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„Executive Function and Bilingualism: A Behavioural Study of Language Switching and Stroop Interference“

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Karin Heidlmayr

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To my parents
List of Abbreviations

ACC – Anterior Cingulate Cortex
ANOVA – Analysis of Variance
AoA – Age of acquisition
BA – Brodmann Area
BIA, BIA+ model - Bilingual Interactive Activation (+) model
CNS – Congruent Non-Switch
CS – Congruent Switch
DLPFC – Dorsolateral Prefrontal Cortex
EEG – Electroencephalography
ELAN – Early left anterior negativity
ERP – Event-Related Brain Potential
fMRI – functional Magnetic Resonance Imaging
IC model – Inhibitory Control model
INS – Incongruent Non-Switch
IS – Incongruent Switch
L1 – First Language
L2 – Second Language
PFC – Prefrontal Cortex
PET – Positron Emission Tomography
RT – Reaction Time
SAS – Supervisory Attentional System
SE – Stroop Effect

Referencing system

The Harvard System of Referencing was chosen for the present diploma thesis. Page numbers were only indicated for direct quotations as this is the habitual method of referencing in psycho- and neurolinguistic research. In references to entire books, if necessary, page numbers were also included in order to facilitate finding the passages.
**Introduction**

The majority of the world’s population uses two or more languages in everyday life, which is a demanding task. The languages of bi- or multilingual individuals have to be selected or inhibited and even rapid switches between languages have to take place in order to satisfy the demands of changing situations and contexts. This crucial exigence in bi- or multilinguals to control the use of more than one language has already been shown to cause differences between bilinguals and monolinguals when they are tested for their cognitive control, also in non-linguistic tasks. Observations like these support theories postulating the use of a level of general cognitive control that is not used exclusively in managing language use.

In the present diploma thesis, first the different levels of language processing will be described. This initial basic description of levels of language processing was considered as useful because in the further chapters different levels of language processing will be evoked, if relevant in the respective issue. Afterwards, the particularities of bilingual language processing and models that try to explain how bilingual language control works will be discussed. Then the influence of bilingualism on other cognitive functions will be presented. Results of studies demonstrating the neural correlates of the levels of language processing, of bilingual language processing or of other cognitive functions will be presented.

Particularly the latter point, the impact of bilingualism on other – also non-linguistic - cognitive functions is of great interest in current neurocognitive research. The second part of the diploma thesis consists of an empirical study on the effect of late bilingualism on inhibitory control in executive functions. In this experiment, late French-German bilinguals will be compared with a French monolingual group on their performances in the Stroop task. This study is aimed at contributing to a better understanding of bilingual language control and the subprocesses it implies as well as to clarify the relationship and interaction between bilingual language control and other cognitive functions.
Theoretical part

1. Linguistic and neuropsycholinguistic features of language processing

1.1. Levels of language processing
Research on the processing of information in the human mind and brain has known a controversy between connectionist and computationalist (also “classicist” or “symbolist”) positions during the past decades. The connectionist approach hypothesizes concepts and information to be represented in the human mind via differential activation of connections between subsymbolic elements in a neural net. On the contrary, the computationalist approach considers the human mind as a system of information processing via strings of symbols. In this conception, symbols are the basic elements of human (higher) cognition. The human mind is supposed to process sequences of these distinct pieces of information, strings of symbols, similar to digital information processing. Computationalism has been the dominant approach in the past four decades and is the preponderant approach in current cognitive psychology. The computational account has principally been developed by Hilary Putnam, Jerry Fodor, etc. (Garson, 2010)

By some researchers, the two positions are considered as incommensurate, others see them as compatible to a certain degree, as being applicable for different levels of information processing. (Garson, 2010) Connectionism has been criticized for giving unrealistic explications on representation and computation of information and for its lack of neurological realism. Moreover it is difficult to experimentally test the predictions derived from connectionist models because different sources of information are assumed to be involved at the same time. Therefore, computational approaches are often preferred for better explaining processes in human cognition. On the other hand, the connectionist approach is continuously being developed and models are becoming better in accounting for the functioning of the human mind. (Eliasmith, 2004)
Fodor (1983), basically holding a computational view, has developed the notion of “modularity” as a general principle of cognitive organisation. “Modules” are functionally distinct systems of information processing that are on the one hand domain(stimulus)-specific and on the other hand impenetrable by other cognitive modules. Fodor’s conception of “modules” means principally systems that form the interface between sensorial input and central processing.

Roughly, modular cognitive systems are domain specific, innately specified, hardwired, autonomous, and not assembled. Since modular systems are domain-specific computational mechanisms, it follows that they are species of vertical\(^1\) faculties. (Fodor, 1983, p. 37)

Inside the system of a module, information is processed from top downward, i.e. phonemic restoration where the listener has to have access to his/her lexical knowledge in order to recognise phonemes. However, continuing with the example, ‘phonemic restoration’ could also be due to the processing of coarticulation cues, it means from low (acoustic information) to higher (phonemic information) levels. Therefore, information processing implies processes in – to a certain degree - both directions. (Spinelli and Ferrand, 2005)

Coltheart (1999) has developed a neo-fodorien concept of modularity, also with modules being cognitive systems specialised to specific classes of stimuli. He claims that these modules, such as “language”, can be divided into numerous specific sub-modules that communicate in an interactive way. As an example, for the module “language” the sub-modules of semantics, syntax, morphology, phonology and orthography exist. Those sub-modules can even be further sub-divided. According to this view, “written language” and “oral language” form two distinct modules constituted of sub-modules. Spinelli and Ferrand argue that the – according to Coltheart’s conception distinct - modules “written language” and “oral language” do not work completely independently from one another but are highly interactive. Their argumentation is based on findings in studies i.e. on the role of phonology in silent lecture, on the role of orthography in the recognition of spoken language or on

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\(^1\) The concept of “vertical” faculties characterizes cognitive faculties (memory, imagination, attention, sensibility, perception, etc.) as distinct from one another according to their contents whereas the idea of “horizontal” faculties defines a cognitive faculty as “a functionally distinguishable cognitive system whose operations cross content domains” (Fodor, 1983, p. 13). Taking the example of memory, in the former theory of “vertical” faculties there would be domain- and content-specific “memories” (i.e. specific memories for respectively events, propositions, visual or acoustic contents, etc.) whereas in the latter theory, memory as a “horizontal” faculty would be independent from specific contents and highly interactive with other cognitive faculties. (Fodor, 1983)
deficiencies in subprocesses of language processing in patients. Thus, interaction seems to take place not only on the sub-modular level but also on the modular level, while certain characteristics of modularity are maintained for the modules of “written language” and “oral language”. (Spinelli and Ferrand, 2005, p. 30-33, 213-215)

For oral verbal naming, most researchers are in accordance with the distinction of the following levels of processing: the conceptual level, the semantic-syntactic level (lemma level), the level of the phonological form of the word and the segments (or phonemes) (lexeme level) and the articulatory level. In a “natural” situation of production, the intention of naming precedes and causes the activation of relevant concepts which is then succeeded by the activation of relevant elements on the other levels of language processing. A general distinction between the non-verbal conceptual representations and the linguistic representations is supported by many studies on patients and on healthy probands. In patients, the capacity to classify colours without being able to name them and in healthy probands errors in verbal production due to influence from the environment (“conceptual intrusions”) support the distinction between conceptual and linguistic representations. Furthermore, interference effects detected in manual tasks, tasks which do not require linguistic production, suggest interference on a non-linguistic level, and therefore the localisation of some type of information exclusively on a non-linguistic, conceptual level. (Bonin, 2007, p. 45-47) This is the case with i.e. the manual version of the Stroop task, used in the present study.

There is still a lot of discussion on further sub-classifications or alternative differentiations of language processing. Researchers discuss whether there is an additional distinction between a grammatical and a semantic/conceptual level, if there is an alternative cognitive pathway that is excluding semantic processing in production, how far lexical and non-lexical concepts need to be separated or if there are multiple conceptual/semantic systems according to the different perceptual modalities they date from, etc. (Bonin, 2007, p. 45-51)

In written verbal naming, the widely agreed distinction is the following: the conceptual/semantic level, the orthographic level and the post-orthographic level (i.e. the
allographic\(^2\) level), the graphical motor pattern and motor execution. Even if phonology is not included in this basic distinction, it plays an important role in the access to orthographic codes. (Bonin, 2007, p. 69s.; Spinelli and Ferrand, 2005, p. 213-215)

Concerning the relation between phonology and orthography, Spinelli and Ferrand (2005) give an overview of recent studies on written and oral language comprehension and processing. They conclude that the activation of phonology during silent lecture appears to be obligatory and irrepressible. Equally, the results of several studies indicate the automatic activation of orthography in oral language comprehension. Thus, written and oral language processing seem to be fundamentally interconnected.

Provided that the oral language primes on the written language (on the levels of individual development and the development of the human species), the bi-directional connections between phonology and orthography are asymmetrical: the influence of oral language on written language is supposed to be stronger than vice versa, the influence of written language on oral language. (Spinelli and Ferrand, 2005, p. 213)\(^3\)

The acquisition of knowledge of orthography leads to the development of procedures of conscious processing of phonology. As conscious phonological segmentation depends on the acquisition of written language, there has also been shown an impact of the type of writing system, being for example logographic, i.e. Chinese, or alphabetic, i.e. Indo-European languages. Speakers of Chinese knowing only the logographic writing system were unable to add or remove individual consonants in spoken Chinese words while speakers knowing both, the logographic and alphabetic writing system, were able to do so. (Read et al., 1986) Spinelli and Ferrand claim that with the acquisition of writing, language processing in general - including oral communication - is fundamentally and permanently modified. (Spinelli and Ferrand, 2005, p. 183, 207, 213-215)

The term “lemma” had been introduced in order to specifically designate the semantic/syntactic (grammatical category, gender, etc.) entity in opposition to the term


\(^3\) „Toutefois, dans la mesure où le langage parlé prime sur le langage écrit (au niveau du développement individuel et de l’espèce humaine), les connexions bi-directionnelles entre la phonologie et l’orthographe sont asymétriques : l’influence du langage parlé sur le langage écrit est supposée plus forte que celle du langage écrit sur le langage parlé. “ (Spinelli and Ferrand, 2005, p. 213)
“lexeme” comprising the phonological and morphological units of a word. There has been discussion to separate the combination of semantic and syntactic traits in this original conception of the “lemma” into an exclusively syntactic “lemma” and a “lexical concept”. The different levels of language processing are concretely shown by Levelt (2001) in the following example on language production:

To produce a content word, a speaker will first select the appropriate item from the mental lexicon. This is “lexical selection.” Next, the selected item’s articulatory shape will be prepared. This is “form encoding.” […] More generally, a first step in preparing a content word is to focus on a concept whose expression will serve a particular communicative goal. This process is called “perspective taking”. […] To initiate lexical selection, the speaker must focus on a lexical concept. I will denote lexical concepts in capitals: HORSE, STALLION, and ANIMAL. The theory assumes that during perspective taking there is coactivation of related concepts. […] Each active lexical concept spreads activation to the corresponding lexical item in the speaker’s mental lexicon. That item is called a “lemma.” It is essentially the lexical item’s syntactic description. […] The target lemma, i.e., the one activated by the focused concept, is selected under competition. The selection latency depends on the amount of coactivation of other lemmas (such as stallion and animal). Lexical selection is complete as soon as the target lemma is selected. This selection triggers the form encoding system. […] Activation spreads from just the selected lemma to the phonological codes it points to; no other codes get coactivated (for instance, the codes of the coactivated lemmas stallion and animal remain silent). (Levelt, 2001, p. 13464)

Support for the distinction “lemma/lexeme” is provided by, firstly, studies on production errors, i.e. erroneous substitution of phonological segments or of grammatical elements (words) without affecting the correctness of the properties coming from the respectively other level of processing. Secondly, observations such as the phenomenon of words being on the tip of one’s tongue - momentary reduced access to phonological representations while considerable semantic and syntactic access is given; thus the lemma is accessible while the lexeme is unavailable - and thirdly, examinations of patients suffering for example from reduced phonological access while having exhaustive semantic and grammatical access support the “lemma/lexeme” distinction. (Bonin, 2007, p. 59-63)

For oral verbal production of words, the majority of researchers support the idea of a distinction into the following levels of representation: conceptual, lemma, lexeme and articulatory. (Bonin, 2007, p. 45) The cases of different patients with cerebral lesions and specific impairments of cognitive and linguistic functions support this idea. Patient EST examined by Kay and Ellis (1987) (cited by Bonin, 2007) showed grammatically correct production but had difficulties in lexical access. Patient GM, a case studied by Henaff-Gonon, Bruckert and Michel (1989) (cited by Bonin, 2007), appeared to have a vast semantic
knowledge but did not manage to name the items. GM thus suffers from impaired access to phonological representations (lexeme level) while access to semantics or morphology (lemma level) remains intact. A similar case, studied by Badecker, Miozzo and Zanuttini (1995) (cited by Bonin, 2007), is the patient Dante who equally suffered from reduced access to the phonological representation of words but was able to identify their semantical and morphological features. Those cases of distinctly impaired features of language processing (semantic/syntactic and phonological representations) due to cerebral lesions support the idea of a separation of language processing into specific levels, in particular the lemma/lexeme distinction. (Bonin, 2007, p. 63s.)

Also in experiments with healthy persons, arguments in favor of the lemma/lexeme distinction have been found. In a behavioural study with different experimental setups, Schriefers et al. (1990) (cited by Bonin, 2007) has found evidence for a separation of semantical interference (lemma level) and phonological interference (lexeme level). Additionally, a distinct processing of concept and semantics was interpreted from the absence of a semantic interference effect in a study on picture identification. (Bonin, 2007, p. 64-68)

On the other hand, there is criticism on this lemma/lexeme distinction, in particular by Caramazza (1997) who prefers to define the lemma level rather as an amodal intermediate level between the conceptual and the lexemic level. Bonin (2007) mentions, that the original intention to introduce this “lemma” level had been exactly to underline the syntactic specification of lexical representations. Brief, the lemma level specifically regards this syntactic specification. It gives information on the grammatical gender but is not sensitive to phonological information. (Bonin, 2007, p. 64-68)

A number of ERP studies on syntactic and semantic processing in sentence comprehension support the hypothesis of distinct processing of these two levels of language processing. Syntactic processing of word category has been found to be reflected by an early left anterior negativity (ELAN). This early event-related brain potential is followed by a late centro-posterior positivity (P600). The P600 is assumed to reflect processes of syntactic reanalysis or repair. On the contrary, semantic processing is reflected in a centro-posterior bilateral
negativity (N400). (Qiu et al., 2006; Isel et al., 2006; Friederici et al., 2004; Hahne, 2001) Thus, syntactic and semantic processing does not take place simultaneously. Especially findings in studies using syntactic and semantic sentence violations support the idea that in sentence comprehension syntactic processing precedes semantic processing. (Friederici et al., 2004) Also the findings in an ERP study by Isel et al. (2006) support a serial model of language processing postulating that the initial phase of syntactic processing (ELAN, 150-300 ms) precedes processing of semantic information and that interaction between semantic and syntactic information would only take place during the latter phase of semantic-thematic processing (300-600 ms). Further (ERP) studies on the interaction between syntax and semantics would be necessary as only few research projects have been done on this issue. (Isel et al., 2006)

Concluding, even if there are some points that still provoke controversy, there is a large consensus on the differentiation of levels of language processing. The overview given above is intended to contribute to a better understanding of the ideas on bilingual language processing, given in the following chapters.

1.2. The organisation of a bi- or multilingual language system

How two or more languages are represented, organised and controlled in one person’s mind and brain is a challenging question in psycholinguistic research. A lot of research and modelling has already been done in order to get a clearer idea on how bi- or multilingual language processing works but many questions still remain to be answered. The present Chapter aims at summarizing studies on bi- and multilingualism.

To begin, a brief definition of what bilingualism actually includes might be important. A bilingual person is defined as:

   An individual who has knowledge of and regularly uses two languages, although the two languages need not be used in the same contexts or known to the same degree. (Vaid, 2002, p. 417)

For a long time, in psycholinguistic research, bilingualism has been understood mainly in its narrower definition of balanced bilingualism. Balanced bilinguals are those who show equal
proficiency in first (L1) and second (L2) language. In most cases, balanced bilinguals are early bilinguals, who have acquired their languages simultaneously. So, psycholinguistic research on bilingualism was mainly focussing on balanced bilinguals for a long time. In further research, it has been found that the use of more than one language can already have an effect, on i.e. cerebral language processing, even if an individual is an unbalanced bilingual. (Brysbaert, 2003) Unbalanced bilingualism means that proficiency is not equally high in the two languages. Research nowadays conceptualises bilingualism in this wider definition cited above. A variety of factors, such as age of acquisition (AoA), proficiency level in the L2, context of acquisition of L2, exposure to L2, etc., are tried to be taken into account in order to be able to cope with the great heterogeneity in bilingual language use.

Apart from the question of examining different types of bilingual individuals, psycholinguistic research on bilingualism - in general - was for a long time considered of minor interest. Monolingualism has for a long time been regarded as the norm while bi- or multilingualism was considered to be only a marginal or deviant phenomenon. Bilingual individuals were considered to differ from monolingual individuals only quantitatively - with a simple accumulation of more than one language in one mind - but not qualitatively – which would mean differences in language processing, in general, between bilinguals and monolinguals. The idea that monolingualism is the norm has known a certain change due to the insight that the majority of language users, worldwide, use more than one language. There have been trials to shift this norm-conception from monolingualism towards bi- or multilingualism. In this view, rather monolingualism is considered as the deviant form of language processing. Again another position has been an approach that doesn’t privilege any of the two groups and takes into account the generally great variability of language use. A major difficulty in these research approaches is the heterogeneity of bilinguals in a variety of aspects (early vs. late bilingualism, proficiency, context of language acquisition, language exposure, etc.). (Vaid, 2002)

As bi- or multilingualism is demographically rather the norm than the exception, it is of importance for the vast majority of language users to be able to manage their use of more than one language. If bi- or multilingual persons, who share their knowledge in more than one language, communicate, code switching and language mixing may occur without impairing
comprehension. In this case, it is not absolutely necessary (which is also dependent on the context) to use exclusively one language and to suppress interference from the other one(s). Sometimes complete language separation is even not desired as a certain pleasure often accompanies code switching and language mixing. On the contrary, in many situations, where there are certain formal constraints or where communication has to be restricted to one language in order to allow mutual understanding, there is the necessity and the possibility of rather pure monolingual language use. In this case, the target language has to be selected and its activation has to be maintained during the communication situation while the (co-activated) non-target language(s) need to be inhibited. (Dijkstra, 2005; Brysbaert, 2003; Green, 1998)

With cases of early bilinguals it has been hypothesized, that first, the child realises that different modes of communication exist - without knowing yet that these correspond to the different languages in use - and only in a second step in language and cognitive development, words are marked in a certain way indicating the language they belong to. But even if conscious (metalinguistic) knowledge on language specificity is not (yet) given, the language-specific lexica can be separated implicitly. Furthermore, in studies with bilingual adults, language decision tasks - tasks to decide if a word belongs to one language or the other - are performed without difficulty and with nearly the same velocity as responding in a lexical decision tasks - tasks to decide if a sequence of letters forms a word in a given language or not. (Font, 2001) These observations indicate that some sort of representations of language tagging must be present on the bi- or multilingual’s mind and do play a role in language comprehension and production in a language system managing more than one language. This will be discussed in Chapter 1.2.4. Different models have been developed to account for the organisation of a bilingual language system, taking into account especially this crucial process of language selection. (Dijkstra and Snoeren, 2004) Two of them will be described in more detail below, firstly, the Bilingual Interactive Activation + (BIA+) model by Dijkstra and Van Heuven (2002) (Chapter 1.2.4.1) and, secondly, the Inhibitory Control (IC) model by Green (1998) (Chapter 1.2.4.2.). But first, language processing of L1 and L2 in the bilingual mind and brain will be examined in the following Chapter. Immediately afterwards, the role of L2 age of acquisition and of proficiency will be discussed.
1.2.1. Bilingual language processing of L1 and L2

One of the crucial questions in bilingual language organisation, that has regained interest with the development and improvement of neuro-imaging methods, concerns the representation of more than one language in the bilingual brain.

Cerebral areas, principally implicated in language processing and in bilingual language control are to be seen in Fig. 1 and Fig. 2. Principal cerebral areas implicated in language processing are Broca’s area (BA 44, Pars opercularis, and BA 45, Pars triangularis) which plays a central role in language production and Wernicke’s area (BA 22, posterior part of the Superior temporal gyrus) which is important in language comprehension. In addition, i.e. motor and auditory areas are implied in language processing. In bilingual language control, the prefrontal cortex (PFC) plays an important role. (Isel et al., 2010) This point is especially of relevance for the present study on the impact of late bilingualism on cognitive control in executive functions. As it will also be demonstrated in psycholinguistic models on bilingual language control in the respective chapters below, cognitive control may be trained by bilingualism as there is permanent necessity to control the use of languages (selection, inhibition). If the training in cognitive control by bilingualism also serves to ameliorate cognitive control in other cognitive functions is aimed to be examined in the present study.

Even if activation in language processing is rather lateralized, mostly concentrated in the left hemisphere, also activation in some areas in the right hemisphere is implied in language processing, for example in the processing of prosody. Thus, despite of a rather lateralized activation pattern in language processing, activation in areas of both hemispheres and inter-hemispheric relations play a role.
Broca’s area (BA 44, Pars opercularis, and BA 45, Pars triangularis) plays a central role in language production and Wernicke’s area (BA 22 p, posterior part of the Superior temporal gyrus) in language comprehension. Activation in language processing is mostly concentrated in the left hemisphere. In addition, motor and auditory areas are implied in language processing. In cognitive control, the anterior cingulate cortex (ACC) (BA 24, 32, 33) and the left prefrontal cortex (PFC) (BA 8, 9, 10, 11, 44, 45, 46, lateral and orbital 47) have been shown to be activated. The PFC is also implicated in bilingual language control. (Isel et al., 2010)
Language processing is now known to be not only restricted to the left hemisphere. As already mentioned, some aspects of language processing, i.e. prosody, imply activation in the right hemisphere. Friederici and Alter (2004) proposed a dynamic dual pathway model of auditory sentence comprehension. Syntactic and semantic information are primarily processed in a left hemispheric temporo-frontal pathway including separate circuits for syntactic and semantic information whereas sentence level prosody is processed in a right hemispheric temporo-frontal pathway. More precisely, the right temporal region is thought to support the identification of prosodic parameters while the right frontal cortex is involved in the processing of sentence melody (for a detailed discussion see Friederici (2002) but also Friederici et al. (2007) for a discussion on the role of the corpus callosum during the interhemispheric interplay of linguistic prosody and syntactic structure during on-line sentence comprehension).

There are also lateralization differences between monolinguals and bilinguals. Even if there are areas in the right hemisphere implicated, monolingual language processing is strongly lateralized, concentrated mainly in the left hemisphere. In bilingual language processing, more right hemispheric activity has been found in comparison to monolinguals. In
neuropsychological studies on cerebral hemispheric functional asymmetry in bilingual vs. monolingual language processing, several studies demonstrated similar laterality patterns in monolingual and bilingual language processing of the L1 while other studies demonstrated lateralization differences of native language processing in bilinguals and monolinguals. (Kroll and Tokowicz, 2005) Comparing bilingual L2 processing to monolingual L1 language processing, regions in the right hemisphere were significantly more implicated in bilingual L2 processing compared to L1 processing in monolinguals. (Vaid, 2002)

Observations of higher implication of right hemispheric areas in bilinguals have led to discussions if proficiency or age of acquisition (AoA) is the main factor causing lateralization differences in cerebral language processing. In general, there is increasing support and acceptance of the idea that bilingual language processing differs not only quantitatively but also qualitatively from monolingual language processing. (Badzakova-Trajkov, 2008; Kroll and Tokowicz, 2005) But even if native language processing has been found to differ – probably due to capacity limitations - between bilinguals and the respective monolinguals, this does not necessarily mean, that L1 processing is “inferior” in bilinguals. (Kroll and Tokowicz, 2005; Brysbaert and Dijkstra, 2006)

Apart from these differences between monolingual and bilingual native language processing, also similarities and differences between the bilinguals’ L1 and L2 processing have been documented. In diverse fMRI studies, activity has been shown to strongly overlap between L1 and L2 processing in bilinguals. (Hernandez et al., 2001)

The predominant outcome has been a pattern of overlapping activation for both languages of bilinguals in the classic language areas on the left side and in the pattern of bilateral activation in homologous sites. However, exceptions to this pattern have been reported in a few fMRI studies. (Vaid, 2002, p. 430)

On the contrary, there are different data to be found in clinical cases of language impairment and recovery, demonstrating either parallel recovery of languages or, in other cases, selective, independent impairment or recovery of only one language. Therefore, on the one hand, arguments supporting the idea of a neurofunctional macrosystem and, on the other hand, arguments for the concept that there are language-specific subsystems in a larger language macrosystem can be found. (Vaid, 2002) The diverging results on cerebral activity in L1 and L2 processing are also a challenge for the currently most appropriate consideration in models
on bilingual language processing, that there is a shared, language non-specific lexicon. (Brysbaert and Dijkstra, 2006)

Interestingly, there are also findings of highly similar neuronal activations of L1 and L2 that are, on the contrary, accompanied by behavioural differences between L1 and L2 in high proficient, even early, bilinguals. Thus, it is necessary to take into account that stronger or weaker spatial overlap in L1 and L2 cerebral processing obviously may not be automatically proportional to competence. (Perani et al., 1998)

Vaid (2002) claims that in neuropsychological research on bilingual language processing the question of differential processing of L1 and L2 raises from a theoretical background considering bi- or multilinguals to be only quantitatively different from monolinguals. Being quantitatively different means that bi- or multilinguals possess more than one language accumulated in one individual’s mind. Thus, the idea can be found that the bilinguals’ two language systems allow a comparison between the language processing of different single languages simply accumulated in one mind. On the contrary, the idea that the acquisition of further languages in addition to L1 alters language processing in general – thus, postulating a qualitative difference between monolingual and bilingual language processing (Kroll and Tokowicz, 2005) – would rather cause focussing on the question of comparing monolinguals to bilinguals (or even different groups of bilinguals) than to compare the two languages. (Vaid, 2002) The hypothesis of bilinguals differing qualitatively from monolinguals has found support in several studies. (Dijkstra, 2000; Brysbaert, 2003; Van Heuven, 1998) L1 language processing has been found to differ between monolinguals and bilinguals and this difference in L1 processing was not only observed in balanced bilinguals (those who show equal proficiency in L1 and L2) but also in bilinguals of lower proficiency in their L2. (Brysbaert, 2003) In the present study it was considered important, on the one hand, to compare performance of bilinguals to a monolingual control group and, on the other hand, to compare the performance between the two languages of bilinguals.

Additionnally, it has to be accounted for a possible influence of structural differences of languages (i.e. writing system, orthography, grammar, etc.) that might cause differences in
activation patterns. (Vaid, 2002) Different writing systems of L1 have been shown to cause differences in L2 acquisition. (Wang et al., 2003) As an example, motor patterns of articulation differ across languages and thus Crinion et al. (2006) suppose a selection mechanism for motor patterns that is sensitive to language and as its neuronal localization he proposes the head of the left caudate. (Crinion et al., 2006) In order to be able to better distinguish general linguistic from language-specific features, studies on a variety of languages and comparatist work are of interest. (Kail, 2004)

Especially of relevance for the present study is the language-specific difference also observed in the neural processing of Stroop interference. Qiu et al. (2006) worked with Chinese native speakers and used a Chinese version of the Stroop Colour Word task. The authors found similar time courses regarding the ERPs for the Stroop interference when comparing their findings on Chinese with English versions of the test. On the other hand, there were differences in the implication of specific areas and activities in the Stroop task. A N450 has been found for Chinese and English whereas a prolonged and greater positivity between 400 and 800 or between 450 and 550 was absent for Chinese in the Stroop Colour Word task.

Thus, the Stroop interference effect in Chinese character Stroop task may be only reflected by the N450. Of course, it might be relative to reactivation of the word meaning. (Qiu et al., 2006, p. 191)

The authors concluded that this is probably due to a different cognitive and neural processing of Chinese characters (visual to meaning) compared to English word processing (graphical via a phonological level towards meaning). (Qiu et al., 2006) Possibly, a Stroop Effect is reflected differently in ERP for structurally different languages. Some aspects may be universal but some aspects of activity might therefore also depend on special characteristics of the respective language.

Badzakova-Trajkov (2008) worked with late bilinguals on a Stroop Colour Word task. Her bilingual participants knew different combinations of Germanic and Slavic languages. When comparing to previous studies, she did not find differences attributable to different language (family) combinations. In the present study, bilinguals knowing the Romance language French as their mother tongue (L1) and the Germanic language German as their first foreign language (L2) were tested. Both languages belong to the Indo-European language group and
share an alphabetic writing system. Thus, no differences in language processing are expected to be caused by these linguistic aspects. As there are not many studies on this language combination yet, it is of interest from a comparatist point of view (Kail, 2004) which postulates the necessity to examine a diversity of languages in order to further discriminate language-specific and general aspects of language processing.

1.2.2. The respective role of age of acquisition and proficiency

In general, there is an agreement that the earlier a second language is acquired, the higher are the chances to reach a high level of proficiency, but many exceptions can be found where even late L2 learners have reached high levels of proficiency. Concerning the sites of activation in bilingual language processing, proficiency has not been sufficiently tested yet as a factor of variability. But considering the already existing empirical data many authors refer to proficiency rather than to the age of onset of bilingualism as the relevant factor for differences in activation when giving post hoc explanations. (Vaid, 2002; Kotz, 2009; Perani et al., 1998; Hahne, 2001)

A possible interpretation of what brain imaging is telling us is that, in the case of low proficiency individuals, multiple and variable brain regions are recruited to handle as far as possible the dimensions of L2 which are different from L1. As proficiency increases, the highly proficient bilinguals use the same neural machinery to deal with L1 and L2. However, this anatomical overlap cannot exclude the possibility that this brain network is using the linguistic structures of L1 to assimilate the dimensions of L2 less than perfectly. (Perani et al., 1998, p. 1849)

Focussing on the role of AoA and of proficiency on specific levels of language processing in L1 and L2, their respective influence has been observed to vary depending on the level of processing. Like phonology, morphology and syntax, the quality and quantity of acquisition of lexical knowledge in L2 is supposed to be impaired by neural maturation, at least for Indo-European languages. In late bilinguals, whose age of acquisition (AoA) of L2 is at least 10 years of age, usually difficulties in syntactic processing in L2 are observed. This detriment is supposed to be due to a lack of exposure to appropriate lexical material of L2 before the age of 3 years, in a critical period in childhood (pregrammatical period 5-20 months) (Isel et al., 2010)

AoA has been shown to be a determining factor for neuronal processing on the grammatical level (morphological, syntactic, etc.) (Wartenburger et al., 2003) and on the level of semantic-
conceptual representations (Isel et al., 2010). Comparing the roles of AoA and of proficiency on these two levels of language processing (grammatical, semantic-conceptual), Wartenburger et al. (2003) claim that AoA is a main determining factor for neural processing on the grammatical level, while the semantic-conceptual level is predominantly dependent on proficiency. Concerning the grammatical level, Kotz (2009) shows in her review on bilingual L2 syntactic processing that many previous studies of ERP, fMRI or PET were for a long time conducted with the intention to study the impact of AoA and the critical period hypothesis while in fact – which was increasingly realized when proficiency was taken into account - the effect of proficiency had been examined. Support for the effect of AoA and the critical period hypothesis was hence weakened and the role of proficiency was increasingly taken into account. (Kotz, 2009) Considering AoA in general, the “critical period” (limited language learning period) hypothesis is highly controversial but for a “sensitive period” (the period in which language is acquired more easily), support is found in many studies. (Cowie, 2008; Kotz, 2009)

Further research (behavioural, neurophysiological, neuro-imaging), that takes into account AoA as well as L2 proficiency as factors, is needed. The importance of taking both factors into account gets even more plausible when the high heterogeneity of these two factors in studies on bilingualism is considered. Due to the findings that multiple language use has an impact on language processing in general and that also L1 processing might differ between monolinguals and bilinguals, also the inclusion of L1 proficiency evaluation would be of interest in future research. (Brysbaert, 2003; Brysbaert and Dijkstra, 2006) As it has been demonstrated in this chapter, it is of importance to take into account L2 proficiency and L2 age of acquisition in studying bilingualism. For this reason, these two points were controlled and evaluated in the present study on the impact of late bilingualism on executive functions.

1.2.3. The mutual influence of languages

In second language learning, positive transfer effects (a facilitation in L2 learning if certain L1 structures can be recruited for L2 learning) occur if L1 and L2 are structurally similar, while negative transfer effects (difficulty in L2 learning if differing L1 structures interfere in L2 learning) when they are structurally different. These transfer effects take place principally from L1 to L2 but might possibly also take place vice versa. In order to be able to differentiate
between language-specific and domain-general features of processing, increased attention should be paid to the consideration of psycholinguistic models on bilingualism in neurophysiologic and brain imaging studies. (Kotz, 2009)

Cross-linguistic related words may not share an exactly identical concept but essential conceptual features. Processing the identical and diverging features of two related words in cross-linguistic priming might thus lead to increased neuronal activity:

In the case of cross-linguistic related words, the concept associated with the two words is not exactly the same, although the two words belong to the same “conceptual basin”. One can speculate that a fine grained analysis would be engaged in order to process the features that differentiate the conceptual representation of the two words. This fine grained analysis would lead to an increase of processing of the target words. (Isel et al., 2010, p. 177)

Concerning language specific connections between the conceptual and the lexical level, Levelt and Meyer (2000) distinguish the existence of “lexical concepts” and “non-lexical concepts” for every specific language. “Lexical concepts” being those concepts for which a specific lexical representation – a specific word – exists in a given language. A “lexical concept” is accessible via a specific lemma. Composed expressions are “non-lexical concepts” for which a specific lexical representation does not exist. Those composed expressions are activated via “superlemmas”; i.e. in English, “corpse” is the direct lexical representation for “dead body”, thus a “lexical concept”, whereas there does not exist direct encoding for “dead tree”, therefore this concept is to be classified among the “non-lexical concepts”. (Bonin, 2007, p. 50)

But not only on lexico-semantic levels, features may be shared between the languages. Also i.e. on the phonological or orthographic level, cross-language interference can occur. (Brysbaert and Dijkstra, 2006) As already mentioned above, conscious phonological segmentation is dependent on the knowledge of written language and more specifically on the sort of writing system, being for example logographic, i.e. Chinese, or alphabetic, i.e. Indo-European languages. It has been shown in a study with Chinese speakers that adding or removing individual consonants was only possible for those participants that knew the logographic and alphabetic writing systems, but not for those exclusively knowing the logographic writing system. (Read et al., 1986) Therefore, the writing system of a specific language has an influence on the phonological level and may influence also other levels of
language processing. Van Heuven et al. (1998) indicate that differences between the two languages may affect cross-language neighbourhood effects (cross-language interference). The authors argue that differing phonological systems in two languages of bilinguals may be a reason for differences in word recognition in the two languages. (Van Heuven et al., 1998) In a compilation of recent studies, Spinelli and Ferrand (2005) also show the interdependence of orthography and phonology in both, written and oral language comprehension. (Spinelli and Ferrand, 2005)

1.2.4. Bilingual language control
Adult bi- or multilinguals can control their language use according to the requirements of different situations but complete conscious inhibition of the non-target language seems to be impossible. Cross-linguistic interference may occur on different levels of language processing (semantic, phonological, syntactic, etc.) (Brysbaert and Dijkstra, 2006). Research so far mainly supports the idea that in comprehension and production the lexica of both languages are activated. (Dijkstra, 2005; Brysbaert, 2003) To explain why items of one or the other language can be selected out of one shared lexical system of co-activated languages, different ideas have been developed. To accomplish this selection task, bilinguals are able to assess the respective language belonging in their mental lexicon. In different models of bilingual language processing, representations of language tagging are named, conceptualised and localised differently: “language tag” (Green, 1998), “language component” (Poulisse and Bongaerts, 1994), “language cue” (De Bot and Schreuder, 1993) or “language node” (Dijkstra et al., 1998; Dijkstra and Van Heuven, 2002). (Dijkstra and Snoeren, 2004)

Findings showing that also the currently not used languages interfere with the production in the target language have lead to the proposition of models considering different levels of (co-)activation and of inhibitory control of the single languages in the bilingual or multilingual mind. (i.e. Paradis, 1994; Green 1998; Van Heuven, 1998).

Paradis (1994) developed the subset and the activation threshold hypotheses. The subset hypothesis considers single languages as separate systems that can be inhibited or activated independently in a bilingual’s mind. In the threshold hypothesis it is claimed, that an element is chosen if it exceeds the activation of its competitors, the others being inhibited. (Paradis, 2004) Furthermore, there exist connectionist models with language nodes connected to lexical
representations (i.e. BIA by Dijkstra and Van Heuven, 1998). In the BIA model - which has been modified afterwards to the BIA+ model that will be described more in detail in Chapter 1.2.4.1 - inhibition of non-target items is interactive according to mutual inhibition of the nodes. Further connectionist models do not imply language markers but language-specific subsystems on the phonemic and lexical levels (i.e. BIMOLA by Léwy and Grosjean). In other theories, language selectivity is represented as a much more predominant factor. Among the latter, some localize language tagging on the conceptual level, some on the lexical level and again others on the lemma level (i.e. IC model by Green, 1998) and sometimes it is even considered that information on which language is to be selected might be present on different levels of processing (lexicon, phonology, syntax). Further research is needed to clarify this point. (Poulisse and Bongaerts, 1994; De Bot and Schreuder, 1993). This idea of multiple indication of language tagging as well as the idea of reactive inhibition after co-activation of more than the target language are supported by findings on production errors of a word chosen from the non-target language but pronounced in the phonology of the target language. The information on language selection might in these cases simply arrive too late for correct lemma choice but early enough for the choice of the correct phonology (phonologic specification is supposed to be processed temporally only after lemma selection). (Poulisse and Bongaerts, 1994; Dijkstra and Snoeren, 2004) Anyway, given this observed separation of language selectivity on the different levels of processing (lexicon, phonology, etc.) might indicate language labeling on different steps of processing, not simply on a level of general language selection or inhibition.

In several fMRI studies, language switching has been shown to evoke an activity in the dorsolateral prefrontal cortex (DLPFC) (BA 46 and 9) (see Fig. 1) in the left hemisphere. (Hernandez et al., 2001; Isel et al, 2010) Comparing late bilinguals to early bilinguals, increased activity in the DLPFC was observed in the former group. The higher involvement of the prefrontal cortex might reflect a higher cost in language switching. (Isel et al., 2010) In previous neuro-imaging studies, activity in the DLPFC has also been detected in non-linguistic task switching (Meyer et al., 1997) and in tasks implicating executive functions. (D’Esposito et al., 1995) Price et al. (1999) found activation in the frontal cortex in language switching but did not find specific DLPFC activity in language switching or translation. According to Hernandez et al. (2001) this may signify that executive function is not implied in all kinds of linguistic and non-linguistic switching tasks. In order to further precise the role of language switching they conducted an experiment excluding language switching. They
examined within-language task switching but did not find increased DLPFC in the accomplishment of this task. (Hernandez et al., 2001)

In comprehension tasks with patients with nonthalamic subcortical lesions, lexical-semantic impairment was observed. Furthermore, according to findings in functional neuro-imaging studies with neurologically healthy subjects, the left caudate is supposed to play a crucial role in lexical-semantic control in production tasks, for monolinguals as well as multilinguals. Additionally, in multilinguals the left caudate also appears to be essential in monitoring and control of language alternatives. (Crinion et al., 2006) If activity in the prefrontal cortex interacts with activity in the left caudate in the control of bi- or multilingual language use remains to be examined in future studies. (Isel et al., 2010)

Two psycholinguistic models especially take into account the role that executive functions, cognitive control and inhibitory control play in the organization of a bilingual language system. The first one is the Bilingual Interactive Activation+ (BIA+) model, developed by Dijkstra and Van Heuven (2002) (Dijkstra and Van Heuven, 2002; Brysbaert and Dijkstra, 2006). The second model is the Inhibitory Control (IC) model by Green (1998). In the following two sections, these two models will be described and a special focus will be laid on the respective considerations of cognitive control and inhibition. In both models the initial co-activation of lexical items of both languages, as it is supported by diverse studies (Dijkstra, 2005; Brysbaert, 2003), plays an important role and is not least one of the crucial points that cause the necessity of inhibitory control. These two psycholinguistic models play a crucial role to explain, why bilingualism may have an impact on other, not exclusively linguistic, cognitive functions. The principal interest of the present study is to examine the impact of late bilingualism on cognitive control in executive functions. Predictions for the performance of late bilinguals compared to a monolingual group and for the performance of bilinguals in their two languages will be formulated with the concepts in these two models on bilingual language control.

In the IC model the localization of inhibitory control on a level superior to the linguistic domain and in the BIA+ model its localization on the “Task schema” level allows the hypothesis of bilingual advantage also in non-linguistic tasks. If the same inhibitory control processes are used in linguistic as well as non-linguistic domains, bilinguals may have an
advantage in cognitive control compared to monolinguals. Due to the training they have acquired in controlling their use of two (or more) languages via this inhibitory mechanism the bilinguals’ performance in diverse tasks implying inhibitory control may therefore be ameliorated. (Bialystok et al., 2005)

The findings of Bialystok et al. (2005) in a study of the effect of bilingualism on performance in the Simon task, a non-linguistic test of executive functions, support the IC model by Green (1998) postulating a level of inhibitory control that is used for linguistic as well as for non-linguistic functions (Supervisory Attentional System (SAS)). In situations of conflict in this tasks, bilinguals showed shorter reaction times (interpreted to reflect faster conflict resolution), related to increased neural activation in the left prefrontal cortex (PFC) and in the anterior cingulate cortex (ACC) in bilinguals compared to monolinguals. These areas are implicated in bilingual language control. (Bialystok et al., 2005) Thus, together with other authors, Bialystok et al. (2008) claim that this implication of executive functions in language switching might lead to a training effect, that may be reflected in ameliorated executive control even in non-linguistic domains.

1.2.4.1. Bilingual Interactive Activation+ (BIA+) model (Dijkstra and Van Heuven, 2002)

The computational Bilingual Interactive Activation + (BIA+) model (Dijkstra and Van Heuven, 2002), to be seen in Fig. 3, consists of two separated systems: a word “Identification system” and a “Task schema” system. Two basic assumptions for the BIA+ model are language non-selective lexical access, which necessitates subsequent inhibition of the co-activated non-target language(s), and a functionally shared lexicon between the languages. The crucial new feature in the BIA+ model in comparison to its predecessor, the BIA model (Dijkstra and Van Heuven, 1998; Van Heuven et al., 1998), is the inclusion of the “Task schema” system as a separate level playing a role in, among other functions, language selection. In contrast to the BIA model, where language selection took place locally, via lateral inhibition structured by language nodes, the separate “Task schema” level is now responsible for the language decision task. The role of the “Task schema” level is inspired by the IC model by Green (1998) and in fact remains quite similar to the role of the “Task schema” level in the IC model: it is an attention-sensitive level and – via the activation of
specific task schemas - activates in the “Identification system” what is required according to
the context - including language selection. In language selection, a specific language task
schema activates the taget language via its “Language node” in the “Identification system”. In
the BIA+ model, the “Language nodes” have the function to indicate which language an item
belongs to. Thus, in comparison to the model’s predecessor, the BIA model, language nodes
have lost the function to influence the activation of words and therefore are no longer a
language filter but are reduced to simple language tagging. (Brysbaert and Dijkstra, 2006)
Furthermore, a crucial aspect in the BIA+ model is the claim that in bilinguals, lexical access
is slower in the language of lower proficiency, mostly L2. (Dijkstra and Van Heuven, 2002)
Top-down inhibition has a stronger effect on a less dominant/less activated language due to its
lower frequency. (Van Heuven et al., 1998)

Fig. 3 The Bilingual Interactive Activation + (BIA+) model by Dijkstra and Van Heuven (2002). (Brysbaert
and Dijkstra, 2006) The arrows indicate excitatory connections. The main site of inhibitory control between
languages has been marked with a red arrow.
Basic features of the BIA model are kept in the “Identification system”, but modifications have been implemented also within this system. In this system, representations of words are organized hierarchically. There is non-selective bottom-up processing, which means that lexical items of both languages are co-activated and compete for attention (cross-language neighbourhood effect). Competition on the different levels is resolved, non-selectively of language, via lateral inhibition. Lateral inhibition means that co-activated elements normally are of great semantical similarity and thus, items neighbouring the selected element need to be inhibited. (Van Heuven et al., 1998) A further modification from the BIA to the BIA+ model was, that in the BIA model, cross-linguistic interference was considered only on the orthographic level while in the BIA+ model, cross-linguistic interference can take place on the orthographic, phonologic and semantic levels. (Brysbaert and Dijkstra, 2006)

1.2.4.2. Inhibitory Control (IC) model (Green, 1998)

The second model on bilingual language processing that will be presented more in detail is the Inhibitory Control model (IC model) developed by Green (1998). Concerning bilingual language control, Green (1998) compares the task of translating a written word into another language or the task of simple picture naming to a Stroop task: In translation, naming the written word needs to be avoided and only the production of the equivalent item in another language is required. In picture naming, a similar conflict arises for bi- or multilinguals as mostly only the term in one specific language is required and competing words from the other language(s) need to be suppressed. Thus, for bilinguals, these situations are cases, in which competition between tasks and between responses arises and needs to be solved.

A basic assumption for the IC model is, on the one hand, that the regulation of language processes works like regulation of any other action, thus, is a form of communicative action. Furthermore, it is assumed that language switching is performed via regulating the levels of activation of language networks with the help of language tags. According to the IC model, there are different levels of control in bilingual language selection. One of these levels of control is the task schema level, in which language selection is operated principally via the activation and inhibition of language task schemas. The relevant task schema is selected by the Supervisory Attentional System (SAS). On a further level of language control, lemmas are marked with a tag for the respective language. (Green, 1998) In sum, there are multiple levels
of control in the IC model that manage the bi- or multilingual language processing (Fig. 4 and Fig. 5):

There are three separable aspects of this model: first, one level of control involves language task schemas that compete to control output; second, the locus of word selection is the lemma level in Levelt et al.’s terms and selection involves the use of language tags; third, control at the lemma level is inhibitory and reactive. The third section applies this model to amplify the account of translation proposed by Kroll and Stewart (1994) and to interpret a crucial finding of these researchers. The IC model generates other predictions, some of which can be assessed against existing data in the area of language task switching, Stroop interference and competitor priming. (Green, 1998, p. 68)

In the IC model, Green especially takes into account the importance of task-specific demands in the selection process. Language selection, among other criteria of selection, is mainly performed by a system executing selection and reactive inhibition according to the requirements of the task. (Dijkstra and Snoeren, 2004)

![Diagram](image)

**Fig. 4 The regulation of the bilingual lexico-semantic system displaying multiple levels of control.** (Green, 1998) The main sites of inhibitory control between languages have been marked with red arrows. **I** Input, **G** Goal, **O** Output, **SAS** Supervisory Attentional System. The main site of inhibitory control between languages has been marked with a red arrow.
Fig. 5 Regulatory processing in a lexical decision task involving language switching is depicted in the schema. Self-inhibitory links on schemas are not shown in the graph. In the example, the L1 task schema is suppressing the L2 task schema and inhibiting L2 lemmas in the bilingual lexico-semantic system. (Green, 1998) The Supervisory Attentional System (SAS) is not depicted in this graph but it controls the activation of the competing Language Decision Task Schemata. I Input, O Output, LDT Language Decision Task.

Lemmas are activated according to the active concepts they are linked to, which is non-selective to language. In this process, not only lemmas in one language, but in the diverse languages of a bi- or multilingual are activated if they share properties of the concepts. Subsequently, inhibitory control of currently not needed elements is performed through tag suppression, which means that lemmas with incorrect tags - also incorrect language tags - are suppressed (reactive inhibition). In this model the aspect is taken into account, that the respective languages show different states of activation, whereas the dominant language will essentially determine reaction time and the selection of response. The actual selection and the reaction time needed for giving responses is supposed to reflect the level of activation of competitors. (Green, 1998)

Like in a model proposed by Costa and Caramazza (1999), the co-activation of competing candidates from other languages is finished when a language selection mechanism is activated. Findings in some studies indicating the existence of language tagging on different levels of language processing (Poulisse and Bongaerts, 1994) remain to be taken into account in the IC model, in which language tagging is only the case on the lemma level.
In the IC model top-down control takes place. The system executing this top-down control (inhibition) is the supervisory attentional system (SAS) controlling competing task schemas. (Fig. 4) Task schemas are the elements that reflect where attention will be attributed to. (Green, 1998)

Inhibiting a previously active schema and overcoming the inhibition of the previously irrelevant language will take time and so a switch cost is predicted. (Green, 1998, p.74)

On switching costs in task and language switching (code-switching), the IC model predicts, that language switching may take time due to both, a change in language schema and the overcoming of previous inhibitions (Green, 1998):

Language switching may take time (1) because it involves a change in language schema for a given task, and (2) because any change of language involves overcoming the inhibition of the previous language tags. I know of no direct tests of the costs of switching between different language tasks such as naming and translation, but the IC model predicts that there will be such costs. However, there have been studies of language switching on specific tasks (both receptive and productive) and these confirm that such costs do exist. Of course, in normal speech situations that permit prior planning of an utterance, intentional code-switching can be fluent and smooth (see Grosjean and Miller, 1994). (Green, 1998, p. 73)

According to Green, it will take longer to switch into a stronger suppressed language, which will be L1, the more dominant language, for unbalanced bilinguals. (Green, 1998) This claim is consistent with those of Costa et al. (2008) and Allport (1994) but there is controversy on this point (Monsell, 2003).

The processes of language control as described by Green (1998) not only account for cross-linguistic interference, task and language (code) switching cost and for the challenges of translation but also for the disadvantage of reduced lexical access observed in bilinguals in comparison to monolinguals (see Bialystok, 2008). The execution of inhibitory control is likely to serve as training for executive control mechanisms also in non-linguistic tasks, which is of advantage for bilinguals. On the contrary, inhibitory control of the multiple language use may hinder immediate access to any item of the totality of the lexicon as parts of it (see language tagging) need to be inhibited in order to allow efficient language production. According to the IC model, inhibition first has to be overcome in order to allow access to previously inhibited items, which results in longer reaction times in their production.
Green supposes that interference is also a question of capacity. If processing of a task and of a target item highly charge the capacity of the system (i.e. working memory), the processing of additional, distracting information will take place a little later and thus will not interfere with target processing in the usual reaction time span. (Green, 1998)

[…] if processing of the target demands the capacity of the system, distracting information will not be processed within the time interval for response and so will not interfere with processing and be subject to reactive inhibition. (Green, 1998, p. 78)

In the test phase of the present experiment, overcharge might also have been the reason for the aberrant results obtained, when filler trials, demanding a task switch to a verbal version of the Stroop task, were additionally included in the experimental procedure. The “system” might have been overcharged with the combination of language, condition and task switching (see Procedure of the present study and Green, 1998).

Green argues that the multiple levels of control in the IC model are likely to correspond to activations in different neuronal regions. There is empirical support for the idea of a shared semantic-conceptual level between L1 and L2, for both early and late bilinguals. (Isel et al., 2010; Brysbaert, 2003; Van Heuven, 1998) In an fMRI study on cross-linguistic priming, priming effects have been detected in both directions (L1 to L2 and L2 to L1). (Isel et al., 2010) Dijkstra et al. worked with Dutch/English homographs (2000) and cognates (2010) and found that the activation of elements of the respective non-target language can be inhibited only to a certain degree, which is also highly dependent on the frequency of the word. These findings support, on the one hand, the hypothesis of a shared semantic-conceptual level between the languages and, on the other hand, the idea that all languages, also non-target languages, are (co-)activated even if only one language is required in the communicative context. Dijkstra et al. (2010) claim, that their findings – showing high effects of word frequency and of orthographic similarity on interlingual interference - support connectionist models on bilingual language processing. Similar support of connectionist modeling comes from Brysbaert (2003) having found high interactions of L1 and L2 especially on the phonological level. These observations are compatible with the IC model as well as with the BIA+ model.
Brysbaert (2003) claims that inhibition of non-target languages obviously takes place in a step later in language processing, after the semantic-conceptual level having already been consulted. This supports the aspect in Green’s IC model but also in Dijkstra’s and Van Heuven’s BIA+ model that there is one lexical pool in which the items of both languages are to be found and inhibition of non-target elements takes place parallel to selection of target elements, after lexical activation via language task schemas has already taken place. In an fMRI study on cross-linguistic priming, activity in the DLPFC was found for both directions of priming (L1 to L2 and L2 to L1) but variations have been found that may be attributed to subprocesses (repetition enhancement respectively repetition suppression) of priming, which supports the aspect in Green’s model that there is an activation (of the target language) and an inhibition (of the inappropriate language) process implicated in switching between languages. (Isel et al., 2010)

Another point, supporting the idea of suppression of non-target elements only in a second step is the basic mechanism used in the present study: The fact that Stroop interference also occurs in a manual version of the Stroop task implicates that interference must take place already on a pre-linguistic level. (see also Bonin, 2007, p. 45-47) As described above, in linguistic production, activation is supposed to take place first at the conceptual level, then on the lexical level, afterwards on the lemma level and finally on the phonological level. All levels, except the conceptual level, are linguistic levels. This observation supports that – if even interference with a non-linguistic task occurs - the conceptual level additionally is unlikely to be language-specific. Furthermore, it suggests that Stroop interference takes place very early in the executive function and that inhibition of the non-target response occurs only after this interaction. Cognitive control in the Stroop task seems to be a process that is in some kind analogous to bilingual language selection according, on the one hand, to the models on bilingual language control, postulating a mechanism of cognitive inhibition that is not only specific of the language domain, and, on the other hand, on observations in literature suggesting an advantage of bilinguals in the Stroop task. (Badzakova-Trajkov, 2008; Bialystok and DePape, 2009)
1.2.5. Language selection in comprehension

In language comprehension, activation on different levels of processing may contribute to language selection. Either the lexical item itself, or its sub-lexical properties or the linguistic or non-linguistic context might be the crucial elements for the realization which language an item belongs to. There are numerous studies showing that on a bi-/multilinguals’ mind semantic-conceptual and lexical items sharing several properties of the ingoing signal are co-activated in the different languages for a certain time. Parallel activation of lexical candidates in different languages has even been shown with multilinguals performing tasks in exclusively one language, and even when this language was a foreign – non dominant -language. (Van Wijnendaele and Brysbaert, 2002; Brysbaert, 2003; Dijkstra, 2005) Obviously only in a second step, the items in the wrong language(s) are inhibited. From the linguistic context and on a pre- (or sub-) lexical level, language-specific information on the writing system, orthography or - especially when the input is auditory - on phonology become available, but nevertheless, candidates from the different languages are co-activated and selection only takes place in a second step. Concerning the non-linguistic context, principally the task than the language is affected by changes. Thus, language selection would be modified only indirectly, according to changed task requirements. These observations suggest that crucial information on which language an item belongs to is available relatively late in language comprehension. Additionally, lexical access has been shown to be faster in the dominant language and notably for words of high frequency, thus being dependent on the level of activation. (Dijkstra and Snoeren, 2004)

There are some indices that there exist sub-lexical language-specific differences as well. Even though there are often already hints, which language it belongs to, in the signal (alphabetic system, frequency of morphological structures, frequency of certain letter combinations, etc.), also the non-target languages are co-activated. And even if the different languages of a multilingual do not share the same alphabetic system, co-activation takes place due to connections on a sub-lexical level and information on language belonging, which are likely to be connected in some way. (Dijkstra and Snoeren, 2004)
1.2.6. Language selection in production

Besides these observations on non-selective lexical access (non-language-specific co-activation of items of different languages) Poulisse and Bongaerts (1994) have found in their studies on errors in production a largely higher level of interlanguage interference (erroneous substitution of the item by a semantically related item in a non-target language) than of intralanguage interference (erroneous substitution of an item by another, semantically related, item of the same language). Thus, language tagging is likely not to be a conceptual trait among any other semantical trait at the conceptual level. (Dijkstra and Snoeren, 2004) Several studies provide support for psycholinguistic models claiming a shared conceptual level between the languages, for early as well as for late bilinguals (Isel et al., 2010; Dijkstra, 2005; Brysbaert, 2003). Silverberg and Samuel (2004) claim that a shared conceptual level is only the case with early bilinguals. As mentioned above (Chapter 1.2.2), diverging neural activation in early and late respectively high or low proficient bilinguals still needs to be further examined in order to find out which factor and which aspect of processing the differences are to be attributed to.

In language production, language tagging is supposed to be available from the beginning, as the intention to produce an utterance in a certain language precedes speaking (for exact localization of language tagging, propositions slightly diverge in the different models on bilingual language processing, see chapter 1.2.4), but even though, co-activation of competing items in other languages is the case. In language production, the selection of an item in a specific language and the inhibition of competing items in other languages takes place relatively late, as it is the case in language comprehension. The application/execution of activation and inhibition is also influenced by the dominance of the respective languages (L1 vs. L2). The dominant language (usually L1) and furthermore generally items of high frequency, on different levels of language processing (lexical, syntactic, etc.), tend to be higher activated and are more likely to interfere when a non-dominant language is the target language. The interference of non-target languages on the target language at a specific moment has been found to take place not only on the lexical level but even so on the levels of syntax and phonology. (Dijkstra and Snoeren, 2004)
1.2.7. Bilingual language capacity and translating as separate cognitive functions

Interpreters and translators sometimes claim to be experts in their interpreting respectively translating task but not experts on the single languages. An argument underlining the observation of a separation of the two cognitive functions of, on the one hand, the capacity to use one or more languages versus, on the other hand, the capacity to translate between them is to be found in Green (1998), where the phenomenon of paradoxical translation is described. Paradoxical translation is the name for the syndrome of certain bilingual aphasics who are able to translate into a language that they cannot use spontaneously or inversely if they cannot translate into a language that they can use spontaneously.

Such a pattern of recovery indicates that speaking a language spontaneously and translating a language are functionally distinct activities. (Green, 1998, p. 70)

Furthermore, given the existence of simultaneous interpreting, where lexical access to both languages is required simultaneously for input and output, the assumption of global inhibition of the non-target language(s) is not satisfying. (Christoffels and De Groot, 2005) The phenomenon of simultaneous interpreting is a challenge for models on bilingual language control, such as the Inhibitory Control model developed by Green (1998) (see above: Inhibitory Control (IC) model (Green, 1998)). Especially of importance in research on simultaneous interpreting but of interest for every model of monolingual and bilingual organisation of language is the question, if the lexicon is separated into an input (comprehension) and an output (production) lexicon or if there is only one lexicon serving both functions. An outline of the discussion and modelling on this point is given in the two previous chapters, 1.2.5 and 1.2.6, but there is no consensus yet and further research is necessary.

Concerning the direction of translation, Green (1998) proposes that it is more difficult to inhibit lemmas from L1, generally stronger activated, than to inhibit lemmas of L2, that are weaker connected to meaning. (Green, 1998)

In behavioral studies, Kroll and Stewart (1994) have shown that directionality effects occur when using translation tasks; translating word from L1 to L2 (forward) takes longer than translating from L2 to L1 (backward). (Isel et al., 2010, p. 170)

Similar questions as for directionality of code switching arise. Further research is needed in both domains, on the directionality of translating as well as on the effects of code switching direction. (Monsell, 2003)
1.3. The impact of bilingualism on diverse cognitive functions

Bilingualism is of great interest especially in psycholinguistic research. Not only the phenomenon of bi- or multilingualism itself is in the focus of research but in particular also its effect on other cognitive functions. Advantages and disadvantages on non-linguistic cognitive functions due to the habituation and training to handle more than one language have been demonstrated in several studies. I.e. Bialystok and DePape (2009) examined the influence of bilingualism on several cognitive tasks and observed that bilingualism had different effects on the access to the mental lexicon, working memory and especially on cognitive control in executive functions. (Bialystok and DePape, 2009)

1.3.1. Lexical access

Even if the advantages of bilingualism commonly outweigh the disadvantages, there are some detriments. Some authors claim that bilinguals generally react slower to linguistic stimuli. This issue is rather controversial. (Badzakova-Trajkov, 2008) Bialystok et al. (2008) demonstrated a reduced lexical access in bilinguals compared to monolinguals (i.e. the effect of words on the tip of someone’s tongue is observed more frequently). Different explanations are possible for this drawback. On the one hand, reduced lexical access might be due to the bilingual’s in sum larger lexicon, because they handle more than one language. On the other hand, lexical access might be minor in bilinguals due to the inhibition necessary in controlling two languages. In this case, the inhibition that is needed to select the target language and to avoid interference by the non-target language(s) necessarily reduces access to the respective lexica. If this is the case, the disadvantage in lexical access is even due to the same factor that accounts for some rather advantageous influences of bilingualism, namely inhibitory control. (Green, 1998; Bialystok et al., 2008; Bialystok and DePape, 2009) Several psycholinguistic models account for this phenomenon and include an aspect of inhibitory control, i.e. the IC model by Green (1998) or the BIA+ model by Dijkstra and Van Heuven (2002). (Dijkstra, 2005; Bialystok et al., 2008)
1.3.2. Working memory

Working memory performance has been shown to be clearly improved in simultaneous
interpreters in comparison to unbalanced bilinguals or even high proficient bilinguals.
(Christoffels and De Groot, 2005; Christoffels et al., 2006) In simultaneous interpreting, or
conference interpreting, language comprehension and production take place parallelly in
different languages. Interpreters have a split conceptual attention. Simultaneous interpreters
have to store information while, at the same time, they have to execute several mental
operations, that is to say comprehending, translating, producing speech and monitoring their
output. (Christoffels and De Groot, 2005) If better capacity of working memory is the cause
for or the consequence of taking the profession of a simultaneous interpreter has yet to be
examined. Anyway, better working memory capacities in simultaneous interpreters appear to
be caused rather by their specific professional practice than merely by bilingualism.

Bialystok et al. (2008) compared bilinguals with monolinguals for their capacity in working
memory but did not find differences between the groups. If there is a benefice of bilingualism
on working memory remains to be clarified in further studies. (Bialystok et al., 2008) In the
present study, a French version of the Reading Span test\(^4\) (Desmette et al. (1995) was done
with bilinguals and monolinguals to evaluate their capacity of working memory.

1.3.3. Inhibitory control in executive functions

In several behavioural studies testing executive functions, advantages in bilinguals in
comparison with monolinguals were shown. Mean reaction times were found to be shorter in
the performance of bilinguals, i.e. in the Simon task\(^5\), the Wisconsin Card Sorting test\(^6\) and
the Stroop task. (Bialystok and De Pape, 2009; Bialystok et al., 2008; Costa et al., 2008) In

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\(^4\) The Reading Span test is a measure of working memory capacity. (Desmette et al., 1995; Christoffels et al.,
2006) In the Reading Span test, participants have to read aloud sentences and are instructed to recall the
respective last word of each sentence. These last words are to be repeated after a block of sentences has been
read. The number of sentences in a block - and therefore the number of words to recall - increases during the test.
Reading Span capacity is measured with the number of words recalled, either percentually or according to the
block length. (Desmette et al., 1995)

\(^5\) In the Simon task, conflict occurs between the spatial response and the location of the stimulus. In this task, the
stimulus may occur at the same or at the opposite side as the spatial response to give. The position of the
stimulus is irrelevant for giving a response but interferes with the spatial response to give. The Simon test is a
neuropsychological test for executive functions.

\(^6\) In the Wisconsin Card Sorting test, participants are given cards depicting different shapes of different color and
number. The cards have to be sorted by shape, color or number but the participants are not told the sorting
criterium. To find out if the sorting criterium is right, the participants can only use the feedback if their piles of
cards are sorted right or wrong. Sorting criteria are changed during the experiment and the participant’s time to
learn the new rule and the errors he/she makes are measured. The Wisconsin Card Sorting test is a
neuropsychological test for executive functions.
the Stroop task, better inhibitory control is reflected namely in a reduced Stroop Effect. The Stroop Effect is caused by the interference that the more automatic process of reading the colour word has on the task of naming the print colour, which is a less automatic process. It is measured as the reaction time difference between the incongruent condition, where the colour word and the print colour diverge, and the congruent condition, where colour word and print colour are identical. A high Stroop Effect is interpreted as high suffrance from the interference while a low Stroop Effect is interpreted to reflect a good capacity of inhibitory control to suppress interfering, competing information. Therefore, the performance of bilinguals on diverse tasks on executive functions, as mentioned above, suggests that the permanent need to suppress a competing language apparently has a training effect not only on the control of languages but also on the control in some non-linguistic functions. (Green, 1998; Costa et al., 2008; Bialystok et al., 2004; Bialystok et al., 2008)

Especially early bilinguals show improved performance in cognitive control of regulation and inhibition of information. (Bialystok, 2005; Bialystok and DePape, 2009) Control processes needed in the handling of a bilingual language system may already play an especially supporting role in the development of control processes during the development of the frontal lobes in children. (Bialystok et al., 2005) It is of interest, not only if early bilinguals but also if late bilinguals show improved cognitive control in executive functions, as it has been observed for bilinguals in several previous studies (Bialystok, 2005; Bialystok and DePape, 2009; Badzakova-Trajkov et al., 2008). In order to contribute to a clearer view on and to a better understanding of the impact of late bilingualism on cognitive control, late bilinguals and monolinguals will be tested for their performance in the Stroop task in the present study.

Zied et al. (2004) examined the influence of bilingualism on the usual decline with age in the efficiency of inhibitory mechanisms. In their study, younger and older unbalanced\(^7\) and balanced\(^8\) bilinguals were tested in a verbal Stroop task. Balanced bilinguals showed overall faster reaction times than unbalanced bilinguals in both age groups. Older unbalanced individuals showed greater interlingual interference in a mixed version of the Stroop task (with stimuli written in one language but the answer had to be given in the respectively other

\(^7\) Unbalanced bilinguals means bilinguals whose proficiency in L2 does not reach proficiency in L1.
\(^8\) Balanced bilinguals have a nearly equally high proficiency in L1 and L2.
language) than older balanced bilinguals. The faster reaction times and the reduced interlingual interference in older balanced bilinguals compared to older unbalanced bilinguals may indicate that manipulating their two languages of high proficiency may support the efficiency of inhibitory mechanisms and may reduce the rapidity of the decline of cognitive control with age. Additionally, as the less-dominant language seems to get lost more rapidly with age than the dominant one in unbalanced bilinguals while both languages remain at an equally high proficiency in balanced bilinguals, the control of language systems is supposed to be asymmetrical in unbalanced bilinguals. (Zied et al., 2004) Bialystok et al. (2004) also found a contribution to an offset of age-related losses in executive processes for bilinguals. Bilingualism seems to decelerate the decline of cognitive control with age.

But not only bilingualism may have a training effect on cognitive control in executive functions. Neville (2009) gives an outline of cognitive functions and especially attentional functions necessary in and trained by musical practice:

Attentional selection includes processes of enhancement of selected signals (signal amplification) as well as suppression of non pertinent information if there are salient “non-signals” (suppression of distractors). The suppression of distractors constitutes an important step in attentional selection and is equally considered as mechanism of executive or inhibitory control. Executive control itself plays an important role not only in the suppression of most immediate responses but also in rapid attentional engaging / disengaging from one target to another and in allocation of attentional resources between different tasks. (Neville, 2009, p. 279)

Bialystok and DePape (2009) found in an experiment using the Simon task, a non-verbal spatial task, that executive control can be ameliorated by both, by musical practice as well as by bilingual language use. Bilinguals performed better than monolinguals in the Simon task, suggesting that – as mentioned above - language control might involve similar cognitive control mechanisms that are needed in other tasks, even for non-linguistic ones. This way, bilinguals may have the advantage of being better “trained” in the cognitive control task due to their need to handle more than one language. Inhibitory control of languages is necessary because both languages are activated when only one of them is used, as indicated by the

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9 “La sélection attentionnelle inclut aussi bien les processus de rehaussement de signaux sélectionnés (amplification du signal) que la suppression, en présence de « non-signaux » saillants, des informations non pertinentes (ou suppression des distracteurs). La suppression des distracteurs constitue une étape précoce de la sélection attentionnelle, et elle est également considérée comme un mécanisme de contrôle exécutif ou inhibiteur. Le contrôle exécutif, quant à lui, joue un rôle important aussi bien dans la suppression des réponses les plus immédiates que dans les engagements / désengagements très rapides de l’attention d’une cible vers une autre et dans l’allocation des ressources attentionnelles entre différentes tâches.” (Neville, 2009, p. 279)
results of several studies on bilingual language processing (Dijkstra, 2005; Brysbaert, 2003; Bialystok et al., 2005).

The better performance in executive functions may also depend on the task, according to the tasks regularly practiced, that are part of their regular experience. Bialystok and DePape (2009) compared musicians and bilinguals in an auditory Stroop task (word/pitch). Musicians performed better in a task where the pitch had to be detected, while bilinguals scored better in detecting the word; nevertheless both, musicians and bilinguals outperformed monolingual non-musicians. In musical practice as in the control of two languages, selective attention, monitoring and shifting are permanently required tasks and are therefore trained by both groups of musicians and bilinguals. (Bialystok and DePape, 2009)

Neville (2009) ponders about possible causal relationships between musical practice and better performance in several cognitive tasks. Cognitive functions especially required in musical practice are attention and executive functions; moreover, processing of signs and of abstract relations is involved. On the one hand, musical practice may train functions that are also necessary in other, non-musical, tasks and thus be the cause for their amelioration. On the other hand, doing music may be chosen or at least continued rather by individuals that already provide good performance in these cognitive functions required and in this case musical practice would be the consequence of better cognitive capacities. Neville departs from the first of the two hypotheses to test a possible causal effect of musical practice on cognitive functions and especially on attention with children aged 3 – 5 years. Her findings show a positive effect of musical training on linguistic comprehension and production, on numerical functions and in intelligence tests. Further examinations on the impact of musical or direct attentional training were done, but this time additionally the factors group size and the parents’ education in parental attitude were taken into account. To test this last factor, an education was offered to the parents in order to develop their parental attitudes. These tests on the interaction of different factors revealed larger effects on cognitive functions if musical or attentional training was done in small groups and accompanied by parental education. (Neville, 2009)
As especially musical practice (Bialystok and DePape, 2009; Neville, 2009) but also activities such as playing video or computer games (Bialystok, 2006; Green and Bavelier, 2003) may have an ameliorating effect on specific cognitive functions – as it is supposed to be the case with bi- or multilingualism – questions on these activities were included in the questionnaire of the present study. Different kinds of sports demanding well coordinated and trained movements, i.e. ping-pong, dancing, martial arts, etc., may have a training effect in the same domain and therefore a question on sportiness was equally included in the questionnaire (adapted version of the questionnaire used by Isel et al., 2010; Appendix A.1 and A.2).

What is globally named “better” inhibitory control in executive functions may in detail be due to either “stronger” or “more flexible” or “more efficiently maintained” inhibition, or even due to a combination of these points. (Neville, 2009) In an fMRI study on cross-language priming, DLPFC activation was found to be differentiable according to subprocesses of language switching, which are selective activation of the target language and inhibition of the non-target language. (Isel et al., 2010) The further inclusion of neurophysiological and neuro-imaging techniques may contribute to a better understanding of the subprocesses of inhibitory control in executive functions and its implication in bilingual language control and language switching or in musical practice.

1.3.3.1. Stroop Colour Word test

The Stroop test (Stroop, 1935) is usually used to examine inhibitory control in executive functions as it requires attentional control to inhibit conflicting information. (Badzakova-Trajkov, 2008; Pardo et al., 1990) The test is used in psychological basic research as well as in clinical diagnostics. (Pardo et al., 1990; Peters et al., 2000)

In the present study pairs of conflicting stimuli, both being inherent aspects of the same symbols, are presented simultaneously (a name of one color printed in the ink of another color—a word stimulus and a color stimulus). (Stroop, 1935, p. 16)

The Stroop Colour Word test combines a linguistic component, colour words, with a non-linguistic component, print colour. In the congruent condition, the meaning of the colour word and its print colour are identical whereas they differ in the incongruent condition. Different possibilities of control conditions exist, depending on what aspect is to be tested. Thus, for control trials, either the print colour can be neutral (i.e. black, white), if the interference of
print colour on word naming is tested, or the colour word can be replaced by a colour-neutral
word or a series of signs (i.e. DOG, XXXX), if the interference of the word on print colour
naming is to be examined. The Stroop Effect is mainly caused by the interference of the more
automatic task of word reading on the less automatic task of print colour naming in the
incongruent condition.

Even if there has already passed a long time of scientific use of the Stroop test, the definition
of the way how to measure Stroop interference seems to be still not completely standardized.
Stroop defines the measurement of interference in a print colour naming task as follows: “The
difference in the time for naming the colors in which the words are printed and the same
colors printed in squares (or swastikas) is the measure of the interference of conflicting word
stimuli upon naming colors.” (Stroop, 1935, p. 22) Anyway, to evaluate Stroop interference,
most researchers measure the difference in reaction times (RT) between the incongruent and
the congruent condition (Badzakova-Trajkov, 2008; Bialystok and DePape, 2009; Qiu, 2006).
In addition to the examination of the Stroop Effect via measuring the difference between RT
in the incongruent and the congruent condition, it is also of interest to look at the differences
between the RT in the congruent and the control condition (Effect of Facilitation; Badzakova-
Tajkov, 2008) and between the RT in the incongruent and the control condition (Effect of
Cost).

The Stroop Effect can be explained by the difficulty in the incongruent condition to overcome
the word-reading response, a highly automatic process, which is assumed to interfere with the
less automatic process of colour naming (Botvinick, 2001). In the original study by Stroop
(1935), the reaction times in a colour word naming experiment and in a print colour naming
experiment were compared. The mean response time was increased in the latter condition,
colour naming, in comparison to the former, word reading. Thus, Stroop interpreted that there
is a strong interference of the habit of calling words on the activity of naming colours which is
shown by this confrontation of the two experiments (colour word naming/print colour
naming). Stroop explains that the faster reaction in reading words in comparison to naming
colours is due to a training effect. Due to every-day activities, we are better trained in reading
words than in naming colours. Consequently, associations are stronger between the reading of
the word and naming of the read word, compared to the associations between print colour
detection and naming its colour. Stroop also found a sex-difference when opposing the colour word naming and the print colour naming, favouring the females. This difference – better performance of female participants – is discussed as being probably caused by differences in education - also some kind of training -, namely the higher practice of women in talking about colour, especially due to clothing, thus being also a product of practice. This interpretation is in contrast to former studies, explaining comparable results as being caused by a greater facility of women in verbal reaction in general, so Stroop (1935).

In the present study, we applied the Stroop task - combining an automatic linguistic task (word reading) with a non-linguistic task (identification of the print colour) – in order to study the participants’ capacity of inhibitory control in executive functions. The experimental task consisted of identifying the print colour, a cognitive process that is less automatised than the linguistic task, reading (Cohen et al., 1990; Stroop, 1935). A conflict between the two tasks arises as the more automatic task of reading has to be inhibited in order to execute the less automatic task of print colour naming. In the Stroop task, mainly efficiency of conflict resolution (when the target response is selected and the competing, non-target response is inhibited) is supposed to be studied when examining reaction times and accuracy. Longer reaction times and higher error rates in the incongruent compared to the congruent condition are interpreted to reflect higher cost in conflict resolution. However, there is some controversy on which phases of conflict processing are actually relevant in Stroop interference, i.e. if also conflict detection (conflict detection in incoming interfering stimuli) etc. plays a role. (Qiu et al., 2006)

Bruchmann et al. (2010) tested the Stroop Effect with masking conditions. With decreasing visibility of stimulus words, and thus with the visibility of their verbal meaning and their print colour, the differences in the responses to the congruent vs. incongruent condition decreased as well. The authors claim, that the behavioural and neural responses to the Stroop Effect depend on the amount of consciously perceived information, therefore on the degree of conscious perception of stimulus conflict.
The Simon task and the Stroop task are classified as tests on executive functions\textsuperscript{10} as the occurring conflicts need a resolution that “[…] is based on intentional processing rather than automatic responding and is therefore an aspect of executive functioning.” (Bialystok, 2006, p. 68) Bialystok continues, that “performance based on this rapid monitoring and switching is also part of controlled or executive functioning. […] performance in the Simon task engages processes involved with selective attention, inhibition, and response switching.” (Bialystok, 2006, p. 68) In the Simon and the Stroop task, similar cerebral regions are activated, that are attributed to processes of cognitive control: notably the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC). (Bialystok, 2006) Therefore, the Stroop task has been chosen for the present study in order to study the participants’ cognitive control in executive functions.

1.3.3.2. Cerebral activation in cognitive control with the special case of Stroop interference

The idea of a training effect on inhibitory control in bilinguals is supported by several studies using the Stroop test. Inhibitory control is necessary in this task in order to resolve conflict. Bilinguals are claimed to be better trained in inhibitory control through their habit to switch between languages in their everyday life as there is permanent necessity to inhibit situation-irrelevant, competing information (the non-target language). (Badzakova-Trajkov, 2008; Zied et al., 2004; Bialystok et al., 2008; Stroop, 1935)

Green (1998) proposed the Inhibitory Control model, in which the nonrelevant language is suppressed by the same executive functions used generally to control attention and inhibition. If this is accurate, and if Posner is correct that experiences in basic attentional processes can be modified through practice, then bilinguals should demonstrate more efficient selective attention and ability to ignore distraction than monolinguals because of their regular use of general executive functions in the management of two languages. (Bialystok, 2006, p. 69)

In the ERP, the N400, a negative centro-parietal deflection, reflects processing of semantic information that is unexpected in the respective sentence context. N400 has more than one source but originates mainly from temporal regions. In a Stroop interference experiment, an

\textsuperscript{10} There is a long debate on the functions that are really tested with the Stroop task (Pardo, 1990) or with the Simon task (Bialystok, 2006). However, nowadays, there is agreement on the idea that these tests allow to study executive functions. Qiu et al. (2006) did not find ERP changes in initial stimulus classification and conclude that their results support the hypothesis that “Stroop interference arises primarily from response competition between the color and word at the output stage, and not from initial stimulus identification and evaluation” (Qiu et al., 2006, p. 190).
N450 is usually observed. The neural generator of the N450 has principally been found in the prefrontal cortex (PFC) as well as in the anterior cingulate cortex (ACC) (for the localisation of the cerebral areas see Fig. 1). As the N400 and the N450 have similar latency and both play a role in conflict resolution and response selection, they can easily be confounded. (Qiu et al., 2006; Badzakova-Trajkov et al., 2009)

The prefrontal and midcingulate cortices are the areas showing the main differences in activity between congruent and incongruent conditions in interference tasks, thus reflecting the monitoring and processing of conflicts. (Bruchmann et al., 2010) In a source-analytic study on the Stroop test, Badzakova-Trajkov et al. (2009) detected the implication of the anterior cingulate cortex (ACC) and the prefrontal cortex (PFC) in controlling cognitive conflict. Bruchmann et al. (2010) found an N400 difference between the congruent and incongruent conditions in the Stroop Colour Word task – the difference in reaction times between the incongruent and the congruent condition is taken by most researchers to evaluate Stroop interference – in an EEG experiment. An equivalent current dipole model (ECD) to detect sources of activity showed a preponderant ACC implication as well as important activity in right prefrontal regions. (Bruchmann et al., 2010) On the other hand, Qiu et al. (2006) only observed PFC activity without ACC being significantly implicated in a Chinese version of the Stroop Colour Word task on participants with Chinese as their mother tongue. One of the arguments given by Qui et al. (2006) to account for the absence of ACC activity is the automaticity of semantic processing of colour words in Chinese and/or that ACC activity might have been overshadowed by the subsequent strong activation in the PFC. Bruchmann et al. (2010) also refer to the implication of a wider network of activity in the control of cognitive conflict in the Stroop task (i.e. left medio-temporal and motor cortices). These authors therefore claim that it would be relevant to combine EEG recordings with fMRI in order to get more specific information on the timing of the implication of the respective brain areas. Also Badzakova-Trajkov et al. (2009) detected further differences in activity, in addition to those most relevant in the ACC, namely in the dorsal and lateral prefrontal cortex, the medial frontal gyrus, the posterior cingulate and the and middle temporal gyrus. Moreover, Badzakova-Trajkov et al. (2009) refer to imaging studies, having detected – in addition to ACC and/or DLPFC (dorso-lateral prefrontal cortex) activity - the implication of i.e. the inferior frontal gyrus or the inferior parietal lobe. Isel et al. (2010) found higher activation of the DLPFC in late bilinguals compared to early bilinguals in language switching.
These findings support the idea that in language switching, processes of central executive functions are involved (Isel et al., 2010). Badzakova-Trajkov (2008) found support for the idea of an advantage of even late bilingualism in an ERP study on cognitive control in executive functions. Less activation in frontal and central areas and generally more widespread activation was the case in bilinguals compared to monolinguals (see Fig. 6). fMRI results in this study did not support the hypothesis of a bilingual advantage.

Fig. 6 ERP results of a study on late bilinguals and monolinguals using the Stroop Colour Word task. “(A) The GFP for the incongruent and congruent Stroop task conditions with difference wave plotted for each group and language separately; (B) The scalp topography of the difference wave at its maximum. Blue is negative potential, red is positive; (C) The scalp distribution of the significant electrodes for the incongruent-congruent comparison. The significant differences between the ERPs are seen in the marked time windows.” (Badzakova-Trajkov, 2008, p. 138) M–E (Macedonian–English) bilinguals showed less activation in frontal and central areas in the incongruent condition in both languages, which might indicating less difficulty to resolve conflict, than monolinguals. G–E (German–English) bilinguals showed reduced frontal and central activity in L2. (adapted from Badzakova-Trajkov, 2008)
Badzakova-Trajkov et al. (2009) found similar early activity differences in relation to the control condition (colour-neutral words) in the congruent as well as the incongruent conditions: ERP comparison congruent-control = 280-430 ms, comparison incongruent-control = 260-400 ms, both with a positive waveform difference over central and parietal regions (LORETA source estimation resulted for both comparisons in a main source of activity in the cingulate gyrus). These activities occurred before the timeframe of Stroop interference, which is the main difference in activity when incongruent and congruent conditions are compared: 370-480 ms, also extending over central and parietal sites but in a negative waveform difference (LORETA source estimation indicated the main source of activity in the anterior cingulate). This early similar activity for the congruent and incongruent condition suggests attentional allocation taking place early and in both critical conditions. Probably, attentional allocation is required in both, the congruent and incongruent condition, as in the incongruent condition conflict arises between the meaning of the colour word and the print colour and in the congruent condition conflict may be due to the necessity to select which stimulus to attend to - the word meaning or the print colour. Conflict detection and resolution obviously only take place later, when major differences are observed between the congruent and the incongruent condition in the EEG. These observations support the idea that different subregions of the cingulate play a role in numerous functions such as attentional allocation and modification, conflict detection and resolution, etc. The ACC is rather implicated in conflict detection and resolution. The activation of its different subregions is likely to vary during the different stages of Stroop processing and might even differ according to the response modality in the Stroop task, being either manual or verbal. (Badzakova-Trajkov et al., 2009)

There exist different theories on the specific roles of ACC and PFC in performance or conflict monitoring and in executive control but these respective implications yet need to be examined in further studies. It is probable, that the network dealing with the Stroop interference is implicated in dealing with conflicting information in general, in monitoring cognitive conflict, independent of the specific task (linguistic, non-linguistic, etc.; Badzakova-Trajkov et al., 2009). Therefore, a training effect may be caused by a diversity of factors, among which there are very likely bi- or multilingualism or musical activity, as it has already been shown in several studies. (Badzakova-Trajkov, 2008; Bialystok and DePape, 2009)
Humphreys et al. (2007) discuss the role of general cognitive control in executive functions and its relation to control in the linguistic domain. Furthermore, the authors give an interpretation of the consequences in linguistic tasks of lesions in the left or the right hemisphere:

[…] the present results show that impairments in executive processes can contribute to problems in naming after brain lesions, and these need to be taken into account over and above specific deficits in the representation of linguistic knowledge. (Humphreys et al., 2007, p. 156)

This observation gives additional support to the idea that cognitive control in executive functions is necessary also in bilingual language control.

In a PET study on the Stroop task conducted with healthy right-handed subjects, Pardo et al. (1990) found a widely distributed network of activation for the Stroop interference effect (differences in activity between the incongruent and the congruent condition) but the clearest difference of activity was found in the anterior cingulate cortex (ACC). The extensive activation found in the study made the authors conclude that the interference effect cannot exclusively be attributed to conflicts in either processing of the stimulus input or in producing output. The outstandingly increased activity of the ACC in the incongruent compared to the congruent condition suggests its crucial role in attentional processing. ACC is interpreted to be involved “in the selection process between competing processing alternatives on the basis of some pre-existing internal, conscious plan” (Pardo, 1990, p. 259), in other words in “selection and recruitment of processing centers appropriate for task execution”. (Pardo, 1990, p. 256) Increased activity in the left PFC and in the ACC was also found when in the incongruent compared to the congruent condition by Bialystok et al. (2005) in the Simon task. These two areas are also involved in the control of bilingual language use. (Bialystok et al., 2005) These findings of similar activation for conflict resolution and for bilingual language control provide support for the localisation of a crucial inhibitory control mechanism on a level superior to the language domain, as it is the case in the IC model. (Green, 1998) Being not exclusively linked to language control, the Supervisory Attentional System (SAS) can therefore probably be implied also in non-linguistic domains. A similar function is attributed to the “Task schema” level in the BIA+ model (Dijkstra and Van Heuven, 2002)
Costa and Santesteban (2004) claim that inhibitory control might only play a role for low proficient bilinguals, while in high proficient bilinguals, a language-specific selection mechanism has already developed. Inferring from this interpretation, only low proficient bilinguals should show better inhibitory control. On the contrary, research on high proficient bilinguals has shown advantages of this bilingual group as well (Bialystok et al., 2004; Bialystok et al., 2008).

Due to some findings in ERP studies, i.e. an absence of P300 in stimulus input processing in adults compared to children, Stroop interference is likely to be treated differently in adults and children, probably caused by more automatic processing from the lexical to the semantic level in adults. Qiu et al. (2006) argue that different cognitive and brain mechanisms seem to account for the somewhat different ERP results found for the Stroop task in adults and children. (Qiu et al., 2006)

These observations in neurophysiological and neuro-imaging studies will be taken into account in the continuation of the present project in a second step when - departing from the present behavioural study - further experiments implicating also neurophysiologic techniques (EEG) will be conducted in order to evaluate also the aspect of neuronal activity in the examination of the effect of bilingualism on inhibitory control in executive functions.

1.3.3.3. Stroop response mechanisms

In literature, different versions of the Stroop task can be found. Bialystok et al. (2008) work with a verbal task, thus print colour identification has to be pronounced and is recorded via a voice key. Manual tasks, which means giving responses using coloured keys of the keyboard or response buttons are applied for example by Qui et al. (2006) and Bruchmann et al. (2010). In both studies stimuli are shown only for a very short time and manual responding is only possible after the stimulus has already vanished. A manual task is to be found also in a study by Badzakova-Trajkov et al. (2009). In this experiment, responses are also given using coloured keys on the keyboard but the stimulus remains on the screen while the corresponding keys have to be pressed. Nevertheless a clear Stroop Effect has been detected.
The aim of the present study is to compare late bilinguals living in an L1 environment to monolinguals for their capacity of cognitive control in executive functions. In order to evaluate this capacity, the participants’ performance in the Stroop Colour Word task will be tested. Moreover, the performance in the Stroop task will be compared between the two languages for bilinguals. Previous research has mainly been done on early bilinguals or on late bilinguals living in an L2 environment (Bialystok et al., 2008; Badzakova-Trajkov, 2008). Therefore, working with late bilinguals living in their L1 environment is of interest as it is a rather unexplored group.
Empirical part

2. Hypotheses and Predictions

2.1. Bilinguals vs. Monolinguals

2.1.1. Accuracy and Reaction times

The research hypothesis of the present study is a better performance of late bilinguals in comparison to monolinguals in detecting and resolving conflicts that are habitually observed in cognitive tasks that include both, a linguistic and a non-linguistic component. The expected better performance is supposed to be due to their training in inhibiting irrelevant knowledge and information.

To compare the performances of bilinguals and monolinguals the results in the three L1 blocks in the experiment for bilinguals (Experiment 1) are compared to the results of respectively only three blocks among the six L1 blocks of monolinguals. The three chosen blocks with monolinguals are those corresponding to the distribution of L1 block positions in the succession of blocks during the experimental procedure. The aim of this choice is to compensate a possible overpracticing effect or effect of fatigue in the course of the experimental procedure.

Bilinguals are expected to perform better in the Stroop task than monolinguals due to the training in inhibiting irrelevant information in the daily use of two or more languages (Bialystok and De Pape, 2009; Zied et al., 2004; Badzakova-Trajkov, 2008; all three studies show a decreased Stroop Effect/Stroop interference for bilinguals). The latency of their answers in all conditions of the Stroop task is expected to be shorter in comparison to monolinguals, as monolinguals are supposed not to be trained in cognitive suppression of irrelevant information to the same level as bilinguals. Both models on bilingual language control described above, the IC model (Green, 1998) and the BIA+ model (Dijkstra and Van Heuven, 2002), permit the hypothesis of better cognitive control of bilinguals also in non-linguistic tasks. Therefore, a reduced Stroop Effect is predicted in bilinguals compared to monolinguals.
General predictions: For the performance of bilinguals and monolinguals in the Stroop task were generally shorter reaction times and higher accuracy for bilinguals in comparison to monolinguals, as indicated in Table 1.

**Table 1. Predictions for reaction times (RT) and accuracy for bilinguals and monolinguals in the Stroop task.**

<table>
<thead>
<tr>
<th>Reaction time (RT) [ms]</th>
<th>RT&lt;sub&gt;Bilingual&lt;/sub&gt;</th>
<th>&lt;</th>
<th>RT&lt;sub&gt;Monolingual&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy [%]</td>
<td>Error&lt;sub&gt;Bilingual&lt;/sub&gt;</td>
<td>&lt;</td>
<td>Error&lt;sub&gt;Monolingual&lt;/sub&gt;</td>
</tr>
<tr>
<td></td>
<td>(Accuracy&lt;sub&gt;Bilingual&lt;/sub&gt;)</td>
<td>&gt;</td>
<td>Accuracy&lt;sub&gt;Monolingual&lt;/sub&gt;)</td>
</tr>
</tbody>
</table>

Concerning reaction times in the three experimental conditions incongruent, congruent and neutral, the following pattern was predicted (Fig. 7): Reaction times were expected to be longest in the incongruent conditions and shortest in the congruent conditions. In response to neutral stimuli, response times were expected to be intermediate, between those in incongruent and congruent conditions. This pattern was expected for bilinguals – in both languages - as well as for monolinguals.

The difference in reaction time between the incongruent and congruent condition is defined as the “Stroop Effect (SE)”, the difference between the neutral and the incongruent condition as effect of “Cost” and the difference between the neutral and the congruent condition as effect of “Facilitation”. (Badzakova-Trajkov, 2008)

**Fig. 7. Predicted relations of the reaction times (RT) in the three experimental conditions in the Stroop task.**
Concerning the Stroop Effect (SE), it was expected to be reduced in bilinguals in comparison to monolinguals when comparing the results in the L1:

\[ \text{SE}_{\text{Bilingual}} < \text{SE}_{\text{Monolingual}} \]

The inhibition of a highly automatic task (word reading) in order to execute a less automatic one (print colour naming) is supposed to be less difficult for bilinguals, even if they are late learners, than for monolinguals. Thus they are expected to suffer less from the interference of the more automatic task on the less automatic one as it is the case in the incongruent experimental condition when the information from these two sources of input are conflicting.

### 2.1.2. Switching cost

Switching cost would be analyzed in post-hoc tests. Due to the pseudo-randomized succession of trials in our experimental procedure, switching takes place in an unpredictable manner. Predictability of switching may reduce the switching cost due to a preparation effect. (Monsell, 2003) Switch and non-switch trials were taken from the pseudo-randomized succession of trials that had not intentionally been designed for this purpose. The analysis for Switching cost was done for the congruent and the incongruent condition. Non-Switch trials were defined as trials preceded by two trials of the same experimental condition whereas Switch trials were those preceded by two trials of the respectively other experimental condition (congruent, incongruent). The choice to take only trials preceded by two trials of the same or the other condition as Non-Switch or Switch trials was done in order to get stronger effects than if taking trials preceded only by one stimulus of the same or the other condition.

Switching between trials of different experimental conditions is supposed to be more costly than continuing to respond to trials in the same condition (Costa et al., 2008; Monsell, 2003):

\[ \text{RT}_{\text{Non-Switch}} < \text{RT}_{\text{Switch}} \]

In Fig. 8 the non-switch and switch situation is demonstrated for the congruent condition and in Fig. 9 the non-switch and switch situation in the incongruent condition are to be seen.
### Fig. 8
The Non-Switch and Switch situations in the congruent condition are shown. Congruent Non-Switch (CNS) trials are those preceded by two trials of the same (congruent) condition; Switch trials are those preceded by two trials of the other (incongruent) experimental condition.

<table>
<thead>
<tr>
<th>Congruent Non-Switch (CNS)</th>
<th>Congruent Switch (CS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial succession</td>
<td>Trial succession</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>Incongruent</td>
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</table>

### Fig. 9
The Non-Switch and Switch situations in the incongruent condition are shown. Incongruent Non-Switch (INS) trials are those preceded by two trials of the same (incongruent) condition; Switch trials are those preceded by two trials of the other (congruent) experimental condition.

<table>
<thead>
<tr>
<th>Incongruent Non-Switch (INS)</th>
<th>Incongruent Switch (IS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial succession</td>
<td>Trial succession</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Incongruent</td>
<td>Congruent</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
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</table>
Switching is supposed to be less costly for bilinguals than for monolinguals. Due to their better inhibitory control, bilinguals should be more at ease to flexibly set, maintain or release inhibition according to the task requirements:

\[
\text{Switching cost}_{\text{Bilingual}} < \text{Switching cost}_{\text{Monolingual}}
\]

Costa et al. (2008) examined Switching cost in the incongruent and congruent condition in the ANT task. In their study, Costa et al. found a higher switching cost when switching to a simpler task than when switching to a more difficult task. Applied on the present study, switching to the congruent condition should be more costly than switching to the incongruent condition because colour naming in a congruent trial is a simpler task than in an incongruent trial. Costa et al. explain this higher switching cost when switching to a simpler task than to a more difficult one as follows: There is higher effort in removing strong inhibition needed in a preceding difficult task which then has to be overcome as it is dispensable in the simpler task (only weaker inhibition to block competing elements is necessary as a dominant response is executed) than in the inverse case, in setting strong inhibition that had not been needed in the preceding trial when switching takes place in the direction from the simpler to the more difficult task. (Monsell, 2003; Costa et al., 2008; Allport et al., 1994; Monsell (2003) gives examples for different tasks in which switching between the more difficult and the easier task has been examined, among which there is for example code switching between trials in L1 and L2 or switching between print colour or word naming in the Stroop task; Costa (2008) demonstrated the phenomenon using the ANT task;) As a probable bilingual advantage in cognitive control should particularly be pronounced in highly demanding tasks, the advantage of bilinguals should be reflected especially in the possibly more costly switch towards the simpler task and cause a more symmetrical switching cost in the two switching conditions (towards a congruent trial respectively towards an incongruent trial). (Costa, 2008)

Monsell (2003) states that subsequent studies have identified problems in this account - postulating more pronounced switching cost when switching towards the simpler task and indicate the role of a greater complexity of influencing factors on switching cost.

On the contrary, one can argue that the pattern of Switching cost is expected to be inverse and setting inhibition is more costly than its removal. This question requires elements of response – focused in the analysis of the experiment - in order to argue in favor of the one or the other idea.
2.1.3. Overpracticing Effect
Reaction times are also analyzed for a possible change during the experiment. On the one hand, an acceleration of reaction time can be expected due to the training of the task itself (“Overpracticing Effect” as a reduction of RT in the advance of the experiment). In this case, the overall slower group in the first block should show a more pronounced effect of acceleration during the experiment as for the already faster group a ceiling effect may occur. (Costa, 2008) Monolinguals are expected to show longer reaction times and thus may show a more pronounced acceleration in form of a reduction of reaction times in the last block compared to the first block.

$$RT_{\text{First block}} > RT_{\text{Last block}}$$

On the other hand, an effect of fatigue might occur. In this case, reaction times would increase in the course of the experiment and especially when comparing the last with the first block.

Not only reaction times but also the Stroop Effect will be looked at in the advance of the experiment and especially will be compared between the first and last block. Also with the Stroop Effect either an Overpracticing Effect or an effect of fatigue may be the case.

$$SE_{\text{First block}} \leftrightarrow SE_{\text{Last block}}$$

2.2. Bilinguals L1 vs. L2

2.2.1. Accuracy and Reaction times
The results for the bilinguals in L1 and L2 are looked at more closely. Not many data concerning the performance in the Stroop task in L2 with bilinguals are to be found in literature. (Badzakova-Trajkov, 2008)

Zied et al. (2004) used a verbal version of the Stroop task to test younger and older balanced and unbalanced bilinguals in their two languages. Unbalanced bilinguals showed longer reaction times when asked to verbally identify print colours in their non-dominant language compared to their dominant language. In this version of the Stroop task, the inhibition of the linguistic component of the stimulus is necessary as well as the activation of the lexica in the
respective language in order to produce the right response. In contrast, in our manual version of the Stroop task, colour naming takes place only non-verbally (pressing colour-marked keys) and thus only requires inhibition of the linguistic component of the stimulus. Therefore, the inverse prediction for the two languages is supposed. While responding has been observed to be slower in L2 in comparison to L1 in the verbal task, when the respective language has to be activated, reaction is supposed to be faster in L2 compared to L1 when only inhibiting the linguistic part is required. In unbalanced bilinguals the non-dominant language is expected to be inhibited easier than the dominant one as it is less automatized and less activated than the dominant language, L1, according to the BIA+ model. (Dijkstra and Van Heuven, 2002; Van Heuven et al., 1998)

Due to lower activation of the non-dominant L2, cognitive control is supposed to have higher impact in L2 than in the more dominant L1. If the BIA+ model is right, in the Stroop task, the inhibition of L2 words is expected to be easier than to inhibit L1 stimulus words when print colour naming is the target task. This may be reflected in shorter reaction times in L2 compared to L1:

$$\text{RTL2}_{\text{Bilingual}} < \text{RTL1}_{\text{Bilingual}}$$

Furthermore, predicting from the BIA+ model, the expected higher impact of cognitive control on L2 should be shown in a reduced Stroop interference in L2 than in L1:

$$\text{SEL2}_{\text{Bilingual}} < \text{SEL1}_{\text{Bilingual}}$$

In addition to the higher impact of cognitive control on a less activated language, the already present strong inhibition of the more dominant language might cause a benefit in other cognitive tasks. This means that treating the less dominant L2 necessitates the strong inhibition of the more dominant L1. This strong inhibition already being set might be advantageous in another task requiring inhibitory control, as it is the Stroop task.

### 2.2.2. Switching cost

Switching between trials of different experimental conditions is supposed to be more costly than continuing to respond to trials in the same condition. (Costa et al., 2008; Monsell, 2003)

This is expected to be the case in both languages of bilinguals:
\[ RT_{\text{Non-Switch}} < RT_{\text{Switch}} \]

Switching is supposed to be less costly in L2 than in L1. Due to expected higher impact of cognitive control on the less activated L2, switching should cause less effort and be more symmetrical in the two switching directions (towards a congruent respectively an incongruent trial) in L2 than in L1:

\[ \text{Switching cost}_{L2} < \text{Switching cost}_{L1} \]

### 2.2.3. Overpracticing Effect

Reaction times are analyzed for a possible change during the experiment and compared between the two languages of bilinguals. Like in the comparison between monolinguals and bilinguals, an acceleration of reaction time during the experiment is expected due to the training of the task itself (Overpracticing Effect). The predictions for differences in the performances in L1 and L2 remain open. On the one hand, acceleration might be more pronounced in L1 due to a certain ceiling effect in L2, where already shorter reaction times are expected. On the other hand, inhibitory control might have even more impact on the already lower activated language if there is the additional training (“Overpracticing”) in the course of the experiment.

\[ RT_{\text{First block}} > RT_{\text{Last block}} \]

Appart from an Overpracticing Effect, on the contrary an effect of fatigue might occur. In this case, reaction times should increase during the experiment, especially when comparing the last to the first block.

The Stroop Effect will also be looked at in both languages if there is change with the advance of three blocks in the experiment. Also with the Stroop Effect either an Overpracticing Effect or an effect of fatigue may be the case.

\[ SE_{\text{First block}} \leftrightarrow SE_{\text{Last block}} \]

The prediction for the performances in L1 compared to those in L2 remains open.
3. Method

3.1. Participants
All participants were French native speakers. The participants were right-handed (Edinburgh Handedness Inventory) (Appendices A.1 and A.2, as part of the questionnaires) and had been looked for in the age group 18-40 years. The specifications of bilinguals and monolinguals on several points are to be found in Table 2 and Table 3. By their own account (see questionnaire Appendices A.1 and A.2), the subjects had no history of current or past neurological or psychiatric illnesses, they had normal or corrected-to-normal vision and normal colour vision. At the end of the experiment, the subjects were paid 10€ per hour for their expenditure of time, which was approximately 2h with bilinguals and 1h with monolinguals.

Experiment 1
In Experiment 1, ten late French-German bilinguals (8 female) of an average age of 28.6 ± 5.2 years were tested. They spoke French as their mother tongue and were late learners of German as their L2 which they had started to study from the age of 10 on at secondary school in France. The average age of acquisition (AoA) of German as their L2 was 10.5 ± 0.8 years. Specifications on several points such as Proficiency or L2 exposure are to be found in Table 2 and Table 3. A criterion for accepting participants for the study was their regular use of German during the past three years. In a questionnaire (Appendix A.2A.1, a modified version of the questionnaire used in Isel et al., 2010) they were asked for the procedure of their language acquisition of German, for the amount and the contexts of their use of German as well as of other foreign languages during the past three years. Furthermore, they had to specify especially the amount and context of their current German use and of their use of other foreign languages.

To evaluate the participants and in order to form subgroups according to proficiency, L2 exposure etc., a questionnaire to auto-evaluate their proficiency in German on a 5-point scale from excellent proficiency (sehr gute Kenntnisse) (1) to poor proficiency (fast keine Kenntnisse) (5) in the categories of Comprehension, Production, Reading and Writing had to be completed (Appendix A.3) and two tests on proficiency of German as a foreign language, among which the standardised DAF test (Das Zertifikat, DAF – Deutsch als Fremdsprache,
Einstufungs- und Diagnostiktest), had to be done by bilinguals. The evaluated proficiency and the scores are to be found in Table 2.

In order to make a differentiation between “high proficient” and “low proficient” late bilinguals, the threshold was set at 80% in the performance on the language tests. In previous studies, performances on L2 proficiency tests were i.e. >90% with high proficient bilinguals (Isel et al., 2010) or on average 80,36% in late proficient bilinguals (Badzakova-Trajkov, 2008). Therefore, taking a performance of 80% in the language tests as a minimum for the classification as “high proficient” was considered appropriate. For the self-assessment of the participants on their proficiency in German, the threshold was set on point 2 on the 5-point scale (excellent proficiency (1), poor proficiency (5)). Setting the threshold of self-evaluation on proficiency on point 2 corresponds to the 80% threshold for evaluation in the language tests and is inspired by proficiency classifications in previous studies (Badzakova-Trajkov, 2008; Costa, 2008). Self-evaluated proficiency has been shown to correspond well with performance measures of proficiency. (Colzato, 2008) Proficiency classifications according to either the performance on the language tests or the self-assessment were not identical with each subject. Therefore, in case of doubt, the proficiency classification according to the performance in the language tests was chosen.

Furthermore, a Reading Span Test was done in L1, French, in order to test the participant’s capacity of working memory. The method was carried out according to the method described by Desmette et al. (1995). For testing the Reading Span in L1, the French standardized version of the Reading Span, also developed by Desmette et al. (1995), was presented to bilingual and monolingual participants. The Reading Span Test was always done following the Stroop experiment. The results are to be found in Table 2.

Experiment 2

Experiment 2 was done with a group of 10 monolingual French native speakers (8 female) aged on average 26,1 ± 2,9 years who had had little use of foreign language during the past three years. Monolinguals were asked to do a questionnaire (Appendix A.1) as well. The monolinguals’ indications on several points are to be found in Table 2 and Table 3. Also with
monolinguals, the French version of the Reading Span Test was done. The results are to be found in Table 2.

**Table 2 Results from evaluations of the participants concerning L2 Proficiency and Exposure, General foreign language exposure, musical and sportive activity, playing video/computer games and performances on the L1 Reading Span Test are shown in the table.**

<table>
<thead>
<tr>
<th></th>
<th>Bilinguals</th>
<th>Monolinguals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN</td>
<td>SD</td>
</tr>
<tr>
<td>L2 Exposure (last three years) [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>18,99</td>
<td>24,22</td>
</tr>
<tr>
<td>High Exposure (&gt; 5,6 %)</td>
<td>35,75</td>
<td>24,77</td>
</tr>
<tr>
<td>Low Exposure (&lt; 5,6 %)</td>
<td>2,23</td>
<td>1,80</td>
</tr>
<tr>
<td>Total</td>
<td>17,13</td>
<td>20,68</td>
</tr>
<tr>
<td>L2 Exposure (current) [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Exposure (&gt; 9 %)</td>
<td>29,57</td>
<td>23,89</td>
</tr>
<tr>
<td>Low Exposure (&lt; 9 %)</td>
<td>4,69</td>
<td>2,15</td>
</tr>
<tr>
<td>L2 Proficiency auto-evaluation [1 = excellent knowledge, 5 = poor knowledge]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HP (&gt; 2)</td>
<td>1,58</td>
<td>0,37</td>
</tr>
<tr>
<td>LP (&lt; 2)</td>
<td>2,45</td>
<td>0,27</td>
</tr>
<tr>
<td>Total</td>
<td>81,30</td>
<td>8,14</td>
</tr>
<tr>
<td>L2 Proficiency tests performance [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HP (&gt; 80 %)</td>
<td>86,46</td>
<td>4,71</td>
</tr>
<tr>
<td>LP (&lt; 80 %)</td>
<td>73,56</td>
<td>5,35</td>
</tr>
<tr>
<td>Foreign language Exposure (last three years) [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreign language Exposure (currently) [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Music practicing time [min/week]</td>
<td>36,00</td>
<td>94,66</td>
</tr>
<tr>
<td>Sport practicing time [h/week]</td>
<td>2,28</td>
<td>2,17</td>
</tr>
<tr>
<td>Video/Computer games practicing time [min/week]</td>
<td>18,00</td>
<td>56,92</td>
</tr>
<tr>
<td>L1 Reading Span [N° of words]</td>
<td>3,85</td>
<td>0,88</td>
</tr>
<tr>
<td>L1 Reading Span [%]</td>
<td>77,50</td>
<td>9,91</td>
</tr>
</tbody>
</table>

The bilingual and monolingual language groups did not differ significantly in musical or sportive activity neither in the time spent on video/computer games playing. As monolinguals in the age group 18-40 show even though little (“inevitable”) exposure to foreign languages, the level of foreign language exposure in the last three years respectively current foreign language use were compared between bilinguals and monolinguals. General foreign language use in the last three years differed between the language groups with high significance ($F1 (1, 19) = 9,384, P < 0.01$) and current foreign language use differed significantly as well ($F1 (1, 18) = 5,947, P < 0.05$). (Table 2)
Table 3 Several classifications of bilinguals and monolinguals have been undertaken according to their indications in the questionnaire respectively according to their performance in the L2 proficiency test.

<table>
<thead>
<tr>
<th></th>
<th>Bilinguals</th>
<th>Monolinguals</th>
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<tbody>
<tr>
<td><strong>L2 Exposure (last three years) (Median: 5.60 %)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High exposure</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Low exposure</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><strong>L2 Exposure (current) (Median: 9 %)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High exposure</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Low exposure</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><strong>Proficiency classification (auto-evaluation) (HP &gt; 2 &gt; LP)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP (High Proficiency)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>LP (Low Proficiency)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td><strong>Proficiency classification (test performance) (HP &gt; 80 % &gt; LP)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP (High Proficiency)</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>LP (Low Proficiency)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Musician</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Musician</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>No musician</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td><strong>Music instrument</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Piano</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Transverse flute</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Guitar</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Trumpet</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Saxophone</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Clarinet</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Singing</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Piano</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No piano player</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Piano player</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td><strong>Sport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not doing sports</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Doing sports</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td><strong>Sport genre</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Sport</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Athletics (Jogging, Cycling, Walking, etc.)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Swimming</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Yoga</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Fitness Studio, Musculation</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Climbing</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Dancing</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Martial arts</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Video/Computer Games genre</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Games</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Puzzle</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Adventure</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Exertainment</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

3.2. Stimuli

An adapted version of the original Stroop task was used in the experiments. The Stroop task consists of colour naming when stimuli in three different conditions are presented: congruent, incongruent and neutral stimuli. In the congruent condition the meaning of the colour word and the print colour match, in the incongruent condition the meaning of the colour word and its print colour differ and in the neutral condition, non-colour words that are matched in length and complexity with the colour words, are presented in equally varying print colours as in the congruent and incongruent conditions.
The task was a manual colour naming task. The participants were asked to identify the print colour of the stimuli and to react (“respond”) to print colour by pressing one of four keys on the keyboard of the laptop marked with the corresponding colours. Participants were instructed to respond as fast and as correctly as possible. Instructions were given in written form (Appendices A.4 and A.5) and repeated orally to ensure that the instructions have been understood.

Four colour-words were presented in the congruent condition with the print colour identical to the word meaning and in the incongruent condition with one of the three other print colours that were not congruent with the word meaning. In L1, French, the following four colour words were presented: ROUGE\textsuperscript{red}, BLEU\textsuperscript{blue}, JAUNE\textsuperscript{yellow}, VERT\textsuperscript{green} and in L2, German, the four colour words corresponding to those in L1 were used: ROT\textsuperscript{red}, BLAU\textsuperscript{blue}, GELB\textsuperscript{yellow}, GRÜN\textsuperscript{green}. In the neutral condition, four non-colour words - similar in length and complexity to the colour words – were presented in the same four print colours. As neutral words in L1, French, were chosen the following: CHAT\textsuperscript{cat}, CHIEN\textsuperscript{dog}, MAIN\textsuperscript{hand}, PIED\textsuperscript{foot} and in L2, German: KATZE\textsuperscript{cat}, HUND\textsuperscript{dog}, HAND\textsuperscript{hand}, FUSS\textsuperscript{foot}. In Experiment 2, in which the subjects were French native speaker monolinguals, only the French colour and neutral words were used.

The print colours used were those corresponding to the colour words: red, blue, yellow and lime were chosen from the standard repertoire provided by the software. Green was replaced by lime for better visibility against the black background. Colour visibility, discriminability and prototypicality of the stimulus words can have an impact on the Stroop Effect, shown in several studies implicating masking of the stimuli (i.e. Bruchmann, 2010). The stimulus words, written in capitals of font “Calibri” in font size 48, were presented individually against a black background\textsuperscript{11} in the centre of the screen. Examples can be seen in Table 4.

\textsuperscript{11} Stimuli were presented against a black background like in the studies i.e. by Pardo et al. (1990) and Bruchmann et al. (2010).
Table 4. Stimuli in the three experimental conditions - congruent, incongruent and neutral – with examples in German and French for every condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Example</th>
<th>L1</th>
<th>L2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congruent</td>
<td>ROUGE</td>
<td>BLAU</td>
<td></td>
</tr>
<tr>
<td>Incongruent</td>
<td>VERT</td>
<td>GELB</td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>CHIEN</td>
<td>HAND</td>
<td></td>
</tr>
</tbody>
</table>

3.3. Procedure

The stimulus presentation and the experimental procedure were inspired in several points by Bruchmann et al. (2010), Badzakova-Trajkov et al. (2009) and Qui (2006). Except for the language used for presenting the stimulus, the procedure was identical in Experiment 1 and 2.

The sequence of single stimulus presentation can be seen in Table 5. The stimulus presentation design was created with the program E-Prime 2.0 (Psychological Software Tools, Pittsburgh, PA). Each stimulus word was preceded by a fixation cross in the centre of the screen. The duration the fixation cross was presented varied between 500 and 1000 ms (500, 625, 750, 875, 1000 ms equally distributed and pseudo-randomized among the stimuli) in order to avoid systematic expectancy to be built up by the participants (inspired by Christoffels et al., 2007). The fixation cross was immediately succeeded by the stimulus which was presented until one of the four colour keys was pressed or maximally for 1500 ms if no key was pressed. The inter-stimulus interval (ISI) was 500. Reaction time (RT) was defined as the interval between stimulus onset and pressing a response key.
Table 5. The sequence of single stimulus presentation and the duration of every phase of stimulus presentation are shown. The duration of the fixation cross varied between 500 and 1000 ms, which is pseudo-randomized in the blocks of stimuli presented.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>+</th>
<th>Stimulus</th>
<th>ISI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration [ms]</td>
<td>500 - 1000</td>
<td>max. 1500</td>
<td>500</td>
</tr>
</tbody>
</table>

The subjects were seated in front of the laptop (Dell, 14’’ screen) in the habitual writing position with both hands positioned on the keyboard. Good illumination of the room was assured. Written instructions (Appendices A.4 and A.5) were given to the subjects and repeated orally before the start of the test. The participants were asked to indicate as fast and as correctly as possible the print colour of the stimulus word by pressing one of the four response buttons. The colours were also indicated on the lower part of the frame parallel to their position on the keys in order to avoid influences on reaction time caused by orienting on the keyboard and a bias of practicing effects during the experiment artificially caused by automatisation of the colour-key-assignment rather than by practicing the Stroop task. The keys d, f, j and k were chosen in order to permit the habitual position of the hands on the keyboard. The keys had to be pressed with the index and middle fingers of the left and the right hand. The colour-finger-assignment was counterbalanced between the subjects so as to vary the finger and the hand used for each colour but kept constant during the experiment for every single subject.

In order to permit the participants to learn the colour-key correspondences, two practicing blocks of 40 trials each were presented before the six experimental blocks. In Experiment 1 (bilinguals), first a block with words in French and second a block with words in German were presented. In Experiment 2 (monolinguals) both practicing blocks consisted of words in French. Feedback about accuracy was given after each practicing and experimental block. If accuracy was at least 80% after the second practicing block, the experiment was started; if 80% accuracy were not reached, the two practicing blocks had to be repeated. The practicing blocks never had to be repeated, all participants reached the threshold of 80% in at least one of the training blocks.
Subjects were asked to do six blocks with 72 trials each. The 72 trials per block were equally taken from the three experimental conditions - 24 congruent stimuli, 24 incongruent stimuli and 24 stimuli in the neutral condition. The trials were presented in pseudo-randomized order: No stimulus word was repeated immediately, no print colour was repeated immediately and stimuli in one condition were not presented more than three times in succession. (inspired by Badzakova-Trajkov, 2008; Christoffels et al., 2007; Hahne et al., 2010; Pardo, 1990) The pseudo-randomized order of trials was created using the program Conan (Nowagk, 1998). Every block started with a trial in the neutral condition. In Experiment 1 (bilinguals), three French and three German blocks were presented, in pseudo-random order. The succession of blocks was also pseudo-randomized between the participants but no more than two blocks of one language were presented in succession. Taken the block distributions for all 20 bilingual subjects together, in each of the 6 block positions during the experiment, stimulus blocks in the two languages were equally distributed (10 times each). In Experiment 2 (monolinguals), six blocks in French were presented. The participants could take a short pause between the blocks and continued when feeling ready by pressing the space key. Originally, 33% of filler trials were planned to be included pseudo-randomly in the experimental blocks. Filler trials would have been stimuli in the three conditions (congruent, incongruent, neutral) while the task demanded (indicated with a sign) would have been a verbal one in this case: reading the stimulus word. The aim was to distract the probands from focusing exclusively on the print colour and thus, with the help of filler trials, to increase Stroop interference. A similar experimental design was done by Bruchmann et al. (2010), whereas filler blocks with a verbal task were presented separately from the manual task, in distinct blocks. Due to some indices of overcharging the probands (i.e. the Stroop Effect was inverse or absent) with this mix of condition, language and task switching, the filler trials were replaced by critical trials. Green (1998) describes that an overcharge of the capacity of the “system” (i.e. working memory) may impede the full processing of the input actually intended to be examined and thus may bias the results. In the present study, task switching in filler trials was therefore excluded from the experiment in order to avoid biases on the effects of switching between conditions and languages. It took the subjects about 5 min to do one experimental block and about 25 min for the whole Stroop experiment.

For bilinguals, the Stroop experiment was preceded by two other tasks: First, conversation in German was held for about 15 min between the participant and the experimenter, a German
native speaker. Second, the questionnaire on general information about the person and about his/her language history, especially concerning French and German, had to be completed. The questionnaire was in German for bilinguals. Conversation in German and the questionnaire in German were intended to activate L2 processing, to switch the language processing mode to German (see Isel et al., 2010) respectively to activate language switching. For monolinguals, only the questionnaire preceded the Stroop experiment. The questionnaire for monolinguals was in French.

3.4. Data Analysis/Statistics
Reaction time (RT) was defined as the interval between the onset of the stimulus word and the button press. Only correct responses were taken for statistical analysis afterwards. The reaction time data were corrected by excluding all data exceeding the mean ± two standard deviations (SD). Furthermore, accuracy was analysed.

In order to compare L1 for bi- and monolinguals, the results of always one bi- and one monolingual were paired. From the monolingual experimental procedure only those three blocks in the equivalent position to the three L1 (French) blocks in the respective bilingual experimental procedure where chosen for analysis.

Repeated measures ANOVA, One-way ANOVA, t-Tests and Pearson Correlation examination were done. Condition (3 levels: Congruent, Neutral, and Incongruent) was used as within-subject factor. Language group (2 levels: Monolingual, Bilingual) was used as a between subject factor.

4. Results
The two dependent measures were the percentage of correct responses (accuracy) and reaction time (RT). Repeated measures ANOVA, One-way ANOVA and t-Tests were done to examine the following factors:
• Condition: congruent, incongruent, neutral.
• Language Group: bilinguals, monolinguals.
• Language: L1 French, L2 German.

For the comparison of bilingual and monolingual performance, Condition and Language Group were the relevant factors while for the comparison of the performance of bilinguals in their L1 and L2, Condition and Language were the relevant factors.

The data were corrected per subject for every experimental condition. Data exceeding Mean ± 2 Standard deviations were removed from the analysis.

4.1. Bilinguals vs. Monolinguals
In order to compare the performance of the bilingual language group with the performance of the monolingual language group – the control group –, only L1 blocks of bilinguals (Experiment 1) and only three L1 blocks among the six experimental blocks of monolinguals (Experiment 2) were selected. The three blocks chosen for monolinguals corresponded in block distribution to the L1 blocks of bilinguals.

4.1.1. Accuracy
Repeated measures ANOVA was done to examine the effect of condition on accuracy (Fig. 10). Accuracy was overall very high, in both language groups. There was no effect of Condition \( (F_1 < 1) \) and no effect of Language group \( (F_1 < 1) \) on accuracy. Accuracy results for monolinguals and bilinguals are to be found in Table 6.

Post-hoc tests using one-way ANOVA were done to examine the effect of Language group in the single conditions. In the incongruent condition, a tendency towards an effect of Language group was found \( (F_1 (1, 18) = 3,02, \ p = 0.099) \).
Table 6. Accuracy [%] (Mean, Standard deviation (SD)) is given for Monolinguals and Bilinguals in the three experimental conditions in L1.

<table>
<thead>
<tr>
<th></th>
<th>Congruent</th>
<th>Incongruent</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN</td>
<td>SD</td>
<td>MEAN</td>
</tr>
<tr>
<td>Monolinguals</td>
<td>98.32%</td>
<td>1.84%</td>
<td>97.07%</td>
</tr>
<tr>
<td>Bilinguals</td>
<td>97.63%</td>
<td>2.27%</td>
<td>98.46%</td>
</tr>
</tbody>
</table>

Fig. 10 Accuracy [%] in total and in the three experimental conditions (congruent, incongruent, neutral) for bilinguals and monolinguals.

4.1.2. Reaction times

RT data were corrected per subject and experimental condition. Data exceeding Mean ± 2 Standard deviations were removed from the analysis.
Repeated measures ANOVA was done to examine the effect of Condition on reaction time, which was highly significant ($F_1 (2, 36) = 37.17, P < 0.001, MSE = 445.8$) (Fig. 11). Language group (bilingual, monolingual) did not have an effect on reaction time ($F_1 < 1$) and there was no interaction between Condition and Language group ($F_1 (2, 36) = 1.50, P > 0.10$). Descriptively, a difference between the two language groups can be seen – with bilinguals being slightly faster –, but this difference has not shown to be significant. Reaction times for monolinguals and bilinguals in the three experimental conditions in L1 are shown in Table 7.

Table 7. Reaction times [ms] (Mean, Standard deviation (SD)) for Monolinguals and Bilinguals in the three experimental conditions.

<table>
<thead>
<tr>
<th></th>
<th>Congruent</th>
<th></th>
<th>Incongruent</th>
<th></th>
<th>Neutral</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN</td>
<td>SD</td>
<td>MEAN</td>
<td>SD</td>
<td>MEAN</td>
<td>SD</td>
</tr>
<tr>
<td>Monolinguals</td>
<td>626.29</td>
<td>81.06</td>
<td>684.99</td>
<td>81.92</td>
<td>647.92</td>
<td>81.49</td>
</tr>
<tr>
<td>Bilinguals</td>
<td>627.77</td>
<td>67.77</td>
<td>666.55</td>
<td>61.59</td>
<td>640.47</td>
<td>62.69</td>
</tr>
</tbody>
</table>

Post-hoc analyses on the effect of condition on reaction time were done using repeated measures ANOVA between respectively two experimental conditions according to the tested effect, to be seen in Fig. 11. The Stroop Effect was highly significant ($F_1 (1, 18) = 54.98, P < 0.001$), as well as the Effect of Facilitation ($F_1 (1, 18) = 22.18, P < 0.001$) and of Cost ($F_1 (1, 18) = 23.66, P < 0.001$).
Fig. 11 Reaction times [ms] in total and in the three experimental conditions (congruent, incongruent, neutral) for bilinguals and monolinguals. The Stroop Effect ($RT_{incongruent} - RT_{congruent}$), the effect of Facilitation ($RT_{neutral} - RT_{congruent}$) and the effect of Cost ($RT_{incongruent} - RT_{neutral}$) are marked in the graph.
A post-hoc analysis of the effect of Language group on the Stroop Effect was done. The Stroop Effect as the difference between $RT_{\text{Incongruent}} - RT_{\text{Congruent}}$ was compared between the language groups with a t-Test. Descriptively, there is a difference between the two language groups (Fig. 12) but it is not significant ($t(1, 18) = 1.52, P = 0.147$).

![Fig. 12 The Stroop Effect [ms] ($RT_{\text{Incongruent}} - RT_{\text{Congruent}}$) in the monolingual and the bilingual language group as well as the difference of the Stroop Effect between the two groups are shown.]

**4.1.3. Switching cost**

For the examination of switching cost the selected data were corrected per subject for every condition and switch respectively non-switch situation. Data exceeding Mean ± 2 Standard deviations were removed from the analysis. The number of data varied in the different categories as Switching cost analysis was a post-hoc examination and therefore, it depended on the pseudo-randomized trial order how many data corresponded to the criteria. In monolinguals, the data of two subjects were completely excluded because there were too few switching data for these subjects (The criterion for inclusion was a number of at least two trials per condition and switching situation, which means at least two trials for respectively Congruent\text{Non-Switch} (CNS), Congruent\text{Switch} (CS), Incongruent\text{Non-Switch} (INS) and Incongruent\text{Switch} (IS)).
To examine the effects of Switching, the reaction times in the Switch and the Non-Switch situation were confronted (RT$_{\text{Switch}}$ vs. RT$_{\text{Non-Switch}}$) separately in the congruent and in the incongruent condition using repeated measures ANOVA. The results are plotted in Fig. 13 for the congruent condition and in Fig. 14 for the incongruent condition in the L1 of monolinguals and bilinguals.

In the congruent condition (Fig. 13), reaction times were shorter in the Non-Switch (CNS) compared to the Switch (CS) situation in both language groups. The effect of Switching (RT$_{\text{Switch}}$ vs. RT$_{\text{Non-Switch}}$) was significant ($F(1, 16) = 4.899, P < 0.05$) but there was no effect of Language group ($F < 1$) and no significant interaction of Language group and Switching ($F(1, 16) = 2.243, P = 0.154$). A post-hoc analysis revealed a significant effect of Switching in the congruent condition for monolinguals ($F(1, 7) = 8.968, P < 0.05$) but not for bilinguals ($F < 1$). In the Congruent Non-Switch situation, monolinguals show faster reaction times than bilinguals which is paradoxically causing Switching cost in monolinguals while in bilinguals there is no Switching cost due to their slower reaction times in the Congruent Non-Switch situation. A post-hoc analysis was carried out to test if the difference between the language groups in the Congruent Non-Switch situation is significant. The descriptive difference in CNS between the language groups is not significant ($F(1, 17) = 1.158, P = 0.298$), neither is there a significant difference between language groups in CS ($F < 1$).
Fig. 13 The Effect of Switching (RT\text{Switch} vs. RT\text{Non-Switch}) in the congruent condition with monolinguals and bilinguals in their L1. CNS Congruent Non-Switch (Trials in the congruent condition that are preceded by two trials of the same, the congruent, condition. There is no switch between conditions.), CS Congruent Switch (Trials in the congruent condition that are preceded by two trials in the incongruent condition. There is a switch between conditions.).

In the incongruent condition (Fig. 14), reaction times were slightly shorter in the Non-Switch (INS) compared to the Switch (IS) situation in monolinguals but the situation was inverse for bilinguals, with even slightly faster reaction times in the Switch situation. The effect of Switching (RT\text{Switch} vs. RT\text{Non-Switch}) was not significant ($F_1 < 1$), there was no effect of Language group ($F_1 < 1$) and no significant interaction of Language group and Switching ($F_1 < 1$). The effect of Switching was not significant neither for monolinguals ($F_1 < 1$) nor for bilinguals ($F_1 < 1$). In a post-hoc analysis, no significant difference between the language groups was found in INS ($F_1 < 1$) or IS ($F_1 < 1$).
Fig. 14 The Effect of Switching (RT_{Switch} vs. RT_{Non-Switch}) in the incongruent condition with bilinguals and monolinguals. **INS** Incongruent Non-Switch (Trials in the incongruent condition that are preceded by two trials of the same, the incongruent, condition. There is no switch between conditions.), **IS** Incongruent Switch (Trials in the incongruent condition that are preceded by two trials in the congruent condition. There is a switch between conditions.).

Besides examining the effect of Switching on reaction times in the incongruent and congruent conditions separately, Switching cost (RT_{Switch} - RT_{Non-Switch}) was also compared between the two conditions. Comparing the Switching cost between the congruent and the incongruent condition within each language group, no significant differences were detected. Comparing respectively Congruent Switching cost and Incongruent Switching cost between the language groups, there were no significant differences. (Fig. 15) In those cases, where there is negative Switching “cost”, it is also not quite appropriate to use the term “Switching cost” as shorter reaction times in the Switching situation compared to the Non-Switch situation indicate that the respective group does not suffer from an additional cost of switching in the experimental condition where this is the case.
Fig. 15 Switching costs in the congruent and incongruent condition are plotted for monolinguals and bilinguals. Switching cost is defined as $RT_{Switch} - RT_{Non-Switch}$. 
4.1.4. Overpracticing Effect

An Overpracticing Effect (reduction of RT with advancing in the experiment) on RT in the three L1 blocks – named Block 1, 2 and 3 according to their position in the progression of the experimental procedure – for monolinguals and bilinguals was highly significant (Fig. 16) ($F_1$ (2, 36) = 6,855, $P < 0.01$). There was no effect of Language group ($F_1 < 1$) and no interaction of Overpracticing Effect and Language group ($F_1 < 1$). Post-hoc analyses showed a significant Overpracticing Effect in bilinguals ($F_1$ (2, 18) = 6,524, $P < 0.05$) but not in monolinguals ($F_1$ (2, 18) = 1,378, $P < 0.277$).

Reaction times were significantly shorter in the third block compared to the first block ($F_1$ (1, 18) = 8,358, $P < 0.01$) and between the second block compared to the first block ($F_1$ (1, 18) = 9,301, $P < 0.01$) but no significant difference was found between the second and the third block.

![Fig. 16 Overpracticing Effect](image)

**Fig. 16 Overpracticing Effect.** The reaction times in the three selected L1 blocks are shown according to their succession in the experiment as Block 1, 2 and 3, for monolinguals and bilinguals.
Examining if there is an Overpracticing effect on the Stroop Effect (Fig. 17), it has been detected to be significant ($F1 (2, 36) = 4.263, P < 0.05$). An effect of Language group ($F1 < 1$) and an interaction of Overpracticing and Language group ($F1 < 1$) were not significant. Post-hoc analyses showed, that in monolinguals, the Overpracticing effect on the Stroop Effect is close to a tendency of becoming significant ($F1 (2, 18) = 2.606, P = 0.104$). In bilinguals, no significant Overpracticing Effect was found ($F1 (2, 18) = 2.039, P = 0.163$).

Between the first and the third block there is significant difference in the size of the Stroop Effect ($F1 (1, 18) = 7.037, P < 0.05$). Comparing the SE in the second and the third block, the difference is significant as well ($F1 (1, 18) = 7.164, P < 0.05$), but not between the first and the second block ($F1 < 1$).

\[\text{Fig. 17 Overpracticing Effect on the Stroop Effect. The Stroop Effect [ms] in the first and last blocks are shown for monolinguals and bilinguals in L1.}\]

\[\text{4.1.5. Subgroups}\]

In order to evaluate an effect of musicality, sportiness and video/computer game playing, subgroups formed according to the indications in the questionnaire (see
No main effects on RT or SE were found. There were also no significant correlations between the respective practicing times of these activities and RT or SE.

4.2. Bilinguals L1 vs. L2

4.2.1. Accuracy
Repeated measures ANOVA was done to examine if there is an effect of Condition on Accuracy in the L1 and L2 of bilinguals (Fig. 18). The accuracy results are listed in Table 9. There was no effect of Condition ($F1 < 1$) or Language ($F1 < 1$). Condition and Language did not interact significantly ($F1 (2, 36) = 2.18, P = 0.14$). Post-hoc one-way ANOVA analyses were done to test the effect of Language on accuracy for each condition. No significant effect was found for any of the three experimental conditions: Congruent: $F1 < 1$; Incongruent $F1 (1, 18) = 1.96, P = 0.18$; Neutral: $F1 (1, 18) = 2.03, P = 0.17$.

Table 8. Accuracy [%] (Mean, Standard deviation (SD)) for L1 and L2 of bilinguals in the three experimental conditions is shown.

<table>
<thead>
<tr>
<th></th>
<th>Congruent</th>
<th>Incongruent</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN</td>
<td>SD</td>
<td>MEAN</td>
</tr>
<tr>
<td>L1</td>
<td>97.63%</td>
<td>2.27%</td>
<td>98.46%</td>
</tr>
<tr>
<td>L2</td>
<td>97.90%</td>
<td>1.90%</td>
<td>97.48%</td>
</tr>
</tbody>
</table>
4.2.2. Reaction times

Repeated measures ANOVA were done to test if there is an effect of Condition on reaction time for the two languages of bilinguals (Fig. 19). Condition had a highly significant effect on reaction time \((F1 (2, 36) = 46.82, P < 0.001, MSE = 158.2)\). Descriptively there is a difference between the languages – reaction times are shorter in L2 in all experimental conditions –, but the effect of language is not significant \((F1 < 1)\). Condition and Language don’t interfere in their effect on reaction time \((F1 < 1)\). Reaction times for the L1 and L2 in the three experimental conditions can be found in Table 10.

Table 9. Reaction times [ms] (Mean, Standard deviation (SD)) are given for L1 and L2 of bilinguals in the three experimental conditions.

<table>
<thead>
<tr>
<th></th>
<th>Congruent</th>
<th>Incongruent</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN</td>
<td>SD</td>
<td>MEAN</td>
</tr>
<tr>
<td>L1</td>
<td>627,77</td>
<td>67,77</td>
<td>666,55</td>
</tr>
<tr>
<td>L2</td>
<td>618,78</td>
<td>63,59</td>
<td>653,71</td>
</tr>
</tbody>
</table>
Post-hoc analyses on the effect of respectively two Conditions on reaction time (repeated measures ANOVA) showed a highly significant Stroop Effect ($F_1 (1, 18) = 120.01, P < 0.001$), a significant effect of Facilitation ($F_1 (1, 18) = 10.53, P < 0.01$) and a highly significant effect of Cost ($F_1 (1, 18) = 32.81, P < 0.001$) (Fig. 19).

**Fig. 19 Reaction times [ms]** in total and in the three experimental conditions (congruent, incongruent, neutral) are plotted for the two languages of bilinguals. The Stroop Effect (RT\textsubscript{Incongruent} – RT\textsubscript{Congruent}), the effect of Facilitation (RT\textsubscript{Neutral} - RT\textsubscript{Congruent}) and the effect of Cost (RT\textsubscript{Incongruent} – RT\textsubscript{Neutral}) are marked in the graph.
The Stroop Effect (RT_{Incongruent} − RT_{Congruent}) is similar in L1 and L2 of bilinguals (Fig. 20), there is no significant effect of Language (t-Test: \( t (1, 18) = 0.57 \), \( P = 0.58 \)).

![Fig. 20 The Stroop Effect (RT_{Incongruent} − RT_{Congruent}) in L1 and L2 of bilinguals and the difference between the Stroop Effect in the two languages are shown.](image)

4.2.3. Switching cost

To examine the effects of Switching the corrected data for reaction times in the Switch and the Non-Switch situation were confronted (RT_{Switch} vs. RT_{Non-Switch}). In Fig. 21 the situation for the congruent condition and in Fig. 22 for the incongruent condition in the L1 and L2 of bilinguals are shown.

In the congruent condition (Fig. 21), reaction times were shorter in the Non-Switch (CNS) compared to the Switch (CS) situation in L1. In L2 RT were longer in CNS than in the CS. The effect of Switching (RT_{Switch} vs. RT_{Non-Switch}) was not significant (\( F1 < 1 \)) neither was there an effect of Language (\( F1 < 1 \)) or an interaction of Language and Switching (\( F1 < 1 \)). Post-hoc analyses did not show significant effects of Switching in neither language (respectively \( F1 < 1 \)).
Fig. 21 The Effect of Switching (RTswitch vs. RTnon-switch) in the congruent condition in L1 and L2 of bilinguals. CNS Congruent Non-Switch (Trials in the congruent condition that are preceded by two trials of the same, the congruent, condition. There is no switch between conditions.), CS Congruent Switch (Trials in the congruent condition that are preceded by two trials in the incongruent condition. There is a switch between conditions.).

In the incongruent condition (Fig. 22), reaction times were shorter in the Non-Switch (INS) compared to the Switch (IS) situation in L2. In L1 the reaction times in Non-Switch and Switch trials were quite similar but in the Non-Switch situation latencies were slightly longer. The effect of Switching (RT_{Switch} vs. RT_{Non-Switch}) was not significant ($F(1, 18) = 1.016, P = 0.327$). Post-hoc analyses did not show a significant effect of Switching neither in L1 nor in L2 (respectively $F(1, 18) < 1$) which means that there is no significant Switching cost\textsuperscript{12} in L1 or L2.

\textsuperscript{12} As already mentioned above - when showing the results for monolinguals and bilinguals in their L1 - in a strict sense it is not to be called Switching “cost” if RTs are shorter in the Switching situation than in the Non-Switch situation.
Fig. 22 The Effect of Switching ($RT_{\text{Switch}}$ vs. $RT_{\text{Non-Switch}}$) in the incongruent condition for L1 and L2 of bilinguals. **INS** Incongruent Non-Switch (Trials in the incongruent condition that are preceded by two trials of the same, the incongruent, condition. There is no switch between conditions.), **IS** Incongruent Switch (Trials in the incongruent condition that are preceded by two trials in the congruent condition. There is a switch between conditions.).

Comparing the Switching “cost” ($RT_{\text{Switch}} - RT_{\text{Non-Switch}}$) between the congruent and the incongruent condition within each language, no significant differences were detected for L1 or L2. Comparing respectively Congruent Switching cost and Incongruent Switching cost between the languages, differences were neither significant in the congruent nor in the incongruent condition. (Fig. 23)
4.2.4. Overpracticing Effect

There is a significant Overpracticing Effect on the RTs in the two languages ($F(1, 36) = 27,068, P < 0.001$) (Fig. 24). An effect of Language ($F(1) < 1$) and an interaction of Overpracticing and Language ($F(1, 36) = 13,114, P < 0.01$) were not significant. In Post-hoc analyses, the Overpracticing Effect on RT turned out to be of higher significance for L2 ($F(1, 18) = 12,664, P < 0.001$) than for L1 ($F(1, 18) = 6,524, P < 0.05$).

The RT difference between the first and the last block was highly significant ($F(1, 18) = 27,068, P < 0.001$). Between the first and the second block, the RT difference was also significant ($F(1, 18) = 8,387, P < 0.01$) as well as between the second and the third block ($F(1, 18) = 13,114, P < 0.01$).
Comparing the Stroop Effect in the three blocks of the two languages, there is an astonishing descriptive difference: in L1 the Stroop Effect decreases with the advance in the experiment while in L2 the Stroop Effect increases. (Fig. 25)

Examining via repeated measure ANOVA, the effect of Overpracticing on the Stroop Effect in the two languages was not significant ($F1 < 1$). An effect of Language was not significant ($F1 < 1$) but the interaction of Overpracticing and Language was significant ($F1 (2, 36) = 3.776, P < 0.05$). Post-hoc analyses showed, that in L1 the reduction of the Stroop Effect during the experiment was not significant ($F1 (2, 18) = 2.039, P = 0.163$). In L2, the increase of SE was also not significant ($F1 (2, 18) = 1.809, P = 0.202$).

There were no significant differences between the first and the third, between the first and the second or between the second and the third block.
4.2.5. Subgroups

Comparisons were done between high-proficient and low-proficient bilinguals, who were classified according to their performance in the language tests. An effect on RT or SE was not significant, neither was there a significant correlation between the percental performance in the language tests and RT or SE. L2 exposure in the last three years and current L2 exposure – indicated in the questionnaire - both did not have an effect on RT or SE.

In order to evaluate if there is an effect of musicality, sportiness and video/computer game playing, on the bilinguals’ two languages L1 and L2 subgroups formed according to the indications in the questionnaire (see Table 2 and Table 3). No main effects on RT or SE were found. Between the respective practicing times of these activities and RT or SE there were no significant correlations.
5. Discussion

5.1. Bilinguals vs. Monolinguals

5.1.1. Accuracy and Reaction times

Revoking the general predictions on accuracy and reaction time (Table 10) it is to be said, that both language groups showed high levels of accuracy in general and also in the three experimental conditions regarded separately. As there is no difference between the language groups, the idea of an ameliorating effect of bilingualism on accuracy is not supported by our data. As far as reaction time is concerned, bilinguals are in total slightly faster than monolinguals but the overall means don’t differ significantly between the language groups. The finding that reaction times are descriptively shorter in bilinguals than in monolinguals is consistent with previous studies on inhibitory control in executive functions (Simon task) in which bilinguals showed shorter reaction times than monolinguals (Bialystok et al., 2005) and gives support to the IC and BIA+ models which both predict better inhibitory control in bilinguals compared to monolinguals.

On the other hand, the lack of statistical significance of the difference between the language groups may be consistent with findings in other experiments using a manual task: Finding no difference might possibly be caused by a ceiling effect for manual tasks as the young adult age group is normally highly skilled in computer use. (Bialystok et al., 2005) On the contrary, Badzakova-Trajkov (2008) has found longer reaction times in late proficient bilinguals than in monolinguals in a manual version of the Stroop task. Testing further participants will allow clearer argumentation in favour or against the predictions of the IC and the BIA+ model.

<table>
<thead>
<tr>
<th>Reaction time (RT) [ms]</th>
<th>RT\textsubscript{Bilingual}</th>
<th>&lt;</th>
<th>RT\textsubscript{Monolingual}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy [%]</td>
<td>Errors\textsubscript{Bilingual}</td>
<td>&lt;</td>
<td>Errors\textsubscript{Monolingual}</td>
</tr>
<tr>
<td></td>
<td>(Accuracy\textsubscript{Bilingual}</td>
<td>&gt;</td>
<td>Accuracy\textsubscript{Monolingual}</td>
</tr>
</tbody>
</table>
Analysing the effect of experimental condition on reaction time, there is a highly significant effect of condition in both language groups, but no effect of language group. The predicted pattern of longest reaction times in the incongruent condition and shortest reaction times in the congruent condition with reaction times in the neutral condition lying in-between turned out to be the case in late bilinguals as well as in monolinguals. (Fig. 27)

Post-hoc analyses on respectively two experimental conditions also showed significant effects. On the one hand, both language groups showed an effect of Cost, which means that reaction times were longer in the incongruent condition compared to the neutral condition. In the incongruent condition, the execution of the colour naming task thus suffers from the interference from the competing information of the non-identical colour-word which is not the case in the neutral condition. On the other hand, there is an effect of Facilitation to be found in both language groups. The Facilitation effect can be explained in terms of a contribution of the identical meaning of the written colour word to even faster naming of the print colour compared to the neutral condition. (Badzakova-Trajkov, 2008)

The crucial analysis in order to get information on the capacity of inhibitory control is the examination of the effect of language group on the difference between the congruent and the incongruent experimental conditions, the Stroop Effect. A reduced Stroop interference was expected for bilinguals than for monolinguals:

\[ \text{SE}_{\text{Bilingual}} < \text{SE}_{\text{Monolingual}} \]

As there is a strong hypothesis on the difference of the Stroop Effect in the two language groups, post-hoc analyses was done. A one-way ANOVA and a \(t\)-Test were done on the
difference between the reaction times in the congruent and the incongruent condition. Descriptively, there is a reduced Stroop interference in bilinguals in comparison to monolinguals but this difference is not significant. This finding is consistent with previous results. Badzakova-Trajkov (2008) found a reduced Stroop interference in late bilinguals (L2 environment) compared to monolinguals, but the difference was not significant. She claimed that twice as many participants (11 bilinguals and 13 monolinguals had been tested) would need to be tested to get more stable results and probably statistical significance of the interference score (beside simple comparison of reaction time difference, in this study also an interference score (“Interference Score =100 (Incongruent RT-ControlRT)/ Control RT”) was used). (Badzakova-Trajkov, 2008) Moreover, the descriptively lower Stroop Effect in bilinguals than in monolinguals is consistent with previous studies finding significant differences between the language groups in tasks on executive function (Bialystok et al., 2005; Bialystok and De Pape, 2009) and allows to claim slight support for the IC and BIA+ models, both postulating better cognitive control in bilinguals. Further participants will be tested in order to allow clearer argumentation if there is support for the IC and BIA+ models.

5.1.2. Switching cost

The two predictions on switching were the general effect of Switching on reaction time with longer reaction times in Switch compared to Non-Switch trials for respectively the congruent and the incongruent condition, for both language groups:

\[
\text{RT}_{\text{Non-Switch}} < \text{RT}_{\text{Switch}}
\]

Secondly, the language groups were predicted to differ in Switching cost which is the reaction time difference between Switch and Non-Switch trials. Bilinguals were supposed to suffer less from switching than monolinguals, thus to show reduced switching cost in general and more symmetrical switching cost when switching to either a trial in the congruent condition or a trial in the incongruent condition with the former switching direction being supposed to be more costly than the latter:

\[
\text{Switching cost}_{\text{Bilingual}} < \text{Switching cost}_{\text{Monolingual}}
\]

In the present study, we found a reduced and more symmetrical switching cost between the congruent and incongruent condition in bilinguals compared to monolinguals. On the other
hand, switching cost in the congruent condition in monolinguals is strongly due to faster reaction times in the Congruent Non-Switch condition. An explanation for this point remains unclear and is also unlikely to be caused by generally slower response to linguistic stimuli in bilinguals, as proposed by some authors (discussed by Badzakova-Trajkov, 2008), because RTs in the present results were in general faster with bilinguals.

The finding of a more symmetrical switching cost together with the descriptively reduced Stroop interference supports the idea of better cognitive control in bilinguals. Better inhibitory control can be interpreted in this present case as more rapid and flexible adaptation of inhibition according to the task (i.e. responding to a trial in the congruent respectively incongruent condition). Our findings of a reduced and more symmetrical Switching cost in bilinguals goes conform with the findings of Costa in a study using the ANT task. In this study, bilinguals showed more symmetrical switching costs, thus were interpreted to suffer less from changes in task requirements which can be explained in terms of higher flexibility in task switching. (Costa, 2008) This greater ease in performing the task is supposed to be caused by the bilinguals’ training in managing the use of more than one language in everyday life, which has been observed to have an impact on cognitive control by several authors. (Bialystok et al., 2005; Badzakova-Trajkov, 2008; Costa, 2008)

Concerning the direction of switching – incongruent to congruent or congruent to incongruent – in the present study, descriptively, a higher switching cost in the congruent condition in comparison to the incongruent condition was detected for monolinguals and to a limited extent also in bilinguals (Fig. 15). However, these differences were not significant.

„Switching cost“ in switching between trials in the congruent and incongruent experimental condition were found to be more symmetrical with high proficient bilinguals in comparison to low proficient bilinguals and monolinguals, i.e. in the ANT task. (Costa et al., 2008) In low proficient bilinguals and monolinguals an asymmetrical pattern of switching cost was observed, showing smaller cost for the switch from a succession of congruent trials to an incongruent one than for the inverse direction, the switch from the a succession of trials in the incongruent condition to a congruent trial. As an explanation for the larger switching cost when switching to the easier, the congruent condition, Costa et al. (2008) suppose that removing strong inhibition plays the crucial role. Inhibition of the competing information is
necessary in the preceding, the incongruent trial, but is released in the congruent condition. If the residual inhibition remaining from the precedent task actually played a role in switching, it would explain asymmetrical switching cost as higher residues would need to be removed when switching from a difficult task where strong inhibition had been applied, to a task requiring the more dominant response and therefore requiring less inhibition (Costa et al., 2008; review by Monsell, 2003 and by Koch et al., 2010) A similar phenomenon is observed in language switching from L1 to L2 respectively from L2 to L1 with the latter switch, the switch to the more dominant language, thus from the more difficult towards the “easier” task, causing higher switching costs for unbalanced subjects. (Costa et al., 2008) Koch et al. (2010) argue that in studies examining inhibitory control in switching tasks quite different results have been found. Also Monsell (2003) claims, that there is controversy on this issue. Therefore, it may be that switching cost asymmetries are not exclusively due to inhibitory control processes. Further research is needed to get a clearer idea on the role of inhibition in switching cost asymmetries.

Our findings support the idea that the removal of strong inhibition in switching from a more difficult to a simpler task is more costly than the application of strong inhibition when switching to a more difficult task. Additionally, this difference was less pronounced in bilinguals which may be due to a bilingual advantage especially in a more demanding task: “In other words, the more demanding the switching task is, the more pronounced the effect of bilingualism.” (Costa et al., 2008) These results are conform with the observations on switching cost described by some authors on different tasks testing cognitive control, among which the Stroop task, the ANT task, etc. (Costa, 2008; Monsell, 2003; Allport, 1994) On the other hand, an important question remains the faster reaction time of bilinguals in the Congruent Non-Switch situation, but the planned continuation of the study with further participants may help to get a clearer idea and more stable results also on this point.

In the study of Costa et al. (2008) no indications are given on the design of experimental lists in order to study switching cost whereas in Christoffels et al. (2007) trials were explicitly arranged in order to create switch and non-switch trials. This difference in planning is probably due to the difference in methodology with Costa et al. working behaviourally and Christoffels et al. working with EEG in the cited studies. In future studies examining the
effect of Switching, trials should be arranged in a pseudo-randomized order that explicitly creates switch and non-switch situations so as to get a larger and more balanced number of data.

5.1.3. Overpracticing Effect
An Overpracticing Effect was found for RT, as predicted:

\[ RT_{\text{First block}} > RT_{\text{Last block}} \]

The reduction in RT was significant between the first and the third and between the first and the second block. Thus, the Overpracticing effect on RT manifests rather in the beginning of the experiment. There was no effect of language group. A Post-hoc analysis showed that Overpracticing was only significant in bilinguals but not in monolinguals. The RTs in the first block very similar but in the second and the third block bilinguals were descriptively faster. Costa et al. (2008) proposed that an Overpracticing effect would rather be the case in monolinguals, expected to already depart with slower RTs in the first block and that bilinguals would accelerate less due to a ceiling effect. The present results rather show that the bilingual acceleration was not limited by a ceiling effect. The present results may also be due to a bilingual advantage in inhibitory control that manifests even more with additionnal training in the specific task with the advance of the experiment.

An Overpracticing effect was also significant for the Stroop Effect:

\[ SE_{\text{First block}} > SE_{\text{Last block}} \]

The difference between the first and the last and between the second and the third block were significant but there was no effect of Language group and Post-hoc analyses did not show significant effects for either language group. Therefore, in both language groups the colour-naming task and inhibiting competing information seem to be trained to a certain degree with the advance of the experiment.

5.1.4. Subgroups
In order to see if there are actually effects of musicality, sportiness or playing video/computer games, further participants would have to be tested to get higher statistical stability.
5.2. Bilinguals L1 vs. L2

5.2.1. Accuracy and Reaction times

Bilinguals had been predicted to show shorter reaction times in L2 than in L1 due to a higher impact of cognitive control on the less activated language, L2:

\[
RTL_{2 \text{Bilingual}} < RTL_{1 \text{Bilingual}}
\]

Bilinguals are descriptively faster in their L2 than in their L1, but this difference is not significant. This descriptive difference gives slight support to the idea of a higher impact of cognitive control on L2, the less activated language with slower lexical access. This idea is crucial in the BIA+ model. (Dijkstra and Van Heuven, 2002)

Higher impact of cognitive control on the less activated language was also predicted to cause differences in the Stroop Effect:

\[
SEL_{2 \text{Bilingual}} < SEL_{1 \text{Bilingual}}
\]

Contrary to the prediction, the Stroop Effect has been found similar in L1 and L2. This quite similar performance of bilinguals in their both languages indicates that the impact of cognitive control is similar in L1 and L2 even though the languages are expected to have different levels of activation. Therefore, in this finding there is no support for the BIA+ model. (Dijkstra and Van Heuven, 2002)

The present results show slightly faster reaction times in L2 compared to L1, but the difference is not significant. This finding allows slight support for the BIA+ model, according to which cognitive control had been predicted to have higher impact on the less activated language, L2. Similar to the present results, Badzakova-Trajkov (2008) has found no significant difference between the RTs in L1 and L2 in late bilinguals living in an L2 environment. If the work in the present study is continued with testing further late bilinguals living in an L1 environment in order to get higher statistical stability, there are two possibilities how the results may turn out. On the one hand, inhibitory control might have equal impact on the two languages and not lead to significant results if further bilinguals are
tested. On the other hand, as Badzakova-Trajkov (2008) claims, that language environment is likely to be relevant for questions on levels of activation. The late bilinguals in Badzakova-Trajkov’s (2008) study were living in an L2 environment whereas in the present study they were living in an L1 environment and possibly have lower L2 activation levels than those living in the L2 environment. Therefore, a significant difference between L1 and L2 might come up when testing is continued with more subjects living in the L1 environment and statistical results become more stable.

5.2.2. Switching cost
RTs were expected to be shorter in the Non-Switch situation compared to the Switch situation (Effect of Switching) in the congruent as well as the incongruent condition:

\[ RT_{\text{Non-Switch}} < RT_{\text{Switch}} \]

No significant effect of Switching was found neither in the congruent nor in the incongruent condition. Therefore, responding to stimuli from either the same or from a different experimental condition does not have an effect for bilinguals.

\[ \text{Switching cost}_{\text{L2}} < \text{Switching cost}_{\text{L1}} \]

The prediction, that Switching cost might be lower in L2 than in L1 due to its lower activation is not supported by the results. The observation, that there is no significant effect of Switching, has been found for both languages of bilinguals. Switching does not cause a cost for bilinguals neither in L1 nor in L2. This finding is also consistent with previous results. Christoffels et al. (2007), also referring to the IC model, worked on bilingual language control and did not find asymmetrical switching cost between the two languages.

5.2.3. Overpracticing Effect
A highly significant Overpracticing effect has been found for L1 and L2:

\[ RT_{\text{First block}} > RT_{\text{Last block}} \]

The Overpracticing effect was also significant in all single block comparisons (between the first and the third, between the first and the second as well as between the second and the third block). There was no effect of language but Post-hoc analyses showed that Overpracticing
was significant in the RTs of both languages, L1 and L2. The effect was of even higher significance for RTs in L2 even if already starting with shorter reaction times in the first block. This observation is inconsistent with the idea, that faster initial RTs would permit less acceleration due to a ceiling effect, claimed by Costa et al. (2008). Possibly, further training of inhibitory control is easier in the less activated language, L2.

Comparing the development of the SE in the course of the experiment, a crucial difference between the two languages was found. In L1 the SE reduced over the three blocks while in L2 the SE increased:

\[
\text{L1: } \text{SE}_{\text{First block}} > \text{SE}_{\text{Last block}} \\
\text{L2: } \text{SE}_{\text{First block}} < \text{SE}_{\text{Last block}}
\]

There was no significant “Overpracticing effect” for the SE in general, obviously due to these two contrary developments. The effect of Language was not significant while the interaction between Overpracticing and Language was. A Post-hoc analysis did not show significance in the SE developments neither in L1 nor in L2. But at least on the descriptive level, in L1 there can be found the pattern of reducing SE with the course of the experiment, an “Overpracticing effect”, while in L2 the increasing SE might be i.e. an effect of fatigue.

5.2.4. Subgroups
In order to see if there are actually effects of musicality, sportiness or playing video/computer games, further participants would have to be tested to get higher statistical stability. This is equally the case for the examination of an effect of L2 proficiency and L2 exposure.

5.3. General Discussion

Bilinguals are expected to have less difficulty in a Stroop task, thus to show in general shorter response latencies and especially to suffer less from the conflict in the incongruent condition, which is usually quantified via the difference between the RT in the congruent and incongruent condition (Stroop Effect), in comparison to monolinguals. This expectancy is due to the supposed training in inhibiting competing but currently non-target knowledge and
information in bilinguals, a capacity necessary in bilingual (or multilingual) language control, especially in language switching. This training effect is expected to influence the performance in other, not language-bound activities, as well. Evidence supporting this theory has been found in several studies (Bialystok et al., 2005; Badzakova-Trajkov, 2008; Costa et al., 2008; Green, 1998). As a model explaining the relation of a training effect of bilingual language control also on non-linguistic tasks, the BIA+ model (Chapter 1.2.4.1) (Dijkstra and Van Heuven, 2002) and the IC model (Chapter 1.2.4.2) (Green, 1998) were presented in the Introduction. In the present study late bilinguals (of high and low proficiency in the L2) and monolinguals were tested on a manual version of the Stroop task and even if in literature early bilinguals (L2 AoA < 6 years) showed better performance than late bilinguals (L2 AoA > 10 years) in tasks on inhibitory control (Bialystok et al., 2005; Badzakova-Trajkov, 2008), better performance in the Stroop task was expected in late bilinguals in comparison to monolinguals due to the influence of a training effect of their multiple language use.

Even if in the present study the differences between late bilinguals and monolinguals were not pronounced, a tendency of better capacity to inhibit interferences from non-target elements on the execution of target functions (better inhibitory control in executive functions) can be observed even if the subjects are late bilinguals living in an L1 environment. The results support the IC model by Green (1998) postulating the existence of more than one level of cognitive control among which there is at least one level of control that plays a role in the management of linguistic as well as non-linguistic functions. The results are consistent with findings in other studies on late bilinguals (Badzakova-Trajkov, 2008) but testing further participants will bring more statistical stability.

Neuronal maturation seemingly determines the increasing difficulty to acquire a language at high proficiency but neuronal plasticity appears to remain at a high level and thus also permits modifications and training effects when L2 is acquired only from approximately the age of 10 years on. Thus, the idea that there is a “sensitive period” for language acquisition but not an exclusive “critical period” is supported by the present results.

This study also constitutes a preparatory work for the neurophysiological part of the project on bilingualism and executive functions. EEG will be done with participants fulfilling the same criteria as in this behavioural study. To some questions, an ERP study is likely to give additional, clearer answers. Due to good temporal resolution in EEG, changes in activity can
be precisely detected. Green (1998) argues that different cerebral regions are expected to show activity corresponding to the different levels of control in his Inhibitory Control model, if his distinctions were correct. According to some previous neuro-imaging studies, for conflict resolution in tasks implying inhibitory control in executive function, such as the Stroop or the Simon task, activity in a wide neural network was detected but in the ACC and left PFC activity was most increased. (Badzakova-Trajkov, 2008; Bruchmann et al., 2010) These areas are also involved in bilingual language control and bilingual advantage (suffering less from interference of conflicting information) has been found in behavioural examination. Therefore, the idea to localize inhibitory control necessary in bilingual language control on a level, that is not specific to the language domain, as it is the case in Green’s (1998) IC model, is supported by findings in several behavioural, neurophysiological and neuro-imaging studies. (Bialystok et al., 2005; Badzakova-Trajkov, 2008; Costa et al., 2008; Dijkstra et al., 2005, Isel et al., 2010) Also the use of different imaging techniques, like fMRI or PET, which also take into account subcortical activity would be of interest.

Also the BIA+ model (Dijkstra and Van Heuven, 2002; Brysbaert and Dijkstra, 2006) contains a distinct level of control, the “Task schema” level. This level of control manages - among other functions - language selection via language nodes. Language nodes mark, which language an element or structure belongs to. The inclusion of this separate, attention-sensitive, level of “Task schemas” and the reduction of language nodes to simple language marks without control function is inspired by and indeed very similar to their respective role in the IC model by Green (1998) where there are also “Task schemas” and language tags, which have the same function as language nodes. This modification of the language control mechanism from the one found in the BIA model - the predecessor model to BIA+ - in which language selection and inhibition is a language-immanent, local process of lateral inhibition towards the language control mechanism in the BIA+ model, where it is localized on a superior level, underlines the relevance of findings in studies on bilingualism supporting the idea that the language selection and switching process is a more central control process and not to be localized on the same level as any other lexical decision. (Bialystok et al., 2005; Brysbaert and Dijkstra, 2006; Isel et al., 2010)

One point to possibly consider in future research is proficiency assessment in L2 of bilinguals. What has been developed by Marysia Johnson (2000) for oral language competence/performance may equally be valid for the evaluation of written proficiency (or
proficiency regarded globally, in oral and written aspects). Johnson examines the validity of the Oral Proficiency Interview (OPI) in its role to account for speech proficiency of second language learners. She concludes from her results that this test reflects the participant’s actual oral proficiency in real-life communication only insufficiently. Thus, it is important always to be aware of what a proficiency test actually is assessing and to be careful when generalizing from the test results to overall proficiency (Johnson, 2000). Going further in her examination of second language proficiency evaluation, Johnson pleads for a focus shift from the evaluation of language competence (the capacity to pass a language exam; individual aspect) towards the evaluation of language performance (the use of language competence in real-life situations; social aspect) respectively tries to get over the strong distinction between these two implementations of language proficiency and supports interaction between the individual and the social domain of proficiency. (Johnson, 2004, p. 170-189)

Given the usually already exhausting experimental procedure, including even further tests in order to evaluate proficiency is often not possible as it would too much toll on the participants. But as far as the experimental procedure allows more differentiated proficiency testing and if it is a crucial research question to test the impact of proficiency (to form subgroups according to proficiency, etc.), future research should, on the one hand, evaluate proficiency as globally as possible (oral, written, competence, performance, etc.). On the other hand, one should consider well which kind of test to take for the evaluation of proficiency in order to have a well adapted evaluation method for the participants’ actual language use. As an example, having terminated language courses several years ago and rather using L2 in daily communication might lead to a shift from language competence towards language performance – manifested in decreased proficiency according to tests of rather scholar character, which are testing linguistic competence, while improved performance can be found in real-life conversation - which should be taken into account as far as possible.

As described above, additional factors such as musical practice, sportiness or video/computer games playing have been inquired in the questionnaire. Especially concerning the ameliorating effect of musical practice on cognitive control in executive functions there have already been done some studies of which the findings support this idea (Bialystok and DePape, 2009; Neville, 2009). Given the high number of subjects among our tested
participants who do practice an instrument or sing in their leisure time, we will also focus particularly on this factor in the selection of participants in the continuation of the study.

6. Conclusion

In conclusion, the finding in the present study that bilinguals show descriptively shorter reaction times and a descriptively smaller Stroop Effect to a certain degree supports the hypothesis of bilingual advantage in inhibitory control in executive functions. This had been predicted according to the IC model by Green (1998) and similarly according to the BIA+ model by Dijkstra and Van Heuven (2002). Summing up, there is slight support for the hypothesis of bilingual advantage in inhibitory control in executive functions because of their training in managing the use of their two languages which needs permanent selection and inhibition. This process of inhibitory control is likely to take place at an attention-sensitive level that is not exclusively implicated in control processes in the linguistic domain but also in the control of non-linguistic functions.

Moreover, the comparison of bilinguals in their two languages in the Stroop task showed descriptively shorter reaction times in the L2 than in the L1 which supports the idea of a higher impact of cognitive control on the less activated language, predicted according to the BIA+ model. On the contrary, the Stroop Effect was very similar in the two languages, which contradicts this prediction. Due to a lack of statistical significance of differences, further behavioural as well as neurophysiological and neuro-imaging examination is necessary for arguing in favor or contra a cognitive advantage of bilingualism and to give a clearer statement on the impact of cognitive control on the two languages of bilinguals.
7. References


Read, C., Zhang, Y.-F., Nie, H.-Y., Ding, B.-Q. (1986). The ability to manipulate speech sounds depends on knowing alphabetic writing, *Cognition* 24, (1-2), 31-44.


Appendix

A.1. Questionnaire for Monolinguals\textsuperscript{13}

QUESTIONNAIRE

Date : .................................................................

Nom : ................................................................. Code-Sujet : ..............................

Date de naissance : ................................................

Sexe : .................................................................

Adresse : .............................................................

E-mail : .................................................................

Numéro de téléphone : .................................................

Diplôme de fin d’études : ...........................................

Etudes & discipline : .................................................

Activité actuelle : ...................................................

\textsuperscript{13} Adaptation of the questionnaire used by Isel et al. (2010)
Préférence manuelle? (Edinburgh Handedness Inventory. Translated in French)

<table>
<thead>
<tr>
<th></th>
<th>GAUCHE</th>
<th>DROITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ecrire</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Dessiner</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Lancer</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Ciseaux</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Brosse à dents</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Couteau (sans fourchette)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Cuillère</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Balai (main supérieure)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Raquette de tennis</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ouvrir une boîte (bouchon)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.Q.</th>
<th>%</th>
</tr>
</thead>
</table>

*Note.* L.Q. refers to lateralisation quotient.

Déficience de la perception de couleurs ? (p.ex. Daltonisme)  Oui □ Non □
Si oui, lesquelles?

Avez-vous des problèmes d’audition ?  Oui □ Non □
Si oui, entendez-vous mal de l’oreille gauche ?  Oui □ Non □
Si oui, entendez-vous mal de l’oreille droite?  Oui □ Non □
Portez-vous un appareil auditif ?  Oui □ Non □

Avez/ Aviez-vous des problèmes de lecture et d’écriture ?  Oui □ Non □

Aviez-vous des difficultés d’acquisition du langage dans l’enfance?  Oui □ Non □
Si oui, lesquelles?

Avez/ Aviez-vous des difficultés avec la parole ? (p. ex. bégaiement)  Oui □ Non □
Si oui, lesquelles?

Souffrez-vous/Avez-vous souffert d’une maladie neurologique ou psychiatrique ?
□

Si oui, laquelle?

114
Questions concernant la biographie (linguistique)

Lieu de naissance :  _________________________________________________________
Langue(s) maternelle(s) :  __________________________________________________
Langue(s) (maternelle(s)) de la mère :  ________________________________________
Langue(s) (maternelle(s)) du père :  __________________________________________
Langue(s) (maternelle(s)) des frères et sœurs :  
_____________________________________________________________________
Langue(s) (maternelle(s)) des grands-parents :  _______________________________
Contact avec personnes parlant une autre langue que le français pendant l’enfance ?  
________________________________________________________________________
_________________________________________________________________________
Où avez-vous grandi ?  
________________________________________________________
Où étiez-vous scolarisé ?  
________________________________________________________
Déménagements ?  
________________________________________________________________________
_________________________________________________________________________
Allez-vous régulièrement en voyage à l’étranger ?  Oui □  Non □
Si oui, dans quel(s) pays et quelle(s) langue(s) est/sont parlée(s) dans ce(s) pays ?  
________________________________________________________________________
Langue(s) (maternelle(s)) de la/ du partenaire :  ____________________________
Langue(s) maternelle(s) des enfants :  ________________________________________
Quelles langues étrangères apprises ? A partir de quel âge ? Etudiée(s) pendant combien d’années ? Auto-évaluation ?

1.  
2.  
3.  
4. Auto-évaluation du niveau de langues étrangères (1 = très bonnes connaissances, 2 = plutôt bonnes, 3 = moyen, 4 = plutôt peu, 5 = très peu de connaissances)

<table>
<thead>
<tr>
<th>Langue</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Utilisation de langues étrangères au cours des trois dernières années (si oui, dans quels cadres (i.e. famille, amis, profession, médias, etc.) et respectivement dans quelle mesure (combien d’heures estimées par semaine)) ? ________________________________________________
___________________________________________________________________________
___________________________________________________________________________

Utilisation actuelle de langues étrangères (si oui, dans quels cadres (i.e. famille, amis, profession, médias, etc.) et respectivement dans quelle mesure (combien d’heures estimées par semaine)) ? ________________________________________________
___________________________________________________________________________
___________________________________________________________________________

Dans quelle langue rêvez-vous ? ________________________________________________

Jouez-vous aux jeux vidéo / aux jeux sur ordinateur (i.e. Nintendo DS, etc.) ? Oui □  Non □
Si oui, lesquels et combien d’heures estimées par semaine ? _________________________
___________________________________________________________________________

Faites-vous régulièrement du sport ?  Oui □  Non □
Si oui, quel(s) type(s) de sport et respectivement combien d’heures estimées par semaine ?
___________________________________________________________________________

Êtes-vous musicien ?    Oui □  Non □
Si oui, quel(s) instrument(s) ?        _______________________________________________

Merci beaucoup pour votre participation !
A.2. Questionnaire for Bilinguals\textsuperscript{14}

FRAGEBOGEN

Age of Acquisition of L2: \hspace*{1cm} Early \hspace*{1cm} Late

Datum: .........................................................

Name: .......................................................... \hspace*{1cm} VP-Code: ........................................

Geburtsdatum: ..................................................

Geschlecht: ....................................................

Adresse: ....................................................... 

E-mail: ........................................................

Telefonnummer: ..............................................

Schulabschluss: ............................................. 

Studium & Studienfach: ....................................

Jetzige Tätigkeit: ..............................................

\textsuperscript{14} Adaptation of the questionnaire used by Isel et al. (2010)
Händigkeit? *(Edinburgh Handedness Inventory.* Translated in German)

<table>
<thead>
<tr>
<th>LINKS</th>
<th>RECHTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mit welcher Hand wird geschrieben?</td>
<td></td>
</tr>
<tr>
<td>2 Mit welcher Hand wird gezeichnet?</td>
<td></td>
</tr>
<tr>
<td>3 Welche Hand wird zum Werfen benutzt?</td>
<td></td>
</tr>
<tr>
<td>4 Mit welcher Hand wird eine Schere benutzt?</td>
<td></td>
</tr>
<tr>
<td>5 Mit welcher Hand werden die Zähne geputzt?</td>
<td></td>
</tr>
<tr>
<td>6 Mit welcher Hand wird ein Messer ohne Gabel benutzt?</td>
<td></td>
</tr>
<tr>
<td>7 Mit welcher Hand wird ein Löffel benutzt?</td>
<td></td>
</tr>
<tr>
<td>8 Mit welcher Hand (obere Hand) wird ein Besen verwendet?</td>
<td></td>
</tr>
<tr>
<td>9 In welcher Hand wird ein Tennis-Schläger gehalten?</td>
<td></td>
</tr>
<tr>
<td>10 Mit welcher Hand wird der Deckel einer Dose geöffnet?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.Q.</th>
<th>%</th>
</tr>
</thead>
</table>

*Note.* L.Q. refers to lateralisation quotient.

Haben Sie Probleme mit dem Farbensehen? (*zB. Rot-Grün-Sehschwäche*) Ja □ Nein □
Wenn ja, welche?

Haben Sie Hörprobleme? Ja □ Nein □
Wenn ja, hören Sie schlecht mit dem linken Ohr? Ja □ Nein □
Wenn ja, hören Sie schlecht mit dem rechten Ohr? Ja □ Nein □
Tragen Sie ein Hörgerät? Ja □ Nein □
Haben (Hatten) Sie eine Lese-Rechtschreib-Schwäche Ja □ Nein □
Hatten Sie als Kind Schwierigkeiten mit dem Spracherwerb? Ja □ Nein □
Wenn ja, welche?

Haben/Hatten Sie Schwierigkeiten mit dem flüssigen Sprechen *(Poltern/Stottern)*? Ja □ Nein □
Wenn ja, welcher Art?

Leiden/Litten Sie an einer neurologischen oder psychiatrischen Krankheit? Ja □ Nein □
Wenn ja, welche?
Fragen zur (Sprach-)Biografie

Geburtsort: _______________________________________________________________
Muttersprache(n): _______________________________________________________

(Mutter)sprache(n) der Mutter: ____________________________________________
(Mutter)Sprache(n) des Vaters: ____________________________________________
(Mutter)Sprache(n) der Geschwister: _______________________________________
(Mutter)Sprache(n) der Großeltern: _________________________________________

Andere Kontaktpersonen in der Kindheit? Sprachen der Kontaktpersonen?
__________________________________________________________________________
___________________________________________________________________________

Wo sind Sie aufgewachsen?
_________________________________________________________________________

Wo wurden Sie eingeschult?
_________________________________________________________________________

Umzüge?
_________________________________________________________________________
_________________________________________________________________________

Reisen Sie regelmässig ins Ausland?       Ja □    Nein □
Wenn ja, in welches Land/welche Länder und welche Sprache(n) wird/werden dort
gesprochen? ________________________________
_________________________________________________________________________

Muttersprache des (Ehe)Partners: __________________________________________
Muttersprache der Kinder: ________________________________________________
Welche Fremdsprachen? Wann angefangen? Wie lange gelernt? Selbsteinschätzung?

1.
2.
3.
4. Selbsteinschätzung der Sprachkenntnisse von Fremdsprachen (1 = sehr gute Kenntnisse, 2 = eher gut, 3 = mittel, 4 = eher weniger, 5 = fast keine Kenntnisse)

<table>
<thead>
<tr>
<th>Sprache</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
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</table>

Verwendung von Fremdsprachen (ausgenommen Deutsch) in den letzten drei Jahren (Falls ja, in welchem Rahmen (zB.: Familie, Freunde, Beruf, Freizeit, Medien, etc.) und wieviele Stunden jeweils, geschätzt, pro Woche)?

___________________________________________________________________________
___________________________________________________________________________

Aktuelle Verwendung von Fremdsprachen (ausgenommen Deutsch) (Falls ja, in welchem Rahmen (zB.: Familie, Freunde, Beruf, Freizeit, Medien, etc.) und wieviele Stunden jeweils, geschätzt, pro Woche)?

___________________________________________________________________________
___________________________________________________________________________

In welcher Sprache träumen Sie?

___________________________________________________________________________

Spielen Sie Computer- oder Videospiele (zB. Nintendo DS, etc.)?

Ja □  Nein □

Wenn ja, welche und wieviele Stunden, geschätzt, pro Woche?

___________________________________________________________________________

Betreiben Sie regelmässig Sport?

Ja □  Nein □

Wenn ja, welche Sportart(en) und wieviele Stunden jeweils, geschätzt, pro Woche?

___________________________________________________________________________

Sind Sie Musiker/in?

Ja □  Nein □

Wenn ja, welche(s) Instrument(e):

___________________________________________________________________________
Deutsch

Wo gelernt? _______________________________________________________________

Ab welchem Alter gelernt? __________________________________________________

Hauptsächliche Art des Input (Unterricht/natürlicher Input):

Wie viel Input 0 – 3 Jahre? Art? ____________________________________________
Wie viel Input 4 – 6 Jahre? Art? ____________________________________________
Wie viel Input 6 – 10 Jahre? Art? ____________________________________________
Wie viel Input 11 – 14 Jahre? Art? ___________________________________________
Wie viel Input 15 – 17 Jahre? Art? ___________________________________________
Wie viel Input 18 – heute? Art? ____________________________________________

Wieviele Jahre Unterricht insgesamt? ______________________________________

Verwendung des Deutschen in den drei vergangenen Jahren (in welchem Rahmen, in
welchem Ausmaß (geschätzte Stunden pro Woche)) ? ____________________________

Aktuelle Verwendung des Deutschen
(geschätzte % pro Tag; 1Stunde am Tag = ca. 6.25% wenn Tag = 16 Stunden):

Familie: _______________________________________________________________
Lebenspartner: _________________________________________________________
Freunde: _______________________________________________________________
Unterricht/Schule: _______________________________________________________
Universität: _____________________________________________________________
Beruf: _________________________________________________________________
Lektüre: ________________________________________________________________
andere Medien (TV, Radio usw.): _________________________________________
Französisch

Wo gelernt? _______________________________________________________________
Ab welchem Alter gelernt? ___________________________________________________

Hauptsächliche Art des Input (Unterricht/natürlicher Input):
___________________________________________________________________________

Wie viel Input 0 – 3 Jahre? Art?_______________________________________________
Wie viel Input 4 – 6 Jahre? Art?_______________________________________________
Wie viel Input 6 – 10 Jahre? Art?_______________________________________________
Wie viel Input 11 – 14 Jahre? Art?_______________________________________________
Wie viel Input 15 – 17 Jahre? Art?_______________________________________________
Wie viel Input 18 – heute? Art?_______________________________________________

Wieviele Jahre Unterricht insgesamt? ________________________________________

Aktuelle Verwendung des Französischen
(geschätzte % pro Tag; 1Stunde am Tag = ca. 6.25% wenn Tag = 16 Stunden):
Familie: _______________________________________________________________
Lebenspartner:_________________________________________________________
Freunde: _______________________________________________________________
Unterricht/Schule: _________________________________________________________
Universität: _______________________________________________________________
Beruf: _______________________________________________________________
Lektüre: _______________________________________________________________
andere Medien (TV, Radio usw.):_____________________________________________

Welche Sprache bevorzugen Sie?  Deutsch □  Französisch □

Vielen Dank für Ihre Mitarbeit!
A.3. Auto-evaluation of the competence in L2 German\textsuperscript{15}

Selbst-Evaluation Sprache

Proband (Name, Vorname) ..................................................................

Geburtsdatum ...................................................................


Die Skala reicht von 1 = sehr gute Kenntnisse bis 5 = fast keine Kenntnisse

Bitte schätzen Sie sich in folgenden Kategorien ein:

• hören (mündliches Verständnis)
• sprechen
• lesen (Leseverständnis)
• schreiben

und kreuzen Sie die für Sie richtige Antwort an.

\textsuperscript{15} Questionnaire used by Isel et al. (2006).
Proband (Name, Vorname) .................................................................
Geburtsdatum .................................................................................

1. Hören (mündliches Verständnis)

<table>
<thead>
<tr>
<th>1 sehr gute Kenntnisse</th>
<th>2 eher gut</th>
<th>3 mittel</th>
<th>4 eher weniger</th>
<th>5 fast keine Kenntnisse</th>
</tr>
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<tbody>
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2. Sprechen

<table>
<thead>
<tr>
<th>1 sehr gute Kenntnisse</th>
<th>2 eher gut</th>
<th>3 mittel</th>
<th>4 eher weniger</th>
<th>5 fast keine Kenntnisse</th>
</tr>
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</table>

3. Lesen (Leseverständnis)

<table>
<thead>
<tr>
<th>1 sehr gute Kenntnisse</th>
<th>2 eher gut</th>
<th>3 mittel</th>
<th>4 eher weniger</th>
<th>5 fast keine Kenntnisse</th>
</tr>
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<tbody>
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</table>

4. Schreiben

<table>
<thead>
<tr>
<th>1 sehr gute Kenntnisse</th>
<th>2 eher gut</th>
<th>3 mittel</th>
<th>4 eher weniger</th>
<th>5 fast keine Kenntnisse</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

Vielen Dank!
A.4. Stroop Test – Instruction for Experiment 1 (Monolinguals)

CONSIGNE EXPERIMENTALE


Pour chaque mot, votre tâche consistera à décider dans quelle couleur est écrit le mot. Pour donner votre réponse, il vous suffira d’appuyer le plus rapidement et le plus correctement possible sur l’une des quatre pastilles de couleurs indiquées sur le clavier de l’ordinateur. Vous pourrez donner votre réponse en utilisant les indexes et majeurs des deux mains.

Vos jugements ainsi que vos temps de réponse seront enregistrés dès lors où vous aurez appuyé sur l’une des pastilles de couleurs.

Exemples :

<table>
<thead>
<tr>
<th></th>
<th>VERT</th>
<th>CHAT</th>
<th>MAIN</th>
<th>BLEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHAT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLEU</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Le test est constitué de six blocs. Chaque bloc dure environ cinq minutes. Entre chaque bloc une courte pause sera réalisée. Une fois prêt(e)s à continuer, il vous suffira d’appuyer sur la barre d’espacement. Le bloc expérimental suivant débutera alors.

Avant de débuter le test à proprement parler, deux blocs d’entraînement vous seront proposés. À la fin de ces blocs, l'expérimentatrice/expérimentateur vous indiquera le score de réponses correctes. S'il reste des points à éclaircir, n'hésitez pas à lui poser des questions.

Merci beaucoup pour votre participation !
A.5. Stroop Test – Instruction for Experiment 2 (Bilinguals)

CONSIGNE EXPERIMENTALE


Pour chaque mot, votre tâche consistera à décider dans quelle couleur est écrit le mot. Pour donner votre réponse, il vous suffira d’appuyer le plus rapidement et le plus correctement possible sur l’une des quatre pastilles de couleurs indiquées sur le clavier de l’ordinateur. Vous pourrez donner votre réponse en utilisant les indexes et majeurs des deux mains.

Vos jugements ainsi que vos temps de réponse seront enregistrés dès lors où vous aurez appuyé sur l’une des pastilles de couleurs ou que vous aurez prononcé le mot.

<table>
<thead>
<tr>
<th>Exemples :</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERT</td>
</tr>
<tr>
<td>CHAT</td>
</tr>
<tr>
<td>MAIN</td>
</tr>
<tr>
<td>BLEU</td>
</tr>
</tbody>
</table>

Le test est constitué de six blocs. Chaque bloc dure environ cinq minutes. Entre chaque bloc une courte pause sera réalisée. Une fois prêt(e)s à continuer, il vous suffira d’appuyer sur la barre d’espacement. Le bloc expérimental suivant débutera alors.

Avant de débuter le test à proprement parler, deux blocs d’entraînement vous seront proposés. A la fin de ces blocs, l'expérimentatrice/expérimenterateur vous indiquera le score de réponses correctes. S'il reste des points à éclaircir, n'hésitez pas à lui poser des questions.

Merci beaucoup pour votre participation !
VERSUCHSANLEITUNG

In diesem Experiment werden Ihnen französische und deutsche Wörter in vier verschiedenen Schriftfarben präsentiert. Die Wörter werden stets in der Mitte des Bildschirms erscheinen. Vor dem Erscheinen jedes Worts wird ein Kreuz am Bildschirm zu sehen sein. Fixieren Sie bitte dieses Kreuz, da es den Ort angibt, an dem anschließend das Wort erscheint!

Ihre Aufgabe ist es, bei jedem Wort zu entscheiden, in welcher Schriftfarbe es geschrieben ist. Um eine Antwort zu geben, drücken Sie bitte so schnell und so korrekt als möglich eine der vier mit Farbpunkten markierten Tasten auf der Tastatur des Computers. Verwenden Sie dazu die Zeige- und Mittelfinger Ihrer beiden Hände. Ihre Antwort sowie die Antwortzeit wird registriert, sobald Sie auf einen der Farbpunkte gedrückt beziehungsweise das Wort ausgesprochen haben.

Beispiele:

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<td>VERT</td>
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<tr>
<td>BLAU</td>
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Das gesamte Experiment besteht aus sechs Blöcken. Jeder Block dauert etwa fünf Minuten. Zu Beginn jedes Blocks wird angezeigt, in welcher Sprache (Französisch vs. Deutsch) die folgenden Wörter sein werden. Vor jedem Block gibt es eine kurze Pause. Sobald Sie sich bereit fühlen, die Pause zu beenden und mit dem nächsten Block zu beginnen, drücken Sie bitte die Leertaste.

Vor dem eigentlichen Experiment gibt es zwei Übungsblöcke. Nach diesen Übungsblöcken wird Ihnen der/die Versuchsleiter(in) das Ergebnis an korrekten Antworten mitteilen. Falls es noch Unklarheiten gibt, steht Ihnen der/die Versuchsleiter(in) gerne für Auskunft zur Verfügung.

Vielen Dank für Ihre Teilnahme!
Summary in French

Partie théorique


Pour le traitement du langage oral, la plupart des chercheurs distinguent les niveaux suivants : le niveau conceptuel, le niveau sémantico-syntactique (niveau de lemme), le niveau de la forme phonologique du mot et des segments (phonèmes) (niveau de lexème) et le niveau articulatoire. En ce qui concerne le traitement du langage écrit, la distinction établie est la suivante : le niveau conceptuel/sémantique, le niveau orthographique, le niveau post-orthographique (c’est-à-dire allographique), la structure motrice graphique et l’exécution motrice. Spinelli et Ferrand (2005) affirment que les niveaux de phonologie et d’orthographe sont très interactifs et que tous les deux jouent un rôle autant dans le langage écrit que dans le langage oral. L’apprentissage de l’écriture modifie profondément et de manière permanente le traitement du langage en général (Spinelli et Ferrand, 2005). La distinction en différents niveaux de traitement du langage a également été corroborée dans des études neurophysiologiques et neuro-imagères. En ce qui concerne les niveaux sémantique et syntactique, on a pu discerner leur traitement dans des études ERP sur la compréhension des phrases : le traitement sémantique est reflété par un N400 alors que le traitement syntactique est reflété par un ELAN et un P600. Le traitement des informations syntaxiques précède celui des informations sémantiques (Friederici et al., 2004).
L’organisation d’un système de langage bi- ou multilingue

La majorité de la population mondiale connaît deux ou plusieurs langues. Pour des individus bi- ou plurilingues, il est nécessaire de contrôler l’usage de leurs langues afin de répondre aux exigences de situations et contextes changeants. Dans la recherche psycholinguistique, le monolinguisme a longtemps été considéré comme la norme. Dans cette perspective, le bi- et plurilinguisme étaient des phénomènes marginaux ou même déviants. Au contraire, il faudrait davantage se concentrer sur le traitement de plusieurs langues, au moins pour deux raisons : premièrement, la prépondérance numérique d’individus plurilingues en comparaison avec le nombre de personnes monolingues sur une échelle mondiale constitue un argument de poids. Deuxièmement, des résultats de recherche soutiennent de plus en plus l’idée que le traitement du langage bi- ou plurilingue diffère qualitativement et non pas uniquement quantitativement du traitement du langage monolingue. De plus, la conception du « bilinguisme » s’est longtemps attachée aux bilingues balancés, c’est-à-dire aux individus qui ont une compétence solide dans les deux langues. Seuls les bilingues précoces ont donc été étudiés dans le peu de recherches qui ont été effectuées sur le bilinguisme. Quand on a commencé à étudier aussi des bilingues tardifs ou de moindre performance dans la L2, un impact sur le traitement neuronal du langage en général a également été constaté, même si la capacité en L2 n’égalait pas celle dans la L1 (bilingues non-balancés). La définition de bilinguisme acceptée aujourd’hui considère qu’un individu « bilingue » est une personne qui sait et utilise régulièrement deux langues, mais l’usage des deux langues peut avoir lieu dans différents contextes et le niveau de connaissances dans les deux langues n’est pas nécessairement élevé (Vaid, 2002).

Le traitement du langage n’est pas exclusivement limité à des aires de l’hémisphère gauche, même s’il y a une forte latéralisation avec la plupart de l’activité dans l’hémisphère dominante, le plus souvent l’hémisphère gauche (Vaid, 2002). Les aires principales impliquées dans le traitement du langage sont l’aire de Broca (BA 44, Pars opercularis, et BA 45, Pars triangularis) dans la production du langage et l’aire de Wernicke (BA 22p, partie postérieure du Gyrus temporal supérieur) dans la compréhension du langage. De plus, d’autres aires cérébrales, à savoir les aires motrices et auditores, sont impliquées dans le traitement du langage. Dans le traitement du langage bilingue, le cortex préfrontal (PFC) joue un rôle dans le contrôle et dans le changement de langues. (Isel et al., 2010) En plus, une activité plus intense peut être détectée dans l’hémisphère droit chez des bilingues en comparaison avec le traitement du langage monolingue. Dans des études neuropsychologiques
sur l’asymétrie fonctionnelle entre les hémisphères cérébraux, d’un côté, des similarités de latéralisation du traitement de la L1 ont été constatées (Vaid, 2002) alors que d’autres études ont permis de discerner des différences entre le traitement neuronal de la L1 chez des monolingués et bilingues. La découverte que le traitement même de la L1 diffère corrobore l’idée d’une différence qualitative, et pas seulement quantitative, entre le traitement du langage bilingue et monolingue (Badzakova-Trajkov, 2008). Mais même s’il y a une différence dans le traitement de la L1 entre bilingues et monolingues, cela ne signifie pas que le traitement de la L1 est inférieur dans l’un des deux groupes (ce qui a été spéculé pour les bilingues à cause notamment d’une limitation de la capacité) (Brysbaert et Dijkstra, 2006). Dans le cadre d’une comparaison du traitement de la L2 avec celui de la L1 chez les bilingues, des aires de l’hémisphère droit étaient significativement plus impliquées dans le traitement de la L2. L’activation plus forte d’aires de l’hémisphère droit pourrait être due à une plus grande implication de mécanismes de contrôle ou à une consultation plus élevée d’informations métalinguistiques.

Un consensus admet que plus une langue est acquise tôt, plus le niveau de capacité dans cette langue est élevé. Mais il y a aussi beaucoup d’exceptions, notamment des individus qui ont appris leur L2 tardivement et qui sont quand même arrivés à un niveau de capacité élevé. En ce qui concerne les aires d’activation cérébrale dans le traitement du langage bilingue, la capacité n’a pas encore suffisamment été examinée comme facteur de variabilité, mais en tenant compte des données déjà existantes, beaucoup d’auteurs se réfèrent plutôt à la capacité comme facteur principal de variation qu’à l’âge d’acquisition (AoA) de la L2 (Vaid, 2002; Kotz, 2009; Perani et al., 1998; Hahne, 2001). Il est nécessaire d’effectuer davantage de recherches (comportementale, neurophysiologique, imagerie cérébrale) qui prennent en compte l’âge d’acquisition de la L2, ainsi que la capacité dans cette langue comme facteurs de variabilité. Il est important de prendre en compte ces deux facteurs si l’on considère la grande hétérogénéité du bilinguisme.

Des adultes bi- ou plurilingues sont capables de contrôler et d’adapter l’usage de leurs langues selon les exigences de la situation, du contexte mais la suppression complète des langues non-cible semble ne pas être possible. Une interférence interlinguale (cross-linguistic interference) peut apparaître à différents niveaux de traitement (sémantique, phonologique, syntaxique,
etc.) (Brysbaert et Dijkstra, 2006). De nombreux résultats de recherche soutiennent l’idée que les lexiques de deux (ou plusieurs) langues sont activés dans la compréhension et dans la production langagière, même si seule l’une des langues est requise dans le contexte (Dijkstra, 2005; Brysbaert, 2003). Pour expliquer comment des items peuvent tout de même être sélectionnés d’une manière sélective par rapport à la langue, différents mécanismes ont été proposés. Dans certains modèles sur le traitement du langage bilingue, les représentations du marquage sont nommées, conceptualisées et localisées différemment, par exemple l’« étiquette langagière » (« langage tag ») (Green, 1998) ou le « nœud langagier » (« language node ») (Dijkstra et al., 1998; Dijkstra et Van Heuven, 2002), (Dijkstra et Snoeren, 2004).

**Le contrôle des langues chez des bilingues**


Dans le modèle IC, le contrôle inhibitoire pour la sélection et la suppression des langues est localisé à un niveau supérieur au domaine linguistique et dans le modèle BIA+, il est localisé au niveau des schémas de tâches (« Task schema » level). Ces conceptions permettent de supposer l’existence d’un avantage bilingue dans des tâches également non linguistiques. Si les mêmes processus de contrôle inhibitoire sont utilisés aussi bien dans le domaine linguistique que dans des domaines non linguistiques, les bilingues, comparés aux monolingues, devraient également être avantagés dans des tâches non linguistiques impliquant un contrôle inhibitoire du fait de l’entraînement du contrôle inhibitoire de leurs deux langues (Bialystok et al., 2005).
Dans le cadre d’une étude menée sur l’effet du bilinguisme sur la performance dans le Simon task (un test non linguistique sur les fonctions exécutives), Bialystok et al. (2005) a constaté un avantage chez les bilingues. Dans le Simon task, les bilingues montraient des temps de réaction plus courts dans des essais de conflit (résolution plus rapide de conflits), accompagnés d’une activation neuronale plus intense dans le cortex préfrontal (PFC) et dans le cortex cingulaire antérieur (ACC) chez les bilingues en comparaison avec les monolingues. Ces aires neuronales sont impliquées dans le contrôle langagier bilingue (Bialystok et al., 2005). Avec d’autres auteurs, Bialystok et al. (2008) maintient que cette implication des fonctions exécutives dans le changement de langues (language switching) pourrait générer un effet d’entraînement pouvant se refléter aussi bien dans un contrôle exécutif amélioré que dans des domaines non linguistiques. Ces études (Bialystok et al., 2005 ; Bialystok et al., 2008 ; Bialystok et DePape, 2009) ainsi que des observations similaires corroborent des modèles psycholinguistiques dans lesquels le mécanisme de contrôle inhibitoire pour l’usage des langues est aussi impliqué dans le contrôle de tâches non linguistiques, p. ex. le modèle IC (Green, 1998), où le « Système Attentionnel de Supervision » (SAS) a cette fonction du contrôle de fonctions linguistiques ainsi que non linguistiques.


**Le test Stroop Colour Word**

Le test Stroop est habituellement utilisé pour examiner le contrôle inhibitoire dans des fonctions exécutives parce qu’il requiert un contrôle attentionnel dans la sélection et l’inhibition des informations conflictuelles en compétition. (Badzakova-Trajkov, 2008; Pardo
et al., 1990) Le test Stroop est utilisé dans la recherche psychologique, ainsi que dans le diagnostic clinique. (Pardo et al., 1990; Peters et al., 2000)

Le test Stroop Colour Word combine une composante linguistique, des mots de couleur, avec une composante non linguistique, la couleur de l’écriture. Dans la condition congruente, la signification du mot et la couleur de l’écriture sont identiques alors qu’ils divergent dans la condition incongruente. Dans une condition contrôle, on utilise soit une couleur d’écriture neutre (p. ex. noir, blanc) soit le mot de couleur est remplacé par un mot neutre, un non-mot ou une série de signes (p. ex. DOG, XXXX). La variante utilisée dépend du facteur à examiner (l’interférence de la couleur sur le mot respectivement du mot sur la couleur).
L’Effet Stroop est causé par l’interférence que la tâche la plus automatique (lecture du mot) génère sur la tâche la moins automatique (dénomination de la couleur d’écriture) dans la condition incongruente.

Partie empirique

Hypothèses et prédictions

En comparaison avec les monolingues, les bilingues tardifs (L1 français, L2 allemand) étaient supposés avoir une meilleure capacité de contrôle inhibitoire lors des fonctions exécutives et donc, être plus performants dans des situations où des conflits devaient être détectés et résolus. Le test Stroop Colour Word, dont une version manuelle a été utilisée dans la présente étude, est une tâche qui fait habituellement apparaître des conflits.

L’exactitude (le taux d’erreur), les temps de réaction, l’Effet Stroop, le Switching cost (la différence de TR entre la réponse à un stimulus qui a été précédé par deux essais d’une autre condition (Switch) et la réponse à un stimulus précédé par deux essais de la même condition (Non-Switch)), et l’effet Overpracticing (Overpracticing effect ; une réduction des TR au cours de l’expérience obtenue grâce à l’entraînement additionnel dans la tâche) ont été testés pour les bilingues dans leur L1 et L2 dans l’expérience 1 et pour les monolingues dans leur L1 dans l’expérience 2.

Les prédictions étaient un taux d’erreur réduit, des temps de réaction plus courts et un Effet Stroop (TR_{Incongruente} − TR_{Congruente}) réduit dans la L1 chez les bilingues en comparaison avec les monolingues. Ces prédictions étaient faites lors de l’hypothèse d’un meilleur contrôle

Pour la comparaison entre les deux langues des bilingues, des temps de réaction plus courts et un Effet Stroop réduit étaient attendus pour la L2 en comparaison avec la L1 parce que le contrôle cognitif était supposé avoir plus d’impact sur une langue activée à un niveau plus bas, comme c’est le cas pour la L2 chez les bilingues tardifs. Cette prédiction est issu du modèle BIA+. Les prédictions quant à l’effet du Switching et l’effet de l’Overpracticing restaient assez ouvertes.

**Méthode**

*Participants*

Tous les participants étaient droitiers. Ils recevaient un dédommagement de 10€/heure pour leur participation.

Expérience 1 : 10 bilingues tardifs (dont 8 femmes) de langue maternelle française, qui avaient appris l’allemand comme première langue étrangère (L2) à partir de l’âge de 10 ans de manière formelle au collège en France et qui avaient eu un usage régulier de l’allemand pendant les trois dernières années, étaient sélectionnés. Le groupe bilingue avait en moyenne 28,6 ± 5,2 ans. Des informations générales et la biographie linguistique étaient demandées dans un questionnaire (Appendice A.2).

Expérience 2 : Comme groupe contrôle, 10 monolingues (dont 8 femmes) de langue maternelle française étaient choisis. Un critère pour leur participation était leur usage restreint de langues autres que le français pendant les trois dernières années. Les monolingues étaient âgés en moyenne de 26,1 ± 2,9 ans. Des informations générales et la biographie linguistique étaient demandées dans un questionnaire (Appendice A.1).
Dans la mesure où la pratique musicale (Bialystok et DePape, 2009; Neville, 2009) ainsi que le fait de jouer à des jeux vidéo ou des jeux informatiques (Bialystok, 2006; Green et Bavelier, 2003) peuvent avoir un effet améliorateur sur le contrôle cognitif au niveau des fonctions exécutives – comme on le suppose pour le bilinguisme – des questions sur ces activités étaient également incluses au questionnaire. De même, une question sur les activités sportives était posée puisque la pratique de mouvements complexes qui exigent une bonne coordination, dont le ping-pong, la danse, les sports de combat, etc., peuvent avoir un effet d’entraînement dans le même domaine des fonctions exécutives que le bilinguisme.

**Stimuli**

Une version manuelle adaptée du Stroop task d’origine était utilisée dans les deux expériences. Les stimuli étaient présentés dans trois conditions expérimentales : congruente, incongruente et neutre. Dans la condition congruente, le mot de couleur et la couleur d’écriture correspondaient, dans la condition incongruente le mot et la couleur d’écriture divergeaient et dans la condition neutre, des mots « neutres » au niveau de la couleur, qui correspondaient le plus possible en longueur et en complexité aux mots de couleur dans les deux autres conditions, étaient présentés dans les mêmes quatre couleurs.

En L1 français, les quatre mots de couleur suivants étaient utilisés pour les conditions congruente et incongruente : ROUGE\textsuperscript{red}, BLEU\textsuperscript{blue}, JAUNE\textsuperscript{yellow}, VERT\textsuperscript{green}. En L2 allemand, les quatre mots de couleur correspondants aux mots français étaient présentés dans les conditions congruente et incongruente : ROT\textsuperscript{red}, BLAU\textsuperscript{blue}, GELB\textsuperscript{yellow}, GRÜN\textsuperscript{green}. Dans la condition neutre, les quatre mots suivants, neutres au niveau de la couleur, étaient présentés dans les même quatre couleurs que les mots de couleur précédents : En L1 : CHAT\textsuperscript{cat}, CHIEN\textsuperscript{dog}, MAIN\textsuperscript{hand}, PIED\textsuperscript{foot} et en L2 : KATZE\textsuperscript{cat}, HUND\textsuperscript{dog}, HAND\textsuperscript{hand}, FUSS\textsuperscript{foot}. Dans l’expérience 2 pour les monolingues, on n’utilisait que les mots en français. Les quatre couleurs d’écriture correspondants aux mots de couleur étaient donc : rouge, bleu, jaune et vert. Les stimuli étaient présentés en majuscules en caractère « Calibri » en taille 48 au centre d’un écran noir. Des exemples sont donnés dans le Tableau 13.
Tableau 11. Stimuli dans les trois conditions expérimentales – congruente, incongruente, neutre – avec des exemples en français (L1) et en allemand (L2) pour chaque condition.

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<tr>
<td>Congruente</td>
<td>ROUGE</td>
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<tr>
<td>Incongruente</td>
<td>VERT</td>
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<tr>
<td>Neutre</td>
<td>CHIEN</td>
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**Procédure**

La consigne donnée aux sujets était de dénommer la couleur d’écriture des stimuli. On demandait aux participants d’identifier la couleur d’écriture des stimuli en appuyant sur une des quatre touches du clavier de l’ordinateur portable qui étaient marquées avec des pastilles de couleur. Les participants devaient répondre aussi rapidement et aussi correctement que possible. Les instructions étaient données sous forme écrite (Appendices A.4 et A.5) et répétées oralement afin de s’assurer que la consigne avait été bien comprise.

Chaque bloc expérimental comptait 72 stimuli, dont 24 dans la condition congruente, 24 dans la condition incongruente et 24 dans la condition neutre. Ces stimuli étaient présentés dans un ordre pseudo-randomisé. Le design de la présentation des stimuli a été créé avec le programme *E-Prime 2.0* (Psychological Software Tools, Pittsburgh, PA). Chaque stimulus était précédé d’une croix de fixation au centre de l’écran. La durée de la présentation de la croix de fixation variait entre 500 et 1000 ms afin d’éviter que les participants ne développent une expectative systématique. La croix de fixation était immédiatement suivie du stimulus qui restait à l’écran jusqu’à ce que le participant donne une réponse en appuyant sur l’une des quatre touches de couleur. Toutefois, le stimulus ne restait affiché que pendant 1500 ms maximum dans le cas où le participant n’appuyait sur aucune touche. L’intervalle entre la disparition du mot stimulus et la présentation de la prochaine croix de fixation (*Interstimulus*
Interval, ISI) était de 500 ms. Le temps de réaction (TR) était défini comme l’intervalle entre le début de la présentation du stimulus et la réponse donnée par une pression exercée sur l’une des quatre touches.

Expérience 1 : L’expérience 1 était développée pour les bilingues. Six blocs expérimentaux, dont trois dans la L1, trois dans la L2, étaient présentés dans un ordre pseudo-randomisé : deux blocs maximum se succédaient dans une langue et la position des blocs dans les deux langues au cours de l’expérience était le plus varié possible parmi les sujets.

Expérience 2 : L’expérience 2 destinée au groupe monolingue égalait l’expérience 1 sur tous les points, excepté que les six blocs étaient dans la L1.

Analyse des donnés

L’évaluation portait sur les temps de réaction et l’exactitude des réponses (le taux d’erreur). Seules les réponses correctes étaient utilisées pour l’analyse. Les données de temps de réaction étaient corrigées par sujet et condition expérimentale (les données excédant la moyenne ± 2 écarts types étaient exclus). Pour comparer les bilingues aux monolingues, nous avons comparé les données de la L1 chez les bilingues à seulement trois blocs des monolingues.

ANOVA à mesures répétées, ANOVA univariante, t-Tests et l’examen de la corrélation Pearson ont été utilisés dans l’analyse statistique.

Résultats

Bilingues vs. monolingues

Les bilingues montraient des temps de réaction plus courts ainsi qu’un Effet Stroop descriptive réduit en comparaison avec les monolingues. Les deux différences n’étaient pas significatives. L’analyse de l’effet du Switching montrait un Switching cost dans la condition congruente pour les monolingues, mais pas dans la condition incongruente et en aucun cas chez les bilingues. Par contre, le Switching cost dans la condition congruente chez
les monolingues était entre autre causé par des temps de réaction plus courts dans la situation 
*Non-Switch*. Il faut donc se montrer prudent avant d’affirmer qu’il y a un avantage ou un 
désavantage bilingue ou monolingué dans ce cas. Un effet de l’Overpracticing significatif a 
été constaté pour les temps de réaction chez les bilingues, mais seulement descriptivement 
chez les monolingues. L’évaluation de la pratique musicale, sportive ou de jeux 
vidéo/informatiques ne montrait pas d’effets significatifs de ces facteurs.

*Bilingues : L1 vs. L2*

Dans la L2, les bilingues montraient des temps de réaction plus courts en comparaison avec la 
L1, mais cette différence n’était pas significative. L’Effet Stroop était similaire dans les deux 
langues. Aucun *Switching cost* n’a été constaté dans les deux conditions pour les deux 
langues. Un effet de l’Overpracticing s’est révélé significatif pour les deux langues. 
L’évaluation de l’impact de la capacité dans la L2, de l’utilisation de la L2 (L2 exposure), de 
da pratique musicale, sportive ou de jeux vidéo/informatiques n’a pas permis de mettre en 
évidence d’effets significatifs sur ces facteurs.

**Discussion et conclusion**

A un certain degré, les résultats (temps de réaction et Effet Stroop descriptivement réduits) 
permettent de dire qu’il y a des indices quant à un contrôle cognitif amélioré même chez des 
bilingues tardifs résidant dans un environnement L1. Ce résultat correspond aux résultats 
obtenus dans les études précédentes (Badzakova-Trajkov, 2008). L’hypothèse d’un meilleur 
contrôle cognitif chez les bilingues est proposée par l’interprétation de certains modèles 
psycholinguistiques, comme p. ex. les modèles IC (Green, 1998) et BIA+ (Dijkstra et Van 
Heuven, 2002), et elle a également été soutenue par des résultats obtenus dans des études 
précédentes (Bialystok, 2005 ; Bialystok et DePape, 2008 ; Badzakova-Trajkov, 2008). Dans 
la continuation de l’étude, des facteurs comme la pratique musicale vont être davantage pris 
en considération lors de la sélection et de l’évaluation des participants.

Concernant les performances dans la L1 et L2 chez les bilingues, d’un côté les temps de 
réaction étaient descriptivement plus courts dans la L2 en comparaison avec la L1. Ce résultat 
soutient l’idée d’un plus grand impact du contrôle cognitif sur la langue moins activée et avec 
un accès lexical plus lent. De l’autre côté, l’Effet Stroop est similaire dans la L2 et la L1 ce
qui suggère que l’impact du contrôle cognitif semble être similaire sur les deux langues, même si elles sont activées à des niveaux différents. L’extension de l’étude sur un nombre plus grand de participants dans l’étude comportementale, ainsi qu’une continuation de l’expérience avec des techniques neurophysiologiques (EEG) vont être très utiles pour obtenir des résultats plus clairs et pour pouvoir argumenter s’il y a soutien pour certains aspects dans des modèles psycholinguistiques.
Abstract in German


Im empirischen Teil der vorliegenden Studie wurden spät Zweisprachige (L1 Französisch, L2 Deutsch) mit Einsprachigen (L1 Französisch) auf ihre inhibitorische Kontrolle in exekutiven


Die Ergebnisse des Vergleichs zwischen Ein- und Zweisprachigen lassen zu einem gewissen Grad auf eine verbesserte kognitive Kontrolle bei Zweisprachigen schließen und stützen damit sowohl das IC Modell (Green, 1998) als auch das BIA+ Modell (Dijkstra und Van Heuven, 2002). Der Vergleich zwischen den beiden Sprachen der Zweisprachigen stützt nur in geringem Maß die Idee gemäß des BIA+ Modells, dass kognitive Kontrolle höheren Einfluss auf die L2 habe, für die ein geringerer Aktivierungsgrad und langsamerer lexikaler Zugriff angenommen wird. Allerdings wird die Ausweitung der Studie auf eine größere Anzahl an Versuchspersonen im Verhaltensexperiment sowie die Fortführung des Experiments auch unter Verwendung von neurophysiologischen Methoden von großem Nutzen sein, um klarere Resultate zu erhalten. In der Fortführung der Studie werden verstärkt auch Faktoren wie das Praktizieren von Musik in der Auswahl der Versuchspersonen berücksichtigt werden.
Abstract in English
The majority of the world’s population uses two or more languages in everyday life, which is a demanding task. The languages on a bi- or multilingual’s mind have to be selected or inhibited and even rapid switches between languages have to be possible in order to meet the demands of changing situations and contexts. This crucial exigence in bi- or multilinguals to control the use of more than one language has been theorized to cause differences between bilinguals and monolinguals when they are tested for their cognitive control, also in non-linguistic tasks. Findings in different studies that bilinguals perform better than monolinguals on tasks testing cognitive control in executive functions (Simon task, Stroop task, etc.) support psycholinguistic models which postulate that the level of cognitive control used to control language selection might also be implicated in control processes in non-linguistic domains. Two of these models are the Inhibitory Control (IC) model by Green (1998) and the Bilingual Interactive Activation + (BIA+) model by Dijkstra and Van Heuven (2002).

In the present study, late bilinguals (L1 French, L2 German) were compared to monolinguals (L1 French) for their capacity of inhibitory control in executive functions. A manual version of the Stroop Colour Word test (Stroop, 1935) was used. Accuracy, reaction time, the Stroop Effect, Switching cost, an Overpracticing Effect and Reading Span were evaluated and compared between monolinguals and bilinguals as well as between the two languages of bilinguals. On basis of the IC and BIA+ models, shorter reaction times and a smaller Stroop Effect were predicted for bilinguals in comparison to monolinguals. Furthermore, predicting from the BIA+ model, shorter reaction times and a smaller Stroop Effect were expected for the L2 in comparison to the L1 in bilinguals.

The finding in the present study that bilinguals show descriptively shorter reaction times and a descriptively smaller Stroop Effect than monolinguals to a certain degree supports the hypothesis of bilingual advantage in inhibitory control in executive functions. This idea is to be found i.e. in the IC model by Green (1998) and similarly in the BIA+ model by Dijkstra and Van Heuven (2002). Summing up, there is slight support for the hypothesis of bilingual advantage in inhibitory control in executive functions because of their training in managing the use of their two languages which needs permanent selection and inhibition. This level of
inhibitory control is likely to be not exclusively implicated in control processes in the linguistic domain but also in the control of non-linguistic functions.

Moreover, the comparison of bilinguals in their two languages in the Stroop task showed descriptively shorter reaction times in the L2 than in the L1 which supports the idea of a higher impact of cognitive control on the less activated language, predicted according to the BIA+ model. On the contrary, the Stroop Effect was very similar in the two languages, which contradicts this prediction. Due to a lack of statistical significance of differences, further behavioural as well as neurophysiological and neuro-imaging examination is necessary for arguing in favor or contra a cognitive advantage of bilingualism and to give a clearer statement on the impact of cognitive control on the two languages of bilinguals. In future studies, musicality will further be taken into account in the selection of the participants as there might also be an impact on cognitive control in executive functions caused by musical practice. (Bialystok and De Pape, 2009)
Curriculum Vitae

Contact Information

<table>
<thead>
<tr>
<th>Surname:</th>
<th>Heidlmayr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forename:</td>
<td>Karin</td>
</tr>
<tr>
<td>Address:</td>
<td>Allhaming 2</td>
</tr>
<tr>
<td></td>
<td>4511 Allhaming</td>
</tr>
<tr>
<td></td>
<td>Austria</td>
</tr>
<tr>
<td>Cell Phone:</td>
<td>+43 699 11 42 64 80</td>
</tr>
<tr>
<td>Email:</td>
<td><a href="mailto:k_heidlmayr@yahoo.de">k_heidlmayr@yahoo.de</a>, <a href="mailto:a0406506@unet.univie.ac.at">a0406506@unet.univie.ac.at</a></td>
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Personal Information

<table>
<thead>
<tr>
<th>Date of Birth:</th>
<th>06.09.1985</th>
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<tbody>
<tr>
<td>Place of Birth:</td>
<td>Wels, Austria</td>
</tr>
<tr>
<td>Citizenship:</td>
<td>Austria</td>
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Education

<table>
<thead>
<tr>
<th>School:</th>
<th>1992-1996 Elementary school in Allhaming</th>
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<tr>
<td></td>
<td>1996-2004 Diploma with honors from the secondary school with focus on natural sciences, mathematics and economy of the Franciscans in Wels (Wirtschaftskundliches Realgymnasium der Franziskanerinnen in Wels)</td>
</tr>
<tr>
<td>University:</td>
<td>Romance studies - French (11th semester, since winter term 2005/06, 1st part completed on January 29, 2008, passed with distinction) at the University of Vienna</td>
</tr>
<tr>
<td></td>
<td>Biology (9th semester, since winter term 2006/07, 1st part completed on August 19, 2009) at the University of Vienna</td>
</tr>
<tr>
<td></td>
<td>ERASMUS semester (winter term 2008/09) at the Université Libre de Bruxelles</td>
</tr>
</tbody>
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### Additional Qualifications

| **Languages:** | German as mother-tongue  
Good oral and written language ability in English and French  
Cambridge First Certificate in English  
Basic language ability in Italian |
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<tr>
<td><strong>Internships</strong></td>
<td>Internship at the Medical University of Vienna – Institute for Clinical Pathology (Insight into different institutes: Histopathology, Neuropathology, Center for Brain Research, Autopsy, etc.) from September 7, 2009 to September 30, 2009</td>
</tr>
<tr>
<td><strong>Honors:</strong></td>
<td>Merit scholarships for the academic years 2006/07 and 2007/08</td>
</tr>
</tbody>
</table>
| **Computer Skills:** | ECDL – European Computer Driving License  
Experience in Internet Research |
| **International Experience:** | School journeys: England, Rome, Southern France, Strasbourg  
Private journeys: Alsace, Paris, Spain, Scandinavia, Rumania, etc.  
ERASMUS semester at the Université Libre de Bruxelles  
Diploma thesis at the Université Paris V – Descartes from April 2010 to October 2010 with a research scholarship from the University of Vienna. |
| **Other Activities:** | Playing the clarinet at the music school in Bad Hall (final exam in April 2006) and in a music orchestra, musical accompaniment at different events  
Giving private lessons in English, French and mathematics  
Lector in the church in Allhaming, 2004-2006  
20 hours of work experience in social work: giving private lessons  
Two days of work experience in a nursery school  
Work experience in office work and as a telephonist during the holidays |

Vienna, 16.11.2010

Karin Heidlmayr