Forschungsprojekt</u>

<u>Zweitsprachverarbeitung bei Kindern</u>

Messung der evozierten elektrophysiologischen und vaskulären Antwort bei Sprachstimuli durch Koregistrierung der evozierten Potentiale (ERP) und der Oxygenierungsantwort mittels cerebraler Nahinfrarot-Spektroskopie (fNIRS).

<u>Zweck und Nutzen der Studie</u>

Liebe Eltern,
Ihr Kind nimmt an einer Studie zur Zweitsprachverarbeitung teil. Dabei werden zum einen mittels EEG (Elektroenzephalographie: Messung von ereigniskorrelierten Potentialen (EKP)) Hirnströme gemessen, die durch akustische (Sprach-)Reize beim Kind hervorgerufen werden. Anhand der erhobenen Daten kann man untersuchen, wie sich bestimmte Eigenschaften einer Sprache entwickeln. Zum Beispiel wird untersucht, wann ein Kind verschiedene Sprachen voneinander unterscheiden kann oder wann es unterscheiden kann, ob die Grammatik eines Satzes richtig oder falsch ist. Das ganz besondere Augenmerk bei diesen Untersuchungen richtet sich darauf, wie sich das menschliche Gehirn im Kindesalter den Anforderungen der Sprache anpasst. Das heißt: während Ihr Kind immer besser und ‚richtiger' Sprechen lernt, verändert das Gehirn seine Verschaltung. Diese Veränderungen bedeuten, dass bestimmte Regionen der Hirnoberfläche immer mehr spezialisiert werden, um sehr schnell Sinn und Unsinn eines Satzes zu erkennen und einem bestimmten Wort eine bestimmte Bedeutung zuzuordnen. Die Hirnstrom-Messungen (EKP) können sehr gut die Abfolge der Prozesse abbilden. So wird ab einem bestimmten Alter im Satz ‚Der Hund bellen die Katze an' das falsch gebeugte Wort durch ein bestimmtes Hirnstromelement ‚beantwortet'. Während dieses Hirnstrompotential uns zuverlässig zeigt, dass Ihr Kind einen Fehler erkannt hat, ist es sehr schwierig festzustellen, welche Hirnregion hierbei die entscheidende Rolle spielt.
Daher möchten wir die EEG-Messungen durch ein gleichzeitig verwendetes, zweites Verfahren ergänzen. Das Verfahren heißt ‚Nahinfrarot-Spektroskopie' kurz NIRS.
Mit der NIRS lassen sich Veränderungen der Sauerstoff-Versorgung in bestimmten Regionen des Hirnmantels feststellen. Man geht davon aus, dass Hirnregionen, die gerade aktiv mit der Verarbeitung bestimmter Reize (in unserem Fall Sprachreize) beschäftigt sind, mehr Sauerstoff benötigen und daher vermehrt durchblutet werden. Durch die Messung der Veränderungen in der Sauerstoffversorgung, lassen sich aktive Regionen des Gehirnes lokalisieren.
Wir sind ganz sicher, dass die Untersuchung Ihrem Kinde keinerlei Schaden zufügen wird. Sollten Sie Bedenken haben können wir einerseits im Gespräch versuchen diese Bedenken auszuräumen. Andererseits wissen Sie, dass Sie jederzeit ohne Angabe von Gründen die Untersuchung ablehnen oder abbrechen können. Aus Abbruch oder Ablehnung der Untersuchung werden Ihnen oder Ihrem Kind keinerlei Nachteile erwachsen. Die Untersuchung dauert ca. 30 Minuten.
Nun interessiert Sie vielleicht weniger die Theorie, sondern insbesondere die Frage, ob und welche Risiken von einer solchen Untersuchung ausgehen.

Zur EEG-Untersuchung (Elektroenzephalographie)

EKP- was ist das eigentlich?

Als EKP (= 'Ereigniskorrelierte Potentiale') bezeichnet man die von dem Gehirn selber produzierte elektrische Aktivität, die als Antwort auf bestimmte äußere Reize entstehen. Für den Spracherwerb ist natürlich die Verarbeitung von akustischen Reizen von besonderem Interesse.

Was passiert mit meinem Kind während einer solchen Messung?

Ganz wichtig: diese Untersuchung ist nicht schmerzhaft und birgt kein Risiko für die Gesundheit Ihres Kindes.

Zunächst einmal werden wir Ihrem Kind eine Art Badekappe aufsetzen, an der Messplättchen (Elektroden) befestigt sind. Auf diese Weise können wir die Gehirnaktivität messen und aufzeichnen.

Sie bleiben während der Untersuchung mit Ihrem Kind zusammen. Während der Untersuchung hört Ihr Kind -je nach Alter- über Lautsprecher oder Kopfhörer Töne, Silben, Worte oder Sätze.

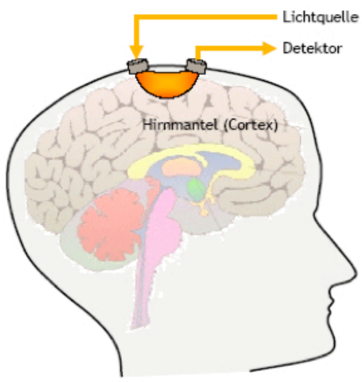
Was soll mein Kind dabei eigentlich tun?

Nichts. Bei der Untersuchung werden nämlich nur Gehirnwellen aufgezeichnet, die automatisch entstehen. Wichtig ist jedoch, dass Ihr Kind sich so wenig wie möglich bewegt.

Zur NIRS-Untersuchung (Nahinfrarot-Spektroskopie, Gerät OxiplexTS der Firma ISS)

NIRS – was ist das eigentlich?

Die Nahinfrarot-Spektroskopie kann Änderungen in der Sauerstoffversorgung im Hirnmantel lokalisieren. Grundüberlegung dabei ist, dass Hirnregionen, die gerade aktiv, also mit der Verarbeitung eines bestimmten Reizes beschäftigt sind, mehr Sauerstoff benötigen und daher stärker durchblutet werden. Die NIRS macht sich zunutze, dass sauerstoffreiches Blut eine andere Farbe hat als sauerstoffarmes. Der Unterschied ist Ihnen vielleicht bekannt: bei guter Durchblutung bekommt man z.B. eine ‚rosige' Gesichtsfarbe, bei schlechter Durchblutung –zum Beispiel bei großer Kälte– aber eine bläuliche Gesichtsfarbe. Ähnliches gilt für das Gehirn. An der Stelle wo der Hirnmantel gerade aktiviert ist, ‚errötet' das Gehirn. Nun können wir diese Änderung nicht mit dem bloßen Auge feststellen, da Licht im sichtbaren Wellenlängenbereich von der Haut ganz absorbiert wird. Im sogenannten ‚Nahinfrarot-Bereich' erreicht das Licht jedoch tiefere Gewebsschichten und wir können Farbumschläge auf der Hirnoberfläche beobachten. Technisch bedeutet das, dass wir Licht mit bestimmten Wellenlängen im Nahinfraroten Bereich einstrahlen und in geringer Entfernung das reflektierte Licht wieder sammeln. Die Veränderung der reflektierten Lichtmenge lässt sich dann umrechnen in den ‚Farbumschlag' auf der Hirnoberfläche. So lassen sich aktive Regionen des Gehirnes (durch die Veränderung der Sauerstoffversorgung) lokalisieren.



Messsituation

Zur Messung werden 8 Sendeoptoden und 4 Detektionsoptoden in einer studienspezifischen Anordnung in die EEG-Kappe eingesteckt, da es für die Qualität der Messung wichtig ist, dass die Optoden stabil befestigt sind und ihre festgelegte Position genau behalten. Die Kappe wird mit einem Brustgurt am Kopf des Kindes gehalten. Um eine Bewegung der Optoden durch Zug an den verbundenen Lichtleitern zu verhindern, werden die Kabel hinter dem Kopf zusammengeführt und befestigt. Dies gewährleistet die nötige Zugentlastung an den Kabeln. Die 12 Glasfaserkabel sind mit dem NIRS-Monitor (OxiplexTS ISS, Champaign, Illinois U.S.A.) verschraubt.

Was ist Nahinfrarotes Licht?

Nahinfrarotstrahlung ist nichts Künstliches. Das Sonnenlicht und jede Halogenlampe hat einen großen Anteil genau in diesem Wellenlängenbereich. Nahinfrarotes Licht hat den Vorteil, dass es nicht vollständig von der Haut absorbiert, sondern eine gewisse Menge reflektiert wird und dann von einem sogenannten Detektor aufgefangen werden kann.

Besteht irgendein Risiko für mein Kind?

Die Abbildung zeigt wie das NIRS-Verfahren in einer Studie einer amerikanischen Arbeitsgruppe genutzt wird.

Zunächst muss gesagt werden, dass seit vielen Jahren Kinder mit genau diesem Verfahren untersucht werden. Unsere Arbeitsgruppe hat seit Jahren Untersuchungen an Erwachsenen und Kindern durchgeführt und es wurden keine Nebenwirkungen beobachtet.

Als wesentliche Gefahrenquelle sind die Lichtquellen zu sehen. Die maximale Ausgangleistung der Lichtdioden am Gerät ist 3.4 mW. Da das Lichteinkoppeln in die Fasern immer mit Verlusten verbunden ist, liegt die maximale Ausgangsleistung am Faserende derzeit bei 1.5 mW. Den Ansprüchen der EN-60825 wird für die Hautbestrahlung damit Rechnung getragen (Abschätzung Haut, Faserbündeldurchmesser). Die Erwärmung der Haut ist daher bei unserem Verfahren minimal (deutlich geringer als bei einem sehr kurzen Sonnenbad).

Da die Lichtleistung aber über dem Grenzwert zur Augenschädigung liegt, werden spezifische Maßnahmen beachtet, um eine versehentliche Beleuchtung des Auges zu vermeiden.

Sollte Ihr Kind die Messproben versehentlich vom Kopf reißen und dabei in die Lichtquelle schauen, wäre dies vergleichbar mit dem Risiko, das durch das kurze Schauen in einen Laser-Pointer entsteht (aufgrund der starken Streuung besteht eine Gefahr für das Auge nur in einem sehr kleinen Abstand, wobei der Lichtstrahl genau in das Auge gerichtet sein muss).

Maßnahmen zur Gefahrenminderung:

Wir ergreifen verschiedene Maßnahmen, um eine Gefahr für das Auge vollkommen auszuschließen. Das Gerät wird erst eingeschaltet, wenn die Proben am Kopf angebracht sind. Um ein Verrutschen oder Abreißen der Messproben zu verhindern, wird Ihrem Kind eine handelsübliche EEG-Kappe (‚Badekappe') aufgesetzt und mit einem Brustgurt am Oberkörper befestigt. Die Messproben sind fest auf der Kappe (zusammen mit den EEG-Elektroden) angebracht. Zusätzlich wird Verbandmaterial, z.B. ein Netzstrumpf über die Kappe und die Kabel gezogen, um die Messproben zu stabilisieren. Ein Herauslösen der Messproben durch den Probanden ist durch das Einsetzen der Proben in die Kappe und den zusätzlich stabilisierenden Verband unmöglich. Außerdem ist selbst bei einem erfolgreichen Herauslösen einer Optode der Bewegungsspielraum durch die Bündelung und Befestigung der Kabel hinter dem Kopf stark eingeschränkt und ein Erreichen des Auges nur mit größerem Kraftaufwand möglich. Ihr Kind wird immer begleitend zur Messung ständig beobachtet. Der anwesende Experimentator kann daher jederzeit sofort eingreifen und die Lichtquellen ausschalten. Zudem ist immer eine sorgeberechtigte Person im Raum. Erwachsene Probanden / Eltern werden vor der Messung ausdrücklich darauf hingewiesen, dass das direkte Hineinschauen in die Lichtquelle eine Gefahr für das Auge darstellt.

Umstände, die zum Abbruch der Studienteilnahme führen

a) Sicherheitsbedenken

b) Widerruf der Teilnahme (ohne Angabe von Gründen jederzeit möglich)

c) sonstige, z.B. Unruhe des Kindes

Datenschutz

Durch Ihre Unterschrift auf der Einwilligungserklärung erklären Sie sich damit einverstanden, dass der Studienarzt und seine Mitarbeiter Ihre personenbezogenen Daten zum Zweck der o.g. Studie erheben und verarbeiten dürfen. Der Studienarzt wird Ihre personenbezogenen Daten für Zwecke der Verwaltung und Durchführung der Studie sowie für Zwecke der Forschung und statistischen Auswertung verwenden. Die Daten werden anonymisiert gespeichert. Die Daten werden nicht an Dritte weitergegeben. Die Ergebnisse der Studie können in der medizinischen Fachliteratur veröffentlicht werden, wobei Ihre/Ihres Kindes Identität jedoch anonym bleibt. Sie können jederzeit der Weiterverarbeitung Ihrer im Rahmen der o.g. Studie erhobenen Daten widersprechen und ihre Löschung bzw. Vernichtung verlangen.

Ich habe diese Aufklärung gelesen und mir war es möglich Fragen zu stellen. Ich weiß wie ich mich bei versehentlichem Manipulieren an der Kappe während des Experimentes zu verhalten habe und habe dies mit dem Versuchsleiter besprochen. Mir ist bekannt, dass ich das Experiment jederzeit ohne Angabe von Gründen abbrechen kann und dass mir oder meinem Kind bei Abbruch oder Ablehnung der Untersuchung keinerlei Nachteile erwachsen.

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Unterschrift der Sorgeberechtigten Ort Datum

Ich habe im Gespräch mit der/dem/den oben unterzeichnenden Erziehungsberechtigten alle Fragen beantwortet, ich bin mit der sachgemäßen Handhabung des Monitors vertraut und weiß, dass bei versehentlichen Manipulationen und technischen Fehlern, die Lichtquellen sofort von mir abgeschaltet werden müssen.

Unterschrift des Versuchsleiters Ort Datum

10. Curriculum vitae

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Geburtsdatum	13.12.1986
Geburtsort	Korneuburg
Nationalität	Österreich

Ausbildung

1997 – 2005 — **Akademisches Gymnasium Wien**
- humanistisches Gymnasium mit Sprachschwerpunkt

1992 – 2007 — **Musikschule Wien**
- Klavier, Querflöte, Musiktheorie, Chorgesang

2005 – 2010 — **Studium der Linguistik an der Universität Wien**
- Schwerpunkt Psycho-, Patho-, Neurolinguistik
- Hospitation bei Aphasietherapie
  > In der Österreichische Akademie der Wissenschaften, Kommission für Linguistik und Kommunikationsforschung,

  > am Neurologischen Rehabilitationszentrum am Rosenhügel, Wien

  > sowie am Zentrum für angewandte Psycho- und Patholinguistik (ZaPP), dem Therapiezentrum des Instituts für Patholinguistik der Universität Potsdam.
- Modul DaF/DaZ (Deutsch als Fremd-/Zweitsprache), nicht abgeschl.
- Wahlseminar Lernberatung
  + Praxissemester als Lernberaterin

2008 – 2010	Studienaufenthalt am Institut für Patholinguistik der Universität Potsdam und an der Humboldt Universität Berlin
2009 – 2010	Diplomandin am Berlin Neuroimaging Center der Charité Berlin

Berufserfahrung

2000 – 2005	Erzieherin auf Feriencamps in Niederösterreich
2003 – 2007	Freie Mitarbeiterin der Jeunesse Österreich, Konzertveranstalter für Klassik und Jazz
Juli – Sept. 2004	Verwaltungstätigkeit in der Polnischen Buchhandlung in Wien
2006 – 2007	Unterricht von Englisch und Deutsch als Fremdsprache, sowie Gruppenanimation und Sport auf dem Internationalen Sprach- und Sportlager des Instituts auf dem Rosenberg, Schweiz
2007 – 2008	Buchhändlerin bei Leporello, Fachbuchhandlung in Wien
Sept. – Dez. 2008 & Okt. 2009	Wissenschaftliche Hilfskraft am Berlin Neuroimaging Center der Charité Berlin

Kenntnisse & Fortbildungen

Sprachen

- muttersprachlich	deutsch, polnisch
- fremdspr., fließend	englisch, italienisch
- fremdspr., sonstige	französisch