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More than one language in the brain.

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0. Introduction

What difference does it make to have one language in the brain or to have more than one? This is an intriguing and currently much inquired question, which can help us unravel more than one mystery concerning language and the brain. At present, we only know bits and pieces of the answer. As research progresses and more pieces of this large and complex puzzle fit together, we discover some general outlines of the answer, and realize the intricacies of the detail. In this chapter, I will attempt to keep our eyes set in that general outline, occasionally dwelling into a detail or two, in the hope of giving you a glimpse of how research is conducted in this field of inquiry.

As we will see, there are indeed differences that relate to having more than one language in the brain. Some of these differences involve cognitive abilities that lie outside of the linguistic systems proper, such as the capacity to ignore irrelevant information when changing tasks, or a certain degree of resilience towards symptoms of neurodegeneration. Other differences between monolinguals and bilinguals involve the interplay of the two linguistic systems: their simultaneous activation and the need to select or inhibit one at a time, or the cost involved in having two lexicons and grammars instead of one. The developmental patterns of preverbal bilingual babies —who detect very early that there is more than one language in their environment— are also different

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from those of monolinguals. These differences eventually emanate from the intensive cognitive training undergone by bilinguals in their lifetimes, given the frequency and speed at which they switch from one language to another.

From a more narrowly linguistic point of view, humans that have more than one language in their brains can provide crucial evidence regarding the neurocognitive nature of the language faculty, with its innate/universal properties and its acquired/variable aspects. Thus, for instance, we will see that variable (parametric) aspects of the grammar appear to be sensitive to *when* they are acquired, and to *what* type of grammatical knowledge was there before, so that native speakers and non-native speakers do not process certain aspects of the grammar in the same way, even at high levels of language proficiency. In contrast, the lexicon seems to be insensitive to when it is acquired and what the words of a previously acquired language look like: at high proficiency, non-native speakers are native-like in lexical matters.

So, in broad terms, it matters a great deal to the brain whether it carries more than one language, and when there is more than one, which one developed first and which one later, and it also depends on the language component what is the length of time that matters (shorter lapse between native and the non-native language for phonology, longer lapse for syntax, insensitive for the lexicon[†]). It also matters to the brain how present these languages are, that is, what the proficiency achieved in each language is, and how frequently the brain uses them, or changes from one to the other, so that in some cases one language can be dominant over another, or not. There are also reasons to think that individuals vary in their abilities to acquire a second language, and that this abilities relate to intrinsic neurobiological differences differences (Díaz et al. 2008). The degree of morphosyntactic similarity of the languages coexisting in one brain might also make a significant difference in how we represent and process them, though currently, more is known about the lexicon and phonology

1 Throughout this chapter, “the lexicon” refers to the open class lexical items, not to the closed class composed of functional elements such as inflectional morphemes, case markers, complementizers and the like. Functional-inflectional elements are taken to be part of syntax, which therefore includes inflectonal morphology (morphosyntax).

in humans that know more than one language, than about the syntax. Perhaps this is partly due to the fact that the finer experimental studies exploring syntax in the brain often require the cooperative work of syntacticians, psycholinguists and neuroscientists, which hopefully books like this will encourage.

The literature covering various aspects of the topics to be discussed in this chapter is vast, and it is therefore not possible to cover it exhaustively. I will provide an overview of the main topics of research and the general outlook that emerges given the evidence found; and since it is not possible to discuss all issues on an equal footing, I will mainly concentrate on those that I find most significative and revealing for linguists with an interest in the neurobiology of language. I will review recent findings on cognitive advantages of bilingualism that are not directly related to the language faculty, and discuss the impact of age and language proficiency in the neural underpinnings of bilingualism. Within the components of language, I will concentrate more on the lexicon and the grammar. Bilingual phonology is a fascinating area of research that directly touches upon earliest stages of language acquisition, but I will not discuss it here. There are excellent overviews of bilingual language acquisition that focus on the early development of phonology and the lexicon, which address the issues that I will leave aside, such as Sebastian-Galles and Bosch (2002), Sebastian-Galles et al. (2005), and Sebastian-Galles and Kroll (2003).

1. The bilingual is not two monolinguals in one person.

François Grosjean, a pioneer researcher on bilingualism, warned in his 1989 paper that the bilingual is not two monolinguals in one person. In this chapter, we will review some discoveries on the neurobiology of bilingualism that show the extent to which this statement is true. We will also keep our focus on what these discoveries reveal about the human language faculty, and the new questions they pose to language research.

Bilinguals outnumber monolinguals in our species: according to some recent estimates, between 60 and 75 per cent of the world's population is bilingual. Although we do not have direct evidence, it has been argued that the capacity to learn more than one language is an adaptive trait in human evolution (Hirschfeld 2008); given what we know of interactions between human groups, is not unlikely that people throughout history have more often than not known more than one language.

For the purposes of this chapter, a person who knows more than one language and can use them to communicate efficiently qualifies as bilingual, even without reaching native-like command in both languages. We will thus adopt the view that "bilingualism is the regular use of two (or more) languages, and bilinguals are those people who need and use two (or more) languages in their everyday lives" (Grosjean 1992). We will not limit our attention to people who can speak two languages with equal mastery, often referred to as "balanced bilinguals"; we will also review studies of "unbalanced bilinguals", for whom one language is dominant over the other in some or another aspect. Finally, we will also consider adults in the process of learning a second o third language from the start. All these people are of interest to the neurobiology of language; we can learn a great deal about language in the brain by considering all kinds of different types of populations.

Psycholinguistic and neurolinguistic research initially tended to restrict itself to the study of monolinguals, and there was not much interest in the study of bilingualism, because it was generally (though tacitly) thought that the neural representation and processing of a given language was not affected by another language, whether acquired simultaneously or later in life. Recent findings challenge this assumption, and suggests instead that research beyond monolingualism holds a great potential for generating knowledge about the neurobiological nature of the human language faculty and the way in which language is organized in our brains.

Broadly speaking, neurocognitive studies of language and bilingualism reveal that the patterns of activation related to language processing are consistent across languages and native speakers; research shows that the processing of different languages occurs in much of the same brain tissue (Kim et al. 1997; Perani et al. 1998; Díaz et al. 2011). When differences between languages are found, they obtain in bilinguals and they correlate with differences in proficiency levels attained in each language, and differences in age of acquisition for each language. This is why the impact of language proficiency and of the age at which a language is acquired have been to date the factors that have received most research attention. The impact of the degree of similarity of the grammars located in one brain is a far less explored issue, as are the differences among different types of grammatical phenomena, though as our knowledge advances, grammatical specificity emerges as a likely relevant factor to be kept into account. As the volume and level of detail of the studies carried out increases, it also becomes increasingly clear that, although all these factors have often been studied separately, there are strong connections between them: proficiency in the language, age of acquisition, and grammatical similarity are likely to be intertwined rather than separate factors.

2. Cognitive advantages of bilingualism.

Perhaps the most striking findings from neurocognitive research on bilingualism relate to cognitive differences that result from using more than one language frequently during a lifetime. In fact, it is becoming increasing clear that speaking more than one language yields cognitive benefits that extend from childhood, through life, and into old age. Recent research into the neurobiology of bilingualism reveals that being fluent in two languages, particularly from early childhood, not only enhances a person's ability to concentrate and ignore irrelevant information, but also delays the onset of dementia and other age-related cognitive decline by an average of 4 to 5 years (Craik et al. 2010). Furthermore, early acquisition of more than one language has other consequences outside of the linguistic domain, such as an earlier development of theory of mind (Kovacs 2009).

The cognitive benefits associated to bilingualism were originally revealed by the research of Bialystok and collaborators (Bialystok, 1999; Bialystok, 2001; Bialystok and Martin, 2004). In a series of experiments, they showed that bilingual children outperform monolinguals in tasks that required attentional control. Bialystok (1999) asked 4 to 5 year-old children to first sort a set of cards according to their color and then to sort them according to shape, and found that bilinguals made less errors when changing tasks. This evidence strongly indicates that bilingualism contributes to the development and strengthening of the attentional control mechanisms that are involved in these changing task-rules. This group of researchers also showed that bilingualism has an impact on the attentional control abilities throughout the lifetime. Bialystok, Craik, Klein, and Viswanathan (2004) tested groups of bilinguals and monolinguals of different ages on the so-called "Simon task", that requires to pay exclusive attention to a specific property of the stimulus, like its color or shape, while ignoring its position on the screen. People take longer to respond when objects that share the relevant property appear in different locations in the screen, the so-called "Simon effect". Bialystok and colleagues found that the magnitude of the Simon effect is smaller for bilinguals, and this difference between bilinguals and monolinguals was more evident in older participants (over 60 years old), which indicates that bilingualism not only facilitates the development of more efficient attentional control mechanisms in childhood, but it also delays cognitive decline (for a review see Craik and Bialystok 2006). Costa and collaborators (Costa et al. 2008, Hernandez et al. 2010) have further shown that this bilingual advantage is also present in adults, at ages at which individuals are at the peak of their attentional capabilities, and that this cognitive bilingual advantage specifically involves conflict monitoring and conflict resolution, two subcomponents of the executive control network that are neuroanatomically distinct.

Bilinguals extract cognitive benefits in the areas of the brain that constitute the *executive control system*, located in the dorsolateral prefrontal cortex; these areas have been found to be active during language switching in bilinguals (Hernandez et al. 2004). The cognitive capacities that are enhanced by bilingualism are not language-specific, because these mechanisms involve domain general cognitive control processes (Abutalebi and Green, 2008), though it is through the acquisition and frequent use of more than one language that they have been trained and strengthened in bilinguals.

The neural underpinnings of language control in bilinguals are still not understood in detail, though much progress has been made in identifying them during the last years. In a pioneering study on the neurocognition of language switch and translation in bilinguals, Price et al. (1999) used positron emission tomography, a technique that provides a high topographical resolution of brain activity, to study language processing in six German-English bilinguals who started learning English at nine years of age. They found that the most active brain areas during translation fell outside Broca’s or Wernicke’s areas, among them the anterior cingulate cortex that controls attention. More recently, Crinion et al. (2006) studied different groups of proficient bilinguals (German-English and Japanese-English) and suggested that the left caudate is strongly involved in language monitoring and control.

A recent study by Garbin et al. (2010) finds similar evidence in favor of the involvement of Broca’s area in language switch in bilinguals, but moreover, these researchers find significant differences in the cortical networks involved in cognitive control between monolinguals and bilinguals: the most interesting difference is the involvement of the left IFG (Broca’s area) also in non-linguistic switch tasks for bilinguals, whereas monolinguals activated the right IFG for the same switch tasks. The fact that the left IFG has been consistently related to bilingual language control indicates that there is a certain degree of overlap between the cortical network responsible for language control and general-purpose non-linguistic cognitive control in the case of bilinguals, but not in monolinguals. This means that early and proficient bilinguals recruit Broca’s area not only for language switching tasks, but also for other non-linguistic switch tasks, whereas monolinguals do not. These results thus suggest that, although the attentional mechanisms that are better developed in bilinguals are not language-specific (they also monitor other types of tasks where language is not involved), and although in non-bilinguals these attentional mechanisms are controlled by bi-hemispheric or right-hemispheric regions of the brain, in bilinguals they are controlled and computed by Broca's area (Brodman 45/44), one of the areas crucially involved in linguistic computation.

3. How separate do bilinguals keep their languages?

How the brain organizes languages in bilingual individuals has been an intensely investigated question in the last years. Is each language located in separate areas of the brain or in overlapping regions? Studies of whole-brain functional neuroimaging show that highly proficient bilinguals activate the same brain regions when they use any of their two languages (Kim et al. 1997; Perani et al. 1998). Hernandez et al. (2001) run an fMRI study of six Spanish/English early bilinguals, all of whom had acquired both languages before the age of five, and found that the two languages were represented in overlapping regions of the brain. That is, given the degree of detail that current neuroimaging techniques allow for, it emerges that early and proficient bilinguals use the same neural circuits for the two languages they know.

However, when a bilingual has learned the second language later in life, linguistic tasks involving this second language activate broader areas of the brain, partially overlapping but distinct from the native language. Kim et al. (1997) run an fMRI study comparing early and late bilinguals while processing their two languages. Results revealed distinct physical loci for native and non-native languages in the case of languages that languages along the periphery of Broca's and Wernicke's regions in the case of late learners, but not in the case of early learners.

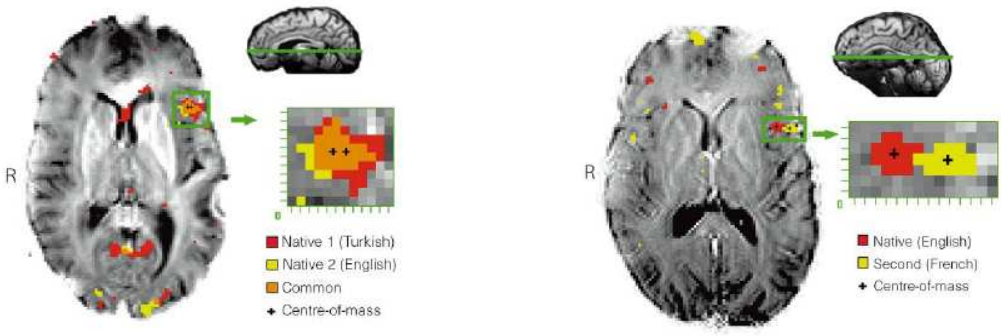

Fig 1. Differences between early (left) versus late (right) bilinguals and brain activations during language processing in the two languages (from Kim et al. 1997)

Dehaene et al. (1997) run a study of French-English bilinguals, all of whom had acquired the second language after the age of seven. In listening tests, an fMRI revealed common areas of activation in the left temporal lobe for all subjects when the native language was used. When the non-native language was used in testing, researchers found highly variable areas of activation in both hemispheres. Several studies also find that Broca's area is generally more activated when listening to the native language than to other lesser known languages (Mazoyer et al. 1993, Perani et al. 1996, 1998). Some of these fMRI studies have suggested that there may be smaller-scale circuits specialized for each language (Dehaene et al. 1997, Kim et al. 1997). Halsband et al. (2002), for instance, studied ten Finnish–English adult bilinguals, all of whom had acquired the second language after the age of 10, using Pet scan. They found differential areas of activation for the two languages in both Broca's area and in the supramarginal gyrus, one of the convolutions lying between Broca's and Wernicke's Areas. Wartenburger et al. (2003) used fMRI testing to study 32 Italian-German bilinguals in three groups, (i) eleven subjects who acquired the German in early childhood and were fluent native speakers, (ii) twelve subjects who acquired German in adulthood but managed to attain a high level of proficiency, and (iii) nine subjects who had German late in life and had limited proficiency. They found that age of acquisition was a statistically significant variable in determining loci of grammatical processing in the brain, but less so in determining semantic processing.

Other findings strongly suggest that early and sustained bilingualism significantly alters the brain's structure: Mechelli et al. (2004) identified an increase in the density of grey matter in the left inferior parietal cortex of bilinguals relative to monolinguals, more pronounced in early bilinguals, and showed that the density in this region increases with second-language proficiency and decreases as the age of acquisition increases. This means that bilingual adults have denser gray matter (the brain tissue that is packed with information-processing nerve cells and fibers), especially in the left hemisphere, where Broca's area (Brodman 45/44) is found, and where linguistic computations are handled by the brain. This density effect is strongest in people who were bilingual before the age of five and are most proficient at both languages.

As we can see, neurocognitive studies on bilinguals strongly suggest that age of acquisition and language proficiency are determinant factors in the neural underpinnings of language and bilingualism, so that early and proficient bilinguals do not "separate" languages in the brain, but as age of acquisition of the non-native language increases and proficiency decreases, the non-native language tends to be located in more extended and individually variable areas: The brain does not represent and compute non-native grammars like native ones, though we still must understand more precisely, and in greater detail when and why this differences emerge (at what ages, for what components, given what conditions, etc).

4. Languages are activated simultaneously in the bilingual.

The brain activates all the languages it knows when it has to use language. In particular, bilinguals activate both of their languages when they have to use one: "Interactions between languages have been observed at all representational levels of language, even when people were tested in purely monolingual language contexts." (Desmet and Duyck 2007: 168-69)

Much of what we know about how the brain copes with more than one language relates to the lexicon. The simple hypothesis that bilinguals have two separate lexicons, one for each language, so that when they use one language, only its lexicon is activated has been shown wrong by many studies: both lexicons are active whenever the bilingual speaks, either in one or the other language.

People who know more than one language must have knowledge of the two phonological and morphosyntactic systems, and also, inevitably, they must know that a given meaning has (at least) two different words attached to it; that is, for instance, a Spanish speaker who knows English must know that the lexical item *uña* in Spanish stands in correspondence to the word *nail* in English because both share the meaning “horny scale of plate of epidermis at the end of the fingers and toes of humans and many apes”, and she must also know there is another homophonous *nail* in English that corresponds to Spanish *clavo*, because they both mean “a slender, pointed piece of metal, usually with a head, used for fastening pieces of wood or other material together, by being driven into or through them”. For the purposes of this chapter, the form of a word will be named “lexical item”, and the meaning it expresses will be named “semantic content”.

Different lexical items can share semantic content, either in case of synonymy or semantic similarity, but more to the point of our discussion, different lexical items in the brain of the bilingual can share semantic content, like in the case of pairs like *uña/nail* in our example above. The activation of semantic content in the brain is independent of the language the lexical item belongs to (Crinion et al. 2006), that is, the semantic/conceptual content associated with lexical items is neurocognitively distinct from the words themselves, so that different word-forms from the languages of the bilingual touch upon the same semantic/conceptual networks in the brain (Kovelman et al. 2008).

In a pioneering study, Van Heuven et al. (1998) found that the lexical items from a bilingual’s native language are active while the bilingual is engaged in recognizing words from a non-native language. It was already known that, in monolinguals, the time it takes for a word to be read and recognized depends on the number of orthographic neighbors the word has. An orthographic neighbor is another word that results from changing one letter in the original one: for example, the Spanish word *una* "one (feminine)" is a neighbor of the word uña "nail", because they only differ in one letter. Van Heuven et al. (1998) discovered that the time it takes Dutch–English bilinguals to recognize an English word like *farm* did not only depend on the number of English neighbors that lexical item has (e.g. *firm*, *fart*), but also on the number of *Dutch* neighbors it has (e.g. *darm* "colon", *faam* "fame"). This result show that lexical representations from the native language are active during a word recognition task in the second language. Following this discovery, other studies revealed the extent of this cross-linguistic activation of the lexicons of the bilinguals: Dijkstra et al. (2000) also found that both lexicons were active when reading cross-linguistic homographs, that is, different words from both languages that have the same orthographic form, like *room*, which is one lexical item in English (synonym of "chamber"), and another one in Dutch (meaning "cream"), because these words took longer to read than those that had no cross-linguistic homographs.

Further studies have shown that this activation of the lexical items irrespective of the language for different types of bilinguals and language-pairs. For instance, further evidence that the native language is activated when using the non-native one had been uncovered by a large number of studies (among them Costa et a. 2000; Duyck, 2005; Duyck et al., 2004; Schwartz et al. 2007). It has also been repeatedly shown that the non-native language is active when the native one is used (see for instance Duyck, 2005 and Van Hell and Dijkstra, 2002, among others). Similar results have been obtained in studies where participants, instead of reading, heard the words they had to recognize (for instance Marian et al. 2008; Marian et al. 2003), and in studies where participants had to actually say the words (Costa et al. 2005; Kroll et al. 2006; Costa et al. 2008; Santesteban and Costa 2006).

Initially, classical psycholinguistic models of the lexicon did not consider the possibility of interactions between two languages in one brain; they were models that only contemplated one lexicon and its relation to semantics and grammar, like the word recognition model from McClelland and Rumelhart (1981) or the word production model by Levelt (1989). However, research on bilinguals reveals that people who know more than one language do not "turn off" the lexicon of the language they are not using, and therefore it calls for a revision of the "isolated lexicon" stance. "The Revised Hierarchical Model" (Kroll and Stewart 1994) became a very influential model of the lexicon in bilinguals; this model was mainly designed to account for successive bilingualism, where the non-native language is learned after the native language has been fully mastered, but could also be applied to simultaneous bilingualism. The conceptual level was assumed to be shared by the two languages, and a division was made between a lexicon for the native language and a lexicon for the second language.

The compelling evidence that linguistic systems are co-activated in neural events that involve the use of language has led current models of the lexicon to assume that the flow of activation from the conceptual/semantic system to the lexicon is not specific to a language (see among others Costa and Caramazza, 1999; Green, 1998; Hermans et al. 1998; Poulisse and Bongaerts 1994). That is, when we hear or say a word, the conceptual/semantic system activates all the corresponding lexical item of the languages we know regardless of the language in use. Ivanova and Costa (2008) have shown that this full activation of the lexicons has a cost in the process of lexical selection and retrieval when monolinguals and bilinguals are compared, such that bilinguals take longer in retrieving a word even when they do so in their dominant language, an effect that has been named "the bilingual cost".

This discovery naturally leads us to the question of how bilinguals manage to produce the words of the target language and prevents words from the non-target language from being uttered. If all the languages of the bilingual are active when language is processed, then there must be some further cognitive operation that controls what language is used at a time.

5. How do bilinguals control what language they speak in?

We have seen there is ample evidence that all languages are active when bilinguals or multilinguals use language. However, bilinguals easily control when to use one language or another, and in order to do this, they must employ some kind of neurocognitive control mechanism.

Proposals as to how bilinguals control their languages in order to produce the one they want to use generally agree that bilingual lexical access must involve some kind of attentional control mechanism (Costa, 2005; Costa et al. 1999; Finkbeiner et al. 2006; Green, 1998; Kroll et al. 2006; La Heij, 2005). Some researchers argue that language control in bilinguals entails the active inhibition of the linguistic representations of the other language, which, despite being activated, is not intended to be used (Green, 1998; Meuter and Allport, 1999).

The most revealing evidence for inhibitory mechanisms in bilinguals has been provided by Costa and collaborators, in a series of experiments on language-switching, where participants are asked to name a picture in one language or another, depending on the colour of the picture. These studies, carried out with various types of bilinguals (of Basque, Catalan, English, French and Spanish), show that low-proficient bilinguals take longer to switch from their less dominant non-native language to their native one than the other way around (Costa and Santesteban, 2004; Costa et al. 2006). This effect has been named the "*asymmetrical switching cost*"; at first sight this result may appear counterintuitive, because it entails that it is "harder" to change from the language you know worse to the language you know better than it is to change from the language you know better to the language you know worse. This is how the researchers explain it: when the bilingual has to speak in the weaker, non-native language, the native language is activated, and therefore it has to be very strongly inhibited. As a consequence of the strong inhibition applied to it, if later these low proficient bilinguals want to speak in the dominant native language, they need to undo the strong inhibition applied to words form their native language. In contrast to this, changing from the strong native language to the weaker non-native language does not require undoing such a strong inhibition, since the words of the weaker language need not be strongly inhibited.

Interestingly, this team of researchers have also discovered that early and highly-proficient bilinguals employ a different mechanism for language control. Given the same language-switching tasks, these bilinguals revealed symmetrical switching costs. That is, it took them the same time to switch from either of the two languages to the other one. Surprisingly, the mechanism employed by these balanced bilinguals yielded a symmetrical pattern not only when switching between the two languages they had known and used throughout their lives, but, surprisingly, also when they had to switch to a third language they had learned much later and knew less.

So, while the switching performance of low-proficient bilinguals leads to an asymmetrical pattern, depending on language dominance, in early and proficient bilinguals it yields a symmetric pattern, which does not only apply to the dominant languages, but also to non-dominant, later learned languages. This neurocognitive difference between early and proficient bilinguals on the one hand, and late not very proficient bilinguals on the other, is reminiscent of the findings by Garbin et al. (2010) we have reported in section 3; this fMRI study reveals that early and proficient bilinguals recruit Broca's area for linguistic and non linguistic switching tasks, whereas monolinguals do not. It is thus very plausible that the symmetrical switch mechanism of balanced bilinguals reflects the involvement of Broca's area, whereas the asymmetrical mechanism reflects lack of involvement of Broca's area in the same tasks.

6. Bilingual Syntax: native and non-native grammars.

There are less studies on syntactic processing in non-monolinguals in comparison to studies on lexical processing, but in the last years this area of research has experienced enormous growth. While evidence on nonnative syntactic processing is still sparse, "even so existing data clearly indicate that syntax is a phenomenon that deserves full consideration" (Kotz 2009).

One general finding that emerges is that the language proficiency of the bilingual has a direct impact in the neurocognitive representation and processing of syntactic phenomena. The impact of age is another factor under close scrutiny, though it is less understood and still subject to much debate. So, whereas there is widespread agreement that proficiency has a direct impact on the neurocognition of syntax, as it does in all domains of language, data concerning the precise impact on syntactic processing of when a non-native language is learned and what the native language looks like do not yet provide a coherent picture that researchers can widely agree upon.

It is generally agreed that native versus non-native differences in language representation and processing are not found in the lexicon/semantic interface, so that as proficiency increases, native and non-native lexical processing are indistinguishable. It is also generally agreed that syntax is different in this respect, so that, within syntax, some aspects of it yield non-native effects, but others do not. What is currently missing is a clear and principled picture of what aspects of syntax fall in one or the other category, and why that is so.

Part of this disagreements relate also to the research methods utilized, and with the advent of experimental studies that employ techniques such as reaction-times, eye tracking, event related potentials and fMRI, we discover native versus non-native syntactic processing differences that could not be detected by off-line techniques such as error-production, grammaticality judgments etc. In any event, and whichever the ultimate explanation for what in syntax differ in native versus non-native speakers, it is essentially neurobiological and must involve neural differences in language representation and processing between the first and the later acquired languages; the experimental methods of cognitive neuroscience are thus best suited to pursue this question in depth.

Similarity to the native language facilitates native like processing of a second language, although it is not yet known whether this effect is due to transfer from the native language representation to non-native language representation (Sabourin et al. 2006), or to the use of shared neural networks for both languages (Mac Whinney 2005). Studies on proficient bilinguals have shown that violations of morphosyntactic contrasts in the non-native language that are shared with the native one elicit stronger neural and behavioral responses as compared with violations of contrasts that are not shared by both languages (Sabourin and Stowe 2008).

When we consider research on syntactic processing that measures the electrophysiological activity of the brain by means of evoked response potentials (ERP), we also find a noisy landscape, with studies that do not find age-effects in non-native syntactic processing, and studies that do. A review of ERP studies in bilinguals indicate that the ERP components characteristic of language processing are modulated by age of acquisition and language proficiency of the bilingual person. That is, the ‘‘native-likeness’’ of a bilingual hinges upon the onset and extent of exposure to the languages (Moreno et al. 2008). Some indications that age impacts bilingualism have obtained in ERP studies on syntactic anomaly detection, where results suggest that late bilinguals fail to develop automatic short-latency syntactic processing mechanisms for the non-native language.

Some ERP studies report that syntax yields differences between natives and non-natives, because they detect different ERP signatures in non-native speakers for certain syntactic tasks, as compared to natives. But other studies report that very proficient speakers are indistinguishable from natives because they show the same electrophysiological components as natives (Steinhauer et al. 2009, see Kotz 2009 for a review).

The evidence is still scarce and the picture that emerges is incomplete, probably because all kinds of morphosyntactic phenomena have been considered on equal footing, without resorting to linguistically motivated criteria given current syntactic theories when the phenomena to test are selected. A review of the literature on ERP studies of native versus non-native syntactic processing suggests that neurocognitive differences obtain when the grammars of the bilingual differ in a linguistically significant way with respect to the syntactic property tested, and there has been a time delay in the acquisition of the non-native syntax; however, non-native speakers appear to process syntax in a native like fashion when the syntactic property tested in the second language has an equivalent correlate in the native language of the subjects investigated. This does not necessarily entail that all syntactic differences between the languages of the bilingual lead to detectable native versus non-native effects, nor does it entail either that all grammatically significant differences should be sensitive to non-native acquisition (Watenburger et al. 2003).

For example, and without intending to be exhaustive in this review of ERP studies, Weber-Fox and Neville (1996), Mueller et al. (2005), Ojima et al. (2005), and Chen et al. (2007), all found non-native effects that obtained when very proficient non-native speakers were processing syntactic phenomena that had no identical correlate in their native language: in the case of Weber-Fox and Neville (1996), non-native effects obtained when testing native Chinese speakers with subjacency effects in English Wh-questions. But Chinese is a Wh in-situ grammar that lacks overt Wh-movement while English is an overt Wh-movement language (see Cheng 1997). The syntactic phenomenon tested thus involved a property absent (or valued otherwise) in the native language of the participants. Mueller et al. (2005) tested Japanese classifier morphology, which German lacks, in Japanese natives versus German natives learners of Japanese. In Ojima et al (2005) and Chen et al. (2007), the phenomenon tested was verb agreement, in proficient bilinguals of English who were native speakers of grammars that lack verb-agreement morphology (Japanese, Chinese). This initial picture strongly suggests that it is in systematic and true grammatical phenomena that diverge in the two languages of the bilingual that we might find native versus non-native processing differences. Although, as we have seen, both age of acquisition and proficiency have been hypothesized and scrutinized as relevant factors conditioning non-native syntactic processing, less attention has been paid so far to the issue of what syntactic phenomena are tested, and why.

In the last decades, a rapidly growing body of studies using experimental methods and neuroimaging techniques has explored syntactic processing, and as a result, findings from linguistic theory and the neurosciences are progressively reaching increasing levels of convergence and reciprocal relevance (Marantz 2005, Moro 2008, Pullvermüller 2002). However, the vast majority of language processing and neuroimaging studies still focus on typologically similar languages (English, Spanish, Italian, French, German, or Dutch, for instance). With the exception of a few recently emerging studies on Japanese, Chinese and Korean, the languages most intensively studied share many parametric properties. In Linguistic Theory, a significant expansion of the language pool investigated, and systematic cross-linguistic inquiry was crucial to uncover the interplay between universal and variable aspects of the language faculty (Greenberg 1963, Chomsky 1981). Research on language representation and processing in the brain should similarly benefit from cross-linguistic studies pursued with criteria rooted in syntactic theory, so that we can differentiate language-particular, parameter-driven effects from universal, invariant properties, and understand the interplay between the two. In order to achieve this goal, it is necessary to conduct studies and gather evidence from a wide array of languages pertaining to different typological groups, and it is crucial to study bilinguals whose languages have opposite parametric specifications.

In a recent review of ERP studies on non-native language processing, Kotz (2009) concludes that “it is necessary to consider and investigate multiple structural subtleties at the linguistic and the neurophysiological level”. In

Generative Linguistics, one prevalent view of cross-linguistic variation, the Principles and Parameters (P&P) approach, holds that specific grammars result from combinations of a finite set of linguistic parameters. Thus, syntactic variation results from differences in the values of this combination of parameters (Chomsky, 1981, see Baker 2001, 2003 for overviews), and the acquisition of syntax would consist in determining the values of these syntactic parameters for the input language. Given the P&P model, native/non-native effects, if at all, should be expected only in computational components of language that are subject to specification via input (i.e. parameters), because in this approach language distance results from differences in the values of a finite number of discrete parameters. If the task of the language learner is setting the values of parameters, then non-native effects might arise with respect to specific parameters, when the native and non-native grammar differ in their value.

Within this approach, Zawiszewski et al. (2011) explored native and non-native syntactic processing in a group of native Basque speakers compared to a group of early and very proficient Spanish-Basque bilinguals, paying special attention to the parametric distance factor. To this end, the study compared how native speakers of Basque and early highly proficient non-natives whose native language is Spanish process certain core parameters of Basque syntax that either diverge from or converge with Spanish syntax. Natives and non-natives behaved alike in those tasks that involved the same parametric value for Basque and Spanish (such verb agreement), but differed in tasks that involved syntactic parameters of opposite values in the two languages such as the head parameter or the case system (nominative in Spanish versus ergative in Basque). The results hence suggest that divergent parameters have a deeper impact in non-native syntactic processing than other seemingly variable but superficially different aspects of language variability.

Clahsen and Felser (2006) propose that only non-local dependencies (such as antecedent-trace relations) yield non-native effects in syntax, whereas local dependencies (such as verb agreement) are processed native-like by non-natives at high degrees of language proficiency and use, regardless of the specifications of the native language. This claim has been contested by Steinhauer et al. (2009), who discuss evidence that syntactic processing becomes native-like at high proficiency, some of which has also been discussed in the previous section, and argue that language proficiency is the ultimate determinant of differences between native speakers and second language learners. There is wide agreement that second language learners s tend to rely more on lexical-semantic information and less on syntactic structure to process various morphosyntactic phenomena, a difference that is reflected in the generation of the N400 ERP component in learners for those morphosyntactic violations that generate either a LAN-P600 biphasic pattern or a P600 in natives. This difference between natives and second language learners is repeatedly encountered across different studies on non-native syntactic processing, even at the earliest stages of language learning in adults (see Steinhaur et al 2009 and MacLaughlin et al. 2010 for reviews).

7. Is there a critical period for second languages?

Ever since Lenneberg (1967) suggested that there is a critical period for language acquisition, the impact of age of early linguistic experience for adult neural representation and processing has been a much debated issue. Concerning first language acquisition, there is wide agreement among language researchers that there is a critical window for language, which closes around puberty. For instance, Mayberry, et al. (2002) showed that deaf adults that had had early language experience achieved native like proficiency in American Sign Language, while deaf adults that had no early language experience did not. See Hagen (2008) for an argument that the critical period for language acquisition is an adaptive trait in human evolution, tightly tied to the biological roots of the language faculty, but crucially involving only native languages learned during childhood.

However, the status of the critical period for language acquisition has been and still is intensely debated in bilingualism, and very especially in the field of Second Language Learning (SLA), that focuses on late childhood, pubescent or post-pubescent language learning once a native language has been fully acquired. Whether a second language learner's linguistic knowledge is represented and processed like the native one has been intensely debated for almost two decades (Gregg, 2003, White 2003); researchers report similarities in the production of second language learners and children acquiring their native language, which cannot be accounted for in terms of transfer from the learners' first language (White 2003). These production data favor hypotheses that place great emphasis on the similarity between first and second language grammar-building (Leung 2007). Recently, however, cognitive neuroscience methods have started to be used in second language learning research, and have provided new evidence on the similarities and differences between first and second languages (Abutalebi, Cappa and Perani 2001, Mueller et al. 2005, Diaz et al. 2008, McLaughin et al. 2010). Also, as discussed in previous sections, both electrophysiological studies (ERPs) and functional brain imaging studies (fMRI) reveal the general picture that both proficiency and age of acquisition has an impact on the representation of language in the bilingual, with an increase relevance of age as the time lapse between the native and non-native languages increases. This general picture has generated growing agreement in the field of SLA that the distinctiveness of second language learners do not involve lexico-semantic aspects of the second language, but do involve some aspects of syntax, although their extent and nature are still poorly understood. Given the uncontroversial status of proficiency as a relevant factor in the representation of language in the brain, it is worth underlying the finding that age of acquisition also makes a difference, for this is the point of debate in the field of SLA, within applied linguistics.

It must also be kept in mind that proficiency and age of acquisition are likely to be correlated factors. Hence, the possibility exists that second language learners achieve higher proficiency levels at earliest ages of onset of learning. The impact of individual variability is also a potentially relevant, though still obscure factor in the neurobiology of language. For instance, Golestani et al. 2006 studied syntactic processing in second language learners tested at 20-28 years of age, who started to learn English at the ages of 10–12 and studied it in school for a total of 5 to 7 years. The proficiency levels varied across individuals. During syntactic production, activation in Broca's area of the second language increased as proficiency increased. As the authors discuss, this result could be due to individual differences, so that more grammatically proficient bilinguals can use cortex that is more 'tuned' for native-like processing, due to either their architectonics and pattern of connectivity, or to differences in the critical period window involving degree to which individuals recruit more 'optimized' neural representations or processes for a second language. This evidence points to the individual variability in non-native syntactic processing.

Thus, the age at which language, whether native o non-native is acquired has significant effects in the domain of phonology and syntax, the two computational components of language (Birdsong, 1999; Birdsong and Molis, 2001; Flege, 1999; Flege, Yeni-Komshiam, and Liu, 1999; Newport, 1990, 1991; Sebastián-Gallés and Bosch, 2002; Sebastián-Gallés, Echeverría, and Bosch, 2005; Sebastián-Gallés and Soto- Faraco, 1999; Weber-Fox and Neville, 1996, 1999; for a review, see Sebastián-Gallés and Kroll, 2003). This variable affects not only the acquisition of phonological or syntactic representations, but also the processing mechanisms. Wartenburger et al. (2003) argued that different linguistic components are affected by age of acquisition to different extents, without affecting semantic information. Hence, there is a growing consensus that, given a relatively high degree of proficiency and use, age acquisition does not impact the lexical-semantic component, it impacts phonology, and it also impacts syntax in ways that still need to be better understood.

In comparison to child/early learners, young-adult/late learners display selective problems in phonology, that are most obviously manifest in foreign accent: Oyama (1976) did a correlational study of foreign accents among immigrants to the United States; the variable age at arrival was a strong predictor of degree of accent but length of stay in the USA was not (see also Flege et al. 1999).   This effect emerges also in morphosyntax (Flege et al., 1999; White, 2003). Johnson and Newport (1989) tested of knowledge of English grammar among Korean and Chinese immigrants to the United States, and found that proficiency correlated negatively with age of arrival; those who arrived at an earlier age were more likely to have a full mastery of English grammar, and this command decreased as age of arrival increased. In sharp contrast lexical–conceptual processing (Weber-Fox and Neville, 1996; Hahne, 2001; Wartenburger et al., 2003).

Age effects in language have been explained in a variety of ways (Birdsong, 1999), including the loss of language-specific learning mechanisms (Bley-Vroman, 1989; Pinker and Prince, 1994), the advantage of small working-memory capacities in childhood, such as the 'less is more' hypothesis (Newport 1993), and 'neural commitment' or 'entrenchment' and consequent interference of second language by earlier learned knowledge (Marchman, 1993).

Among the neurobiological proposals to account for age-related differences in language, an influential ones is the model advocated by Ullman (2001), (2004), in terms of procedural versus declarative memory. In Ullman's DP model, the brain systems underlying two well-known memory capacities, declarative and procedural memory, also subserve aspects of the mental lexicon and the mental grammar. The grammar is subserved mainly by procedural memory, whereas lexical-semantic knowledge is mostly subserved by declarative memory. These two systems have a maturational pattern such that the brain can incorporate new knowledge to the procedural memory system easily in childhood, but this capacity is diminished in favour of declarative memory after puberty. In this view, the difficulties experienced with syntax by second language learners are interpreted as a consequence of the fact that, especially after puberty, the grammatical/procedural system is less available than lexical/declarative memory (Ullman 2001).

This dual system for language has been incorporated to models of bilingualism like Paradis (2004), who joins Ullman's claim that it is the ability to incorporate knowledge into procedural memory decays in adulthood. Post-pubescent language learners rely more on the declarative memory system to compensate for the decline in procedural memory. The DP model could account for the different loci of language activation in early versus late bilinguals, since declarative and procedural memory involve distinct brain regions, and also for why the acquisition of semantic knowledge –subserved by declarative knowledge– remains unaffected by age, and is only sensitive to proficiency.

The impact of age in language remains somewhat controversial, particularly in educational and social studies, although it is much more accepted within the neurocognitive community. Whether the impact of age in language is due to a critical period for language acquisition is still a matter for debate, particularly in the case of a second language, where some researchers accept it as an effect of the critical period for language acquisition, but others interpret it as reflecting less exposure and practice (and less proficiency).

8. Conclusion.

The curse that allegedly dispersed humankind in the biblical story of Babel could never work, because humans are not necessarily monolingual. In fact, humans are distinctively and characteristically capable of learning, knowing and using more than one language, a trait that is unheard of in other species with communicative systems. Given this inherent feature of the human language faculty, linguistic diversity does not constitute an insurmountable obstacle in the path of human cooperation, and Babel's curse can be easily overcome.

Despite the fact that bilingualism is pervasive in our species, not much is known about its neural underpinnings, though its study is a fast growing research area, of which we can only provide a partial view. Bilinguals and multilinguals are particularly relevant subjects of study to understand the interaction between aspects of language that are independent from experience, part of the human genetic endowment, and those that depend on experience, and yield language diversity. In their review on native versus non-native language processing, Clahsen and Felser (2006) stated that “non-native language processing has long been the subject of much speculation and little empirical investigation.” The advent of experimental methods, the increasing number of researchers that take part in the goal of understanding bilingualism and multilingualism, and the ever growing variety of languages and types of bilinguals studied have radically changed this picture. Bilingual and non-native language processing is a thriving area of discovery today, as reflected in these words from neuroscientists that study bilingualism, “Possibly, in an unexpected twist, it is the study of bilinguals that may reveal the language processing potential not fully recruited in monolinguals and lead us to the biological extent of the neural tissue underlying all human language.” (Kovelman et al. 2008:1468).

As we have seen, a brain that holds more than one language does not keep the two languages separate, isolated one from the other. Instead, when the two languages are acquired simultaneously or nearly so, the brain hosts them together, in the same neural tissue, as a monolingual brain would do with a single language. As age of acquisition increases and proficiency decreases, the representation of the language is less specific to language areas and more widespread, indicating less computational efficiency. Sustained bilingualism enforces specific neural networks for the executive control system that differ from those in monolinguals; as a result, bilinguals have enhanced cognitive capacities in these domains, which can detectably delay symptoms of neurodegeneration, given the compensatory resources available to the lifetime bilingual. Languages are simultaneously activated in the brain and inhibited if not required; again, early, sustained and balanced bilingualism yields distinct and more efficient neural mechanisms for language control in language areas, while other types of bilingualism do not. Proficiency and frequency of use are significant factors in neurobilingualism, in all language components. Although there is much we do not know at present about syntactic processing in bilinguals, what we know indicates that variable (parametric) aspects of syntax may be sensitive to age of acquisition (similar to what is found in phonology), whereas other invariable aspects of syntax are not, provided a native language has been normally acquired. Lexical-semantic aspects of language are impervious to age, only sensitive to proficiency.

These findings suggest that the brain is not very much interested in separating one language from another. Rather, the brain appears to compute and store "language" as one single cognitive function, with phonology, syntax and semantics as somewhat distinct components. Only when a language is learned late, and given less exposure and use, does the brain start to signal a difference, and treat this second language distinctively, locating it more broadly, less specifically, and hence computing it less efficiently.

Any thriving research field is full of disagreements and debates, and the neurocognition of language is no exception. However, there is ample agreement that research on bilingualism and multilingualism are privileged windows into brain plasticity, critical learning periods, and the degree to which language is constituted of specific neurocognitive substrates. Linguistics has undoubtedly much to contribute in this challenging and fascinating endeavour. For those linguists interested in the study of the neurobiological foundations of language, bilingualism and multilingualism offer a unique opportunity to explore the nature of those properties shared by human languages, and those that vary and are patently dependent on experience. As we discover this, we will learn how grammar is shaped by cognitive forces, and how the human brain evolved its computational capabilities to beget words, and knit them into sentences of limitless expressive power that allow us to wonder what it is like to have more than one language in the brain.

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