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Two Languages, One Brain

Even though evolution has resulted in millions of species, it still has not generated my favourite species, the Babel fish. This animal was dreamed up by the British writer Douglas Adams in his wonderful novel *The Hitchhiker's Guide to the Galaxy.* If you have not read it, put down this book and go out and buy it … and later, we'll see each other at the 'restaurant at the end of the universe'. Here is more about the Babel fish:

> 'The Babel fish,' said *The Hitchhiker's Guide to the Galaxy* quietly, 'is small, yellow and leechlike, and probably the oddest thing in the Universe. It feeds on brainwave energy received not from its own carrier but from those around it. It absorbs all unconscious mental frequencies from this brainwave energy to nourish itself with. It then excretes into the mind of its carrier a telepathic matrix formed by combining the conscious thought frequencies with nerve signals picked up from the speech centres of the brain which has supplied them. The practical upshot of all this is that if you stick a Babel fish in your ear you can instantly understand anything in any form of language. The speech patterns you actually hear decode the brainwave matrix which has been fed into your mind by your Babel fish.'[fn1]

Don't tell me that the Babel fish isn't an interesting species! How many problems could we solve if this creature really existed … the strangest creature in the universe. At the very least, we wouldn't have to worry about struggling through second-language learning. We would just go to a fish store – problem solved.

Bilingual speakers are not Babel fish (they are not used to whispering in anybody's ear), but they do have something in common: in both of their brains there must be linguistic representations that correspond to two languages. In other words, the only way the fish can translate from one language to another is by having both of them stored in its little brain. And while bilinguals only speak two languages and not *all* languages in the universe, the question is the same: how do two languages coexist in one brain, and what are the consequences for their continuous use? This chapter is dedicated to this issue and others intrinsically related to it.

The study of how the brain sustains higher-level cognitive abilities, or what we will refer to as cortical representations of cognitive functions (language is one of them), is extremely complex. The brain and cognitive bases of language, memory, attention, emotion, and so on, are difficult to study. This is because, among other things, the cognitive processes involved in these capacities are not independent, but interactive, and in complex ways. Think about how the emotional system interacts constantly with the attentional system when a highly emotional stimulus suddenly piques our interest. Remember, for example, the last time you were at a noisy party and were trying to have a conversation. You could probably barely pay attention to the person speaking to you and all the other conversations around you just seemed like background noise. However, if someone having a nearby conversation had said your name, perhaps that would have caught your attention. So, even though everything but your own conversation seems just like noise, your ears would have detected your name and would have directed your attention to that conversation. Yes, our name is a highly emotional stimulus: we care very much about what other people say about us.

To make things more difficult, the more we understand about the relationship between cognition and the brain, the more it is evident that higher-level cognitive functions involve neural circuits that are distributed in different areas of the brain. This is not to say, however, that there may not be certain areas that have a greater or lesser importance in the functioning of each of these skills, but it does mean that the relationship between the brain and cognition is even more complex than we thought. You can think of the brain as an orchestra and as in any orchestra, there are different instruments with greater or lesser importance to mark harmony, melody, or rhythm in a musical piece.

For many years our knowledge about how language is represented in the brain has come from studying the verbal behaviour of people who suffer some kind of brain damage. We call these language disorders *aphasia*. Brain damage can arise from various causes, such as tumours, infections, congenital malformations, strokes, neurodegenerative diseases, or traumatic brain injuries. The study of how injuries in different areas of the brain result in different verbal behaviour patterns has been fundamental to relating cognitive functional models of language, informed by linguistics and cognitive psychology, with neural correlates. However, in the last thirty years, the development of neuroimaging techniques has dramatically advanced the field of cognitive neuroscience. These techniques allow us to 'see' live (or almost live) brain activity of healthy people while they perform different experimental tasks. For example, we can analyse which brain circuits are activated when reading a text compared to naming drawings, hearing phrases, or thinking about plans for the weekend.

We can register the brain activity triggered by these tasks by measuring the oxygen consumption of certain areas or by registering the electrical activity generated by groups of neurons. In addition, the degree of temporal and spatial precision is more than adequate. These techniques also allow us to make predictions about which areas of the brain should be most involved in different aspects of language processing. These hypotheses were more difficult to make when we were able to study only the verbal behaviour of people with brain damage, and, in many cases, we could only know with certainty which tissue was damaged after the patient's death. Let's see how these studies have helped us to better understand how two languages coexist in the same brain.

BRAIN DAMAGE AND BILINGUALISM

In one of the 2015 Formula 1 World Championship pre-season training sessions, the McLaren driver Fernando Alonso had an accident: he hit the wall of a curve in the Montmeló, Catalonia, circuit. As a result Alonso suffered a concussion and had to be admitted to the hospital, where he was kept under observation for a couple of weeks. Fortunately, he recovered successfully and continued competing in the world championship. The causes of the accident still have not been completely clarified. At first glance, it seemed strange that a driver as experienced as Alonso had made a mistake, apparently an enormous one, which led to all kinds of speculation regarding a technical failure of the car. I'm not a frequent follower of motor sports, so I wouldn't have paid attention to this if it had not been for the following: along with the rumours about the cause of the accident, news began to spread that right after the accident Alonso could only speak Italian (a language he knew and used often, among other things for having been a former driver of the Ferrari team), but not his native language, Spanish, or the language with which he interacted daily with the members of his team, English. This was framed as strange behaviour on his part. There were headlines such as 'Fernando Alonso Wakes Up in Italian' and some that even surprised me like 'Alonso Not the First Spanish Athlete to Wake Up Speaking in Italian' (in case you are interested, the other was the cyclist Pedro Horrillo).

I find this story especially interesting for two reasons. First, because Alonso's strange verbal behaviour made so many people (or at least journalists) pay attention, showing that there is general interest about language, and in this case, about bilingualism. In fact, this news attracts attention regardless of whether the affected party is well known to the public, as we can see from the story of an American man who woke up from unconsciousness speaking Swedish.[fn2] It's funny how these cases often lead to bizarre speculation such as wondering whether the man knew Swedish before losing consciousness or whether his ancestors were Swedish. In any case, we probably agree on the following: no brain damage can result in the sudden learning of a new language, nor can the knowledge of a language be transmitted through genes, at least as far as we know right now.

The other reason why I find Alonso's case especially interesting is because he himself denied that the situation had taken place. In subsequent statements the driver said: 'It was all normal, I did not wake up in 1995, or speak in Italian, or anything that has been said. I remember the accident and everything that happened.' Who knows why anyone would say that Alonso woke up speaking only in Italian for a few minutes.

Before we explore what we know about the linguistic deterioration of a bilingual's languages resulting from brain damage, we should take a little time to define some basic concepts in neuropsychology.

The first lesson I learned from Alfonso Caramazza during my post-doctoral work at Harvard University was that in neuropsychology there are two types of behavioural patterns that are highly informative. On the one hand, we have the so-called *associated deficits*, which refer to two or more linguistic dysfunctions that appear together as a result of damage to a specific area of the brain. For example, if a bilingual speaker shows a specific dysfunction in each of his languages due to this damage (for example, he has problems repeating words), we refer to this as an association of dysfunctions in the two languages. That is, the two languages are affected in the same way by the brain damage. On the other hand, more interesting, perhaps, is what *dissociated deficits* tell us. Imagine in this case that, as a result of brain damage, a person shows certain linguistic problems in one of his languages but not in the other. In other words, the patient shows a dissociation between speech in his two languages. That is, his ability, for example, to repeat words in one language is dissociated from his ability to repeat words in the other language. Dissociations offer us a lot of information, because they suggest that whatever brain damage a patient suffers, this affects one type of cognitive process (repetition of words in language A) and not other types (repetition of words in language B), which in turn suggests that such processes are supported by different brain circuits that are to a certain extent cognitively independent.

Maybe the following analogy will help. The windshield wipers of a car are independent of the braking system. So we may encounter situations in which one works but the other doesn't. However, both rely on the correct functioning of the electrical system and, therefore, if that breaks down, both the windshield wipers and brakes will stop working. In the first case, there is a dissociation and in the second, an association. Below I describe an example of these dissociations, which we will return to later in cases of bilingualism. (If you are curious to learn more about these dissociations, Oliver Sacks has written very well about them.)

Students in secondary education tend to find language classes difficult and boring, especially when it comes to syntactic analysis. In this case, they may be right: the subject is indeed difficult and, sometimes, boring. If you had to study language this way, you might remember generating tree structures based on sentences (subject, predicate, etc.). To create one of those trees, you had to determine the grammatical categories of the words and their function with respect to the rest of the words within the sentence. It is much more difficult to do this in terms of language use, at least with regard to spoken language. However, not everything is that complicated, and one of the things that children learn naturally is the difference between nouns and verbs. Determining what nouns and verbs are is extremely simple compared to identifying determiners, adverbs, and conjunctions, for example. It is as if we understood the relationship between objects-nouns and actions-verbs naturally. And, in fact, the linguistic difference between nouns and verbs exists in all languages and is a central grammatical property in linguistic theories. This difference reflects, to some extent, our view of the world or conceptual structures: nouns tend to describe objects and verbs tend to describe actions. They tend to, just tend to. In addition to the fact that this difference is useful in linguistic descriptions, the question that we are interested in here is to what extent this difference has a cerebral correlate. That is, it is not immediately obvious that there are certain neural circuits that facilitate to a greater extent the processing of nouns and others that support the processing of verbs.

As it turns out, there are quite a few people who after brain damage have more problems processing nouns than verbs. In addition, the opposite pattern can be found in other patients, that is, those who experience more problems with verbs than nouns. Some suffer from what is called *anomia*, which refers to the difficulty in accessing words from the mental lexicon when we want to express ourselves. To put it simply, these people suffer much more often than healthy speakers from situations of having something 'on the tip of the tongue'. Imagine how cumbersome that would be! When these patients are asked to say aloud the name of an object in a drawing (like *a broom*), it is common for them to fall into an anomic state in which they cannot recover the name of the object, although they know perfectly well what object is represented in the drawing. But interestingly, it is in that same situation that the patient may be able to name the verb that corresponds to the action that is carried out with that noun (like *to sweep*). In other words, brain damage can affect certain grammatical categories' representations to a greater extent than other categories' representations – what we have previously described as a dissociation of deficits. These observations suggest that, in fact, the difference between nouns and verbs does not only have implications for linguistic theories, but our brain seems to take this difference into account when organizing the mental lexicon. We will return to this example of dissociation later.

The question that interests us now is to what extent a brain lesion affects each of the bilingual speaker's languages differently, and whether we can observe some sort of relatively constant pattern. My opinion on this matter is perhaps somewhat controversial, but I believe that the more common pattern, and by far, is that the two languages of the bilingual speaker are each affected in a very similar manner and degree. In other words, it does not seem very common to find cases in which one of the languages is much more affected than the other, always considering, of course, the degree of knowledge of the two languages prior to brain damage.

I say that this view is controversial because you will be able to find a long list of different patterns of impairments and recovery of the two languages in other books on bilingualism and neuropsychology. For example, in the typology described by Michel Paradis, we find up to five types of linguistic recovery: the pattern of *parallel recovery* is when the patient recovers his linguistic abilities similarly in both languages; *differential recovery* occurs when a patient recovers one of his two languages to a level similar to that which he had before the brain damage but does not do so for the other language; the *antagonist recovery* refers to a curious situation in which the recovery of one language negatively affects the other language. Finally, there are two more typologies. *Successive recovery*, where one of the languages begins to recover only when the other is fully recovered; and the so-called *blended recovery* in which both languages are mixed involuntarily, thus hampering their restoration.

I'm not saying that these types of cases do not or cannot exist, or that they are uninteresting (in fact, I think they are quite interesting, as we will see later). All I'm saying is that the most common case is parallel impairment of both languages. In addition, the examples that support some of these dissociations are more often from clinical observations (often when the patient's impairment is acute) than from controlled, systematic studies. However, I must admit that there are contradictory findings. I think it is relevant to mention here that studies on bilingual aphasics are especially complicated, given that, very often, it is difficult for us to know precisely what the patient's linguistic levels were before impairment and what he did with his languages. To further complicate the matter, factors such as age of acquisition of the second language and linguistic dominance (the language that a person uses with more fluidity) can also affect impairment and recovery patterns.

From my point of view, there are two reasons why the most frequent pattern of language deterioration is parallel. The first is that, as we will see later, neuroimaging studies show that there is significant overlap between the areas of the brain that sustain the processing of both languages. So, if there is such overlap, at least at the macroscopic level, it is reasonable to think that the two languages are affected similarly in many cases. The second reason has to do with the fact that oftentimes linguistic impairments are the result of damage affecting several areas of the brain, making it difficult to detect potential dissociations between languages. Therefore, in principle, it is possible that certain neural circuits are more involved in the representation of one or another language, but that these differences are only visible in a microscopic way.

Here are a couple of examples about the type of evidence that supports parallel impairment of the two languages. The first comes from a study that came up as a result of a question that my mother asked me one Sunday afternoon while we were eating. The question was simple: 'I have a friend who has been diagnosed with Alzheimer's disease. Although I've always spoken to her in Catalan, which is her second language, in what language will I likely end up speaking with her, in Spanish or Catalan?' What my mother asked was a common concern. Let's reformulate the question in academic terms: how do languages deteriorate as a consequence of a neurodegenerative disease? My answer was even simpler: I did not know, and the worst thing is that there were not many studies I could consult.

After consulting the few studies carried out on the subject, I noticed that the issue was not entirely clear, so I set out to do something about it. In collaboration with neurology departments from several hospitals in Barcelona, we evaluated the linguistic competence of three groups of Spanish-Catalan bilinguals. These bilinguals had spoken on average for more than fifty years in the two languages and possessed a high knowledge of both. Most of them lived in the metropolitan area of Barcelona, where the daily use of both languages is very common. Two of the groups consisted of participants who had been diagnosed with Alzheimer's disease and were in a mild to moderate stage of the disease, according to standardized neuropsychological tests. The third group included individuals who suffered from mild cognitive impairment and those who had not been diagnosed with Alzheimer's. In different experimental sessions, we asked the participants to say the name of what was presented in drawings in both their languages. They also performed a translation task in which they were presented with a word in one language that they had to say aloud in the other language. As you can see in Figure 2.1, we obtained at least two clear results. First, bilinguals who had poorer performance in neuropsychological tests also had poorer performance in the linguistic tasks that we had designed. This was not a very surprising result since it is expected that an impact on the cognitive system in general also harms language. Second, the language impairment associated with cognitive deterioration was of equal magnitude for both languages. Although the participants performed the tasks a little better in the language they reported as more dominant (whether it was the first they had acquired or not, and whether it was Spanish or Catalan), there was a pattern of parallel language impairment. In addition, the type of errors that participants committed in both languages was also similar. For example, although the percentage of errors arising from an unintended language (a translation into the irrelevant language) was greater for the non-dominant language, the pattern of deterioration was also parallel. In other words, the disease was deteriorating the two languages in the same way and at the same pace. I could now tell my mother that her friend would continue to speak the same language but with greater difficulty.

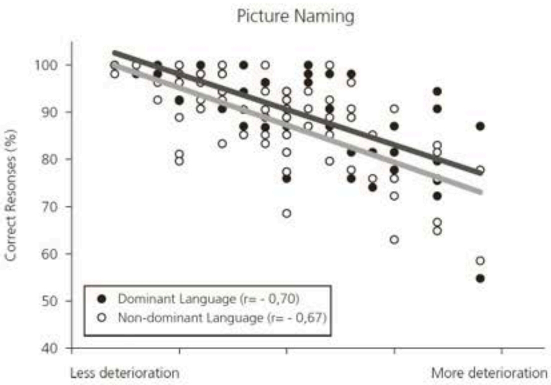

Figure 2.1. Each of the circles corresponds to a participant's score from the three groups in the study. Black circles correspond to the score in the dominant language and white circles show scores in the non-dominant one. The horizontal axis of the graph corresponds to the participants' scores in a standard neuropsychological test. The further to the right the circles are, the greater the participant's cognitive impairment measured in that test. The more cognitive impairment there is, the worse the scores are. The slope is similar for both languages, reflecting parallel impairment.

The second example has to do with the impairments that we commented on earlier, where there are much greater difficulties in accessing words from one grammatical category compared to another. Remember: verbs before nouns. We only have a partial understanding of the origin of this dissociation and how the brain represents words or lexical items. However, the phenomenon itself would seem to indicate that, at a minimum, the grammatical distinction of noun versus verb is one of those that the brain considers when organizing lexical information. In the context of bilingualism, the question is whether the two languages are organized based on the same variables or dimensions. About eight years ago, we had the opportunity to address this question, when a fifty-five-year-old bilingual man who suffered from a progressive primary aphasia was generous enough to collaborate with us by participating in several linguistic tests. His disease is a neurodegenerative one in which one of the most notable symptoms is the progressive deterioration of linguistic capabilities beginning from the earliest stages of the disease.

Thanks to this man's patience, we were able to track his linguistic skills for two years, which allowed us to evaluate how language skills were deteriorating as the disease progressed. From our own observations, we quickly noticed that he had many more problems when the activity involved verbs than when it involved nouns. His mistakes were basically due to anomic episodes (tip-of-the-tongue states), but he also made some semantic errors, for instance saying 'pear' when shown a drawing of an apple. In addition, he showed worse performance overall in his second language (Catalan) than in his dominant one (Spanish), despite having learned them both before the age of four, and having used Catalan with his wife and children. What was more interesting was that the dissociation between nouns and verbs was present in both languages. This was not an isolated case and, in fact, it perfectly complemented our observations from a previous case in which a patient who suffered from Alzheimer's disease showed the opposite dissociation, that is, a much larger and disproportionate impairment for words corresponding to nouns compared to verbs, but again, in both languages.

These cases, and similar ones, suggest that the brain tends to apply the same principles to both languages when it organizes information about words – in this case, their grammatical category. In other words, the properties that are important for language organization in the brain are the same for a bilingual's two languages. And in fact, this claim is consistent with the results of studies in which brain activity is analysed during the processing of nouns and verbs among healthy bilinguals. In these studies, it has been found that certain cerebral areas seem to have different degrees of influence on the representation of these different grammatical categories. The crucial point to mention here is that these differences are also observed in the second language.

These studies are just a few examples of the many investigations which show that parallel impairment in the two languages is the most common pattern of linguistic impairment due to brain damage. However, there are also other studies that show some dissociations.

Consider, for example, this clinical case: Raphiq Ibrahim from the University of Haifa studied the verbal behaviour of a forty-one-year-old man who suffered a brain injury as a result of encephalitis caused by a type of herpes simplex (yes, the same one that can appear on the lips can spread to the brain and severely affect it). This injury especially affected his left temporal lobe, an area of the brain critical for language processing, among other things. The patient was a high-school biology teacher in the city of Haifa, Israel, and although his first language was Arabic, he was highly proficient in Hebrew, a language that he had learned at the age of ten and used regularly both at school and in his private life. Ibrahim explored the patient's verbal behaviour on several linguistic tasks in his two languages two years after the patient suffered the injury and after he underwent surgery to remove the damaged area. The patient had little speech fluidity, with many pauses and anomic states in which it was difficult for him to access words from the mental lexicon. However, reduced fluency was much more evident when the patient spoke in Hebrew than when he spoke in Arabic. Although his scores on standard tests, which involved naming drawings, were below normal in both languages, they were much worse in Hebrew. Also, his understanding of speech and the ability to read and write were more impaired in Hebrew. Nevertheless, and interestingly, his ability to simply repeat words was not affected in either language. The patient received intensive language therapy in both languages for three months, and even though his performance got better in both, such improvement was much more apparent in Arabic. These results led the author to argue in favour of the existence of cortical centres that are specific to each of the languages, in this case, two similar languages that are both Semitic.

Before moving on to the next section, I would like to take a moment to thank all the people and their families who have collaborated in this type of research, always with a commendable predisposition to help science. This help is especially generous when one is suffering from cognitive deterioration due to a disease. Indeed, they are patients with great strength and courage. To all of you, thank you, truly.

PHOTOGRAPHING THE TWO LANGUAGES

Almost twenty years ago, while I was doing my PhD, I was a research assistant in one of the first studies to be carried out with the objective of exploring how two languages were represented in the bilingual brain. The study aimed to investigate the effect of the age of acquisition of the second language on both languages' cortical representation. This involved analysing brain responses of highly proficient bilingual speakers using positron emission tomography. To do so, we studied Italian-English bilinguals with a late age of second-language acquisition (at age ten) and Castilian-Catalan bilinguals with an early age of second-language acquisition (at age four). One of the difficulties we faced was that at that time our laboratory did not have access to that particular neuroimaging technique, so, in collaboration with a team of neurologists from Milan, we decided to conduct the experiment in the Milanese hospital of San Raffaele. This meant that the participants had to travel from Barcelona to Milan, in such a way that they also had a pleasant end of week in the Lombard city. It was all in the name of science.

There have been many studies exploring the brain activity of bilinguals while processing their two languages. Work has been carried out using various techniques (functional magnetic resonance imaging, positron emission tomography, magnetoencephalography, and so on), experimental paradigms, and language pairs. It would be hard to describe them all here, but instead I will try to give a general overview of what I think we have learned from them.

At a general level, we can say that the areas of the brain involved in the representation and processing of a bilingual's two languages are the same. It's as if the brain were somehow prepared to handle any language signal in the same manner regardless of the language or languages to which it is exposed. However, this does not mean that there aren't certain differences in their cortical representation, which will depend on many variables, such as the age of acquisition of the second language, the proficiency level of this language, and the similarity between the two. To make things more difficult, these variables tend to interact in complex ways. This is just a rough generalization but let's dig a little deeper.

Let's look at, for example, the following meta-analysis which compared the results of fourteen studies that used functional magnetic resonance imaging to explore the cerebral representation of bilingual speakers' two languages. The authors separated the studies according to the degree of knowledge (the competence) that the participants had in their second language. In eight of these studies it was considered that the participants had a high command of the second language, and in the remaining six the participants were deemed to have a moderate to low command. In the first of these subgroups, activation was detected in the left hemisphere in the classic brain network that is involved in language processing, including frontotemporal regions.

In Plate 1, the areas in red correspond to the activation of the dominant language, the areas in blue represent activation of the second language, and purple shows areas that are activated when both are processed. In panel A, which depicts highly proficient bilingual speakers, there is a large overlap in this network between the two languages. Indeed, nearly all the colours in panel A are purple, that is, almost all those areas that correspond to the first language also correspond to the second, and vice versa. On the other hand, the results of the studies that involved moderate- to low-proficient bilinguals were somewhat different. As you can see in panel B, there is much less overlap between the two languages. Let's pause for a moment to analyse these differences.

At first glance, it seems that the second language is represented in a more distributed network than the first language, that is, it tends to involve more areas of the brain. Also, when comparing the activation triggered by the second language in bilinguals of different competences, the less-proficient bilinguals seem to require more right-hemisphere areas, as if this were a compensation mechanism. This is interesting, because there is clinical evidence showing that lesions in areas of the left hemisphere (especially frontal areas) can force corresponding areas of the right hemisphere to perform, to a certain extent, the left hemisphere's functions.

Another interesting finding is that the left superior temporal gyrus was less activated for the bilinguals with lower second-language proficiency. This area of the brain has been linked to conceptual or semantic processing. One possible interpretation is that this is less activated when knowledge of a language is less. That is, the semantic information that we extract from a second language in which we are not very proficient is less than what we extract from our native language. It makes sense. Less competence in a second language also results in greater activation of areas related to language control, such as the dorsolateral prefrontal cortex and the anterior cingulate cortex, which could be interpreted as a greater need for attentional resources when encountering the second language. We will return to this question in various sections. In short, these results suggest that processing a second language in which one is not very competent is costlier and, consequently, the processing of a second language requires a more extensive brain network.

It is possible that for the last few paragraphs you may have been thinking that the level of competence in a second language is usually linked to when it was learned. Although this is not always the case, when a second language is acquired as a child and, more importantly, continues to be used, the odds are that the speaker is highly competent in it. The question, then, is to what extent the cortical representation of this second language depends on its age of acquisition and not just on its level of competency. As it turns out, just like the competency level in a second language, the age of acquisition also seems to have independent effects on cortical representation. For example, in tasks that involve semantic and grammatical processing, such as understanding sentences, a language learned relatively late (during puberty or later) tends to activate areas related to language, such as Broca's area and the insula, to a greater extent than the first language. In fact, this latter finding is consistent with others that reveal that, in the first language, words that are acquired later (for example, ‘screwdriver’) produce greater neuronal activity than words learned at younger ages (such as ‘rabbit’), particularly in areas related to phonological processing and motor planning of speech. These differences between languages do not seem to be present when the two languages have been learned in the first years of life and competency in both languages is high.

Given this scenario, it is reasonable to ask the following question with respect to the cortical representation of a second language: what has a greater effect, the age of acquisition or the acquired competency? That is, what has more influence on how the brain represents a second language, having learned it as a child or knowing how to use it extremely well? It is difficult to answer this question because, as we have seen, there is an important correlation between the two variables and, therefore, it is difficult to evaluate their effects independently. Moreover, these two factors can influence different linguistic aspects in various ways. For example, it has been suggested that semantic or conceptual processing in the two languages is very similar among individuals who have attained a high level of competency in the second language regardless of their age of acquisition. However, when syntactic processing is measured, there seem to be certain differences, and the age of second-language acquisition has important effects that are independent of the level of competency. It is still difficult to say which of these variables has a greater effect on the cortical representation of a second language.

There are several explanations as to why brain activation is greater when processing a second language compared to the first, especially when the level of second-language proficiency is not very high. There are various factors that are not mutually exclusive, such as the cost associated with controlling two languages, the lack of automaticity in processing a second language, the cognitive effort that this may entail, and the greater burden on second-language motor control.

INTERFERENCE

As we have seen, neuroimaging techniques are allowing us to discover the cerebral bases of linguistic processing both in bilinguals and monolinguals. Using these techniques, we can identify areas of the brain that are involved in certain linguistic activities. However, they also have some limitations: among other things, they do not allow us to identify areas of the brain that are 'essential' to carrying out a specific task. Let me explain: it's one thing that a part of the brain is activated while performing a specific task (for instance, processing a second language); it's another thing that this activation is essential to perform this task. Let's go back to the analogy between the brain and an orchestra: imagine that we are listening to a concert in which a violin has a solo but there are other instruments that enter and accompany the violin such as a tuba, drums, and so on. The piece will sound very good if all of them are playing their part. In fact, to a non-expert in music, it may seem that all the instruments are equally necessary for the piece of music to make sense and sound good. However, while the violin solo plays a fundamental role, the tuba may not. So if the tuba part weren't played, the concert would continue sounding 'relatively good'. But without the violin, the result would be much worse.

To discover what areas of the brain are essential to carry out a task, we have to look at what happens when those areas do not act correctly, either because they are damaged (as we've seen before) or because we interfere with its normal functioning. Currently, two of the most commonly used techniques to interfere with the operation of certain areas of the brain are transcranial magnetic stimulation and intraoperative cortical electrical stimulation.

Transcranial magnetic stimulation uses a metal coil to generate a magnetic field that is applied on the skull of an individual. The magnetic field in turn produces an electric field in the brain that interacts briefly with the normal electrical functioning of neurons. Don't be alarmed: the stimulation is painless and the neuronal alterations are temporary, such that the neurons return to their normal state after a very short period of time. What this technique allows us to do, then, is to alter the normal functioning of cortical structures. Stated in a more exaggerated way, it gives us the ability to produce virtual, brief injuries (and sometimes enhance brain functions) in healthy individuals, and to analyse what the result is from a behavioural perspective. This is important because it allows us to establish causal relationships between the neurons stimulated and the cognitive functions they produce. Importantly, this technique is also used for therapeutic purposes in cases of depression, migraines, epilepsy, and so on. Currently, the number of studies that have explored language representation in bilingual individuals using this technique is limited. However, results show that the temporary interruption of certain areas of the brain (such as the prefrontal cortex) may result in a lack of linguistic control, which may cause a person to involuntarily mix languages or even block access to one of them to a greater or lesser extent. For example, the stimulation of the dorsolateral prefrontal cortex causes problems when choosing a language and avoiding interference from the other language. It is as if the speakers subjected to stimulation in that area had lost control of the languages they know. In the next few years, we will surely see a boom in studies of this type in the context of bilingualism.

Let's move on to the second technique mentioned above, cortical electrical stimulation. I couldn't resist sharing with you a figure of the so-called cortical homunculus, or Penfield homunculus, that appears frequently in neuroscience textbooks. As you can see in Figure 2.2, the homunculus is a representation of our entire body in the brain, both in terms of sensitivity and motor skills. And yes, this map really exists, even if it looks a little like a cartoon.

How was this map created? Well, by using intraoperative cortical stimulation. When employing this technique, if certain areas of the brain are activated by electricity, you can determine their relationship to certain capabilities. It's possible to come up with a somatotopic, motor, or cognitive abilities (e.g. language) map, thanks to pioneering studies carried out in the 1950s by, among others, the neurosurgeon Wilder Penfield. Today, this technique is always used for medical purposes: for example, when neurosurgeons have to remove a brain tumour and need to know what the side effects of such surgery will be on the patient. Depending on the location of the tumour, one of the cognitive abilities that is 'mapped' is language, since it is a fundamental function that the neurosurgeon should avoid damaging in the course of the operation. But how can the neurosurgeon know what stimulation does to language processing? The procedure of cortical stimulation is performed while the patient is awake. Once the surgeon has opened the skull and has accessed the brain, general anaesthesia is reduced and the patient is revived while the surgeon continues to apply local anaesthesia on the scalp and skull. The surgeon can apply electrical stimulation directly to the brain without producing pain, since the brain does not have pain receptors. The patient is then asked to, for example, name what he/she sees in a series of drawings while electrical stimulation is applied to the different areas that could be damaged in the operation. The stimulation will affect the patient's ability to carry out this task only in some areas (it would be like taking away instruments one by one from the orchestra and seeing how the musical piece sounds). In this way, if they were compromised by surgery, the patient could end up with problems with language use, which would dramatically affect their communicative capacity. It's better to leave these areas alone.

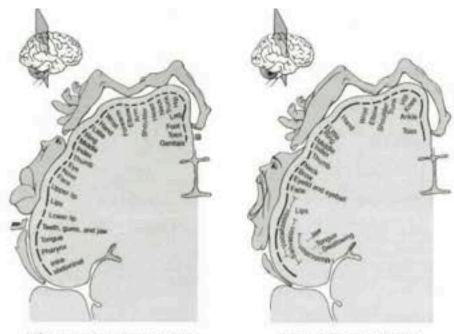

Figure 2.2. The cortical homunculus, showing the anatomical divisions of the primary somatosensory cortex in image (a) and the primary motor cortex in image (b) (taken from http://personal.uwaterloo.ca/ranney/mindheartsoul.html).

Can we have a mapping similar to that of the homunculus for both languages of the bilingual? That would be nice, but this is more complex. It is interesting, however, to see that this question was already intriguing to Dr Penfield, who resided in a bilingual area, the region of Quebec. In an interview with the Canadian newspaper *The Montreal Gazette*, Dr Penfield answered a question regarding the convenience of education in two languages. The interview was titled 'Bilingual Brain Superior – Penfield'. This fact wouldn't be very surprising if it weren't for the fact that it was published on 15 June 1968 … more than fifty years ago. And the debate continues! Why might this be the case? When the patient is a bilingual speaker, a mapping is often done of the two languages, so as to know which areas, upon stimulation, interrupt the processing of both or one of the languages. The results of these investigations are somewhat contradictory. While there are studies that show a wide overlap between the areas of the brain responsible for processing the two languages, others have identified that the stimulus only affects one of them. When this is the case, in general, it seems that there are more areas involved in processing a second language compared to the first. It appears that the dominant language requires fewer neuronal resources for processing.

Let's consider a study conducted by Timothy Lucas and his collaborators at the University of Washington and published in the *Journal of Neurosurgery*, in which the areas of the brain that interfered with picture naming were mapped in the first and second language among twenty-two patients with epilepsy. In twenty-one of the patients some areas of the brain were identified that interfered specifically with either the first or second language. However, it is important to note that fewer than half of the patients showed common areas of representation for the two languages, areas that, when stimulated, interfered with the processing of both languages. Finally, this study also compared the linguistic organization of bilinguals with that of 110 monolinguals and, as expected, similar results were found. Together, these results were interpreted by the authors as follows: there seems to be some functional separation between the cortical representation of the two languages. That is, there are areas of the brain that are fundamental for the processing of the first language and others for the second. Likewise, there are certain areas that are involved in the processing of both languages. Finally, the representation of the first language in bilinguals seems to be similar to the first language in monolinguals, which would suggest that learning a second language does not significantly alter the cortical representation of the first.

Studies of this type allow us to have more accessible and precise information about the areas of the brain involved in, or rather essential to, cognitive processes. Although they could be considered opportunistic, because they must always have medical implications, I think they will uncover very relevant information in the coming years. In particular, the recording of electrical activity and brain stimulation with implanted electrodes offer the possibility to explore the verbal behaviour of patients more exhaustively. These implants also meet medicinal needs, and are usually implanted to explore the origin of epileptic seizures of patients that have not responded well to conventional pharmacological therapies. Be on the lookout for more about this matter in the newspapers.

CONTROL, CONTROL, CONTROL

If you've ever tried to learn a foreign language, you have probably experienced the unpleasant sensation that, when you finally have enough courage to try to address someone in that new language, the words don't come to mind. There is no doubt that you know what you want to say and even know the words that you want to say; but, when putting them together and opening your mouth, things just don't seem to flow. You may also have the sensation that if you decide to try to speak anyway, the words will come out one by one without forming coherent sentences, or you will notice a massive interference from your dominant language. Do not get too frustrated; it happens to everyone. You probably already know that, bad as they may seem, situations like these are what lead many people to believe that they are better at understanding than speaking a second language, a statement that in many cases I think illustrates our perception of linguistic understanding rather than reality.

These fluency problems arise, in part, because it is difficult for us to control access to the second language. Not only is it hard for us to access its words and grammatical structures, but the words and grammatical structures of the first language are also there, interfering with our verbalization. Recently, a friend gave me an excellent example of this interference. In Barcelona, all tourists want to visit the Basilica and Expiatory Church of the Holy Family (*la Sagrada Familia*), and my friend kindly helped a clueless group find it by giving them directions in English. The tourists were grateful and gave her a sober 'thank you', to which my friend responded with a very polite '*de* nothing'. '*De* nothing?!' This wasn't due to lack of knowledge, it was lack of control. Of course, my friend knew that this was not a phrase in English, but she also knew what words to say to return the courtesy; in fact, another simple 'thank you' would have sufficed. But this time, her tongue did not obey her brain.

My friend is not alone in situations like this. All of us who have tried to master a second language in adulthood have realized that it does not only involve learning new linguistic representations, but it also requires the acquisition of a special skill we call 'linguistic control'. This is fundamental to being able to acquire the verbal fluency that allows us to communicate efficiently, and to say 'you're welcome' instead of '*de* nothing'. But how is linguistic control acquired? Well, you know, it's like grandma's special ingredient: practice.

Bilingual speakers who are competent in two languages are like jugglers. When the communicative situation requires it, they are capable of focusing their speech on one of them without apparent difficulties, avoiding the massive interference from the other language's representations. So, for example, if an English-Spanish bilingual is interacting with an English monolingual, he will rarely have intrusions from the Spanish lexicon or commit a translinguistic error, that is, the error of 'slipping' a word from Spanish into the conversation in English. Think about it: if this were common, communication with bilingual speakers would be impossible (unless we knew their two languages), and bilingualism would clearly entail problems for communication. That is to say, if at all times we were involuntarily mixing the lexical, syntactic, and phonological representations of two languages, it would be very difficult to hold a conversation.

Whenever I point this out, someone usually notes that there are many situations in which bilingual speakers change languages during a conversation, introducing elements from both. This is true, and we call this phenomenon 'code-switching'. This verbal behaviour, however, is far from random and does not seem to correspond to a failure of linguistic control (at least in most cases), but to other questions that are communicative in nature. What is specifically interesting to me is that code-switching adheres to certain grammatical restrictions and, therefore, cannot be considered the result of errors in linguistic control, at least on most occasions. In other words, the switches follow systematic rules. Consider, for example, the following: '*No sé dónde he dejado las keys*', where the article '*las*' matches the word 'keys' in number (e.g. plural).

Bilingual speakers are not only able to focus their attention in the desired language, but they are also capable of maintaining bilingual conversations with diligence. This concept is a bit difficult to understand if one has never experienced it before. In fact, it surprises and irritates many people who live in monolingual environments. Imagine the following situation: a family of five is eating at the dinner table (on the menu are tuna croquettes and green beans). The father speaks in Spanish with his wife and his son, but he uses Catalan with his daughter. The daughter, in turn, speaks Catalan with her father, but Spanish with the rest. The son and the mother understand the two languages, but speak in Spanish with the rest of the family, including the grandmother, who only speaks Spanish although she understands Catalan. This communicative situation is what I call bilingual conversation, in which the two languages are continuously put into play in an orderly manner. That is, it is not that they are randomly used or mixed without rhyme or reason. On the contrary: the language that is used is determined by the person to whom it is directed. We will not discuss here how these differences arise with respect to the language each individual chooses, since the reasons may be multiple and due to several causes (for example, the presence of other relatives who do not understand one of the languages). As strange as it may seem, this situation of 'orderly mixing' commonly occurs. (And yes, the family I just described is the one in which I grew up.)

At first glance, bilingual conversations present a paradox. Since all the participants at the dinner table know the two languages, wouldn't it be easier and less taxing to decide what language to speak in rather than switching between them? And if there is disagreement at the time of choosing, they could use the languages on alternate days, simple as that; this way, everyone uses both languages without problems. Well, it is not that easy, and it turns out that having conversations of this type does not seem to be all that difficult, at least for highly proficient bilinguals. In fact, it would seem that when we establish what language to use with each individual, what indeed seems difficult is to address him in the *other* language. If you do not believe it, and you know two languages, try to have a conversation with a friend in the language you do not usually use with him and see how long that lasts. So, it seems that it is more difficult to change the language in which we are used to talking to someone than to switch from one language to another depending on the listener, even within the same conversation. When we are used to talking to someone in a specific language and are forced to use a different language, we sometimes unintentionally slip into the language that is usually used with that person. For example, in a situation in which two friends use English and Spanish at the same time, when they also include someone who only knows English, they will switch to English (not only to be polite, but to be able to communicate). However, there are times when the two friends interact in Spanish, which can lead to an uncomfortable situation. Although it's hard to believe, in most cases this change is involuntary and is not meant to exclude anyone from the conversation. In fact, this may even occur among monolinguals. For example, Spanish-speaking monolinguals may say '*Encontrémonos en el* check-in' ('Let's meet at the check-in counter') or '*¿Has traído tu smoking para la cena formal?*' ('Have you brought your tuxedo jacket for the formal dinner?'). Should they not say *check-in* and *smoking* in English? This would be very difficult to change given that *check-in* and *smoking* are most frequently used.

Everything I have just explained shows that bilingual speakers can be viewed as jugglers, since they use their two languages in a quite sophisticated way. When the conversation requires it, they are able to focus on one language and avoid mixing the two while at the same time they can change from one language to another when the conversation involves bilingual situations. How do they control the two languages?

Although studying the cognitive processes and corresponding neural bases involved in linguistic control has always drawn the attention of language students, this interest has grown at spectacular rates in the last twenty years. The first issue that needs to be determined is what happens to the representations of the language that is not currently involved in a conversation, the one we call *language not in use*. For instance, when a Spanish-English bilingual is speaking with someone in English (the language in use), what happens to the Spanish (the language not in use) representations? If linguistic control acted as a simple switch and the intention to speak in a specific language was enough to 'turn off' the unwanted and 'turn on' the desired one, then this question would be relatively trivial. Simply, the system would block the activation of the language not in use and the bilingual would become a 'functional monolingual'.

The reality seems to be somewhat more complex and numerous studies have shown parallel activation of the two languages, regardless of the one that is being used. Let's look at one of these studies that I think has a great deal of value.

In the study, Guillaume Thierry and his colleagues at the University of Bangor in Wales analysed whether there was activation of representations of the language not in use when bilingual participants carried out a task in the other language. In other words, whether the language that was not being used was 'turned off' or 'kept on'. The task was simple: two words were displayed on a computer screen and participants were asked to say whether the two words were related in meaning. There were pairs that were related (*train-car*) and others that were not (*train-ham*). The task was carried out only in English and the participants were highly proficient Chinese-English bilinguals who lived in Wales. Interestingly, the task of judging semantic relatedness was not the critical factor, it was just meant to mislead. The key manipulation was that in half of the word pairs, the Chinese translations of the words shown on the screen looked similar in form whereas the other half of the pairs did not. For example, in the pair *train-ham*, the corresponding Chinese translations are *huo che-huo tui*. As you will notice, these words are similar in their form and, therefore, from the researchers' point of view, they were considered formally related. On the contrary, in the pair *train-apple*, the corresponding Chinese translations are dissimilar (*huo che-pin guo*) and thus would be considered formally unrelated. But remember that in the experiment, the words were presented only in English and never in Chinese.

The authors hypothesized that, if by reading the words in English, the participants translated them automatically (and unconsciously) into Chinese (i.e. if when a language [English] is processed, the language not in use [Chinese] is also activated), then different responses would be observed for these two types of pairs. This did not happen at the behavioural level: the participants were equally fast and accurate in their responses to both types of pairs.

The experiment seems to have failed. But, not so fast. During the task, the researchers also recorded the electrical activity of the participants' brains using an electroencephalogram. After analysing this signal, it was observed that the brain response was significantly different when responding to words in Chinese that were related compared to unrelated words. Remember that the task only involved stimuli in English![fn3]

These results, among others, suggest that when bilingual speakers process one language, they cannot 'turn off' the other as if it were a light bulb. On the contrary, it would seem that both are active to a certain point during language processing. That said, how is it possible that we do not confuse and mix them? The issue of control is a little more complicated.

Without going into too much technical detail, I would like to introduce at least one of the experimental paradigms most used to understand how linguistic control works in a bilingual individual. I have chosen the paradigm of language switching because, besides having used it for more than ten years, it is to some extent easy for anyone to carry out. It is one of those experiments that you can even do at home.

One way to study the mechanisms of linguistic control among bilinguals is to explore the behavioural patterns and how their brain correlates in tasks that involve switching back and forth between languages. Consider, for example, the activity in Figure 2.3. A series of drawings are presented to participants one after the other and they are asked to say aloud the words that the pictures represent. The drawings may appear framed with a blue or red border (the colours in particular do not matter). The participants must say the words in one or another language depending on the colour that borders each drawing. So, for example, if the subject is a Spanish-English bilingual, they may be asked to name the drawings with blue borders in Spanish and those with red borders in English. The trick is that the colour of the frame varies randomly, in such a way that there are times when two or more drawings appear in a row with the same colour border and others in which they alternate borders of different colours. For example, imagine the following sequence: car in red, umbrella in red, chair in blue, glass in blue, table in red. The correct answers would be: *car, umbrella, silla, vaso, table*.

In this sequence we find different types of stimuli, or *trials*. There are trials where the language used to name the drawing is the same as the trial immediately before, as for example when *umbrella* or *vaso* appeared. We call these *repetition trials*, since the language that is used is the same. We also have trials in which the language used to name the drawing changes with respect to the trial immediately before, as when we see *silla* in blue and *table* in red. These are called *switch trials*, given that the language used to denominate them changes with respect to the one used in the previous drawing. As usual, the speed (in milliseconds) that it takes participants to name the word that describes the drawing and the error rates are measured.

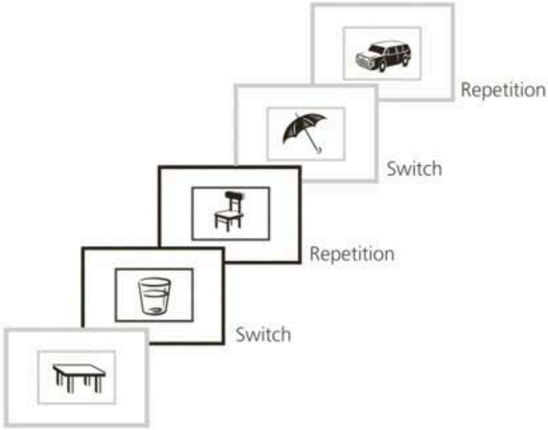

Figure 2.3. Representation of language-switching tasks. The participants have to say aloud the name of what each drawing represents. The language they should use is determined by the colour of the border. Thus, we find trials in which the language to be used is repeated (repetition trials) and trials that change (switch trials).

I encourage you to do the experiment at home. Take six common objects, like a pair of scissors, a glass, a pencil, and so on, and put them out of sight (for example, under the table) of the person you have chosen as a participant. Now tell him that you will be showing him a series of objects and that he has to name what he sees aloud as quickly as possible. Tell him that if you show the object to him with your right hand, he will have to use his first language, and if you show him with your left hand, he will have to use his second language. Start showing objects randomly with each of your hands. If you do it at a reasonable speed, for example by presenting the new object around one second after the participant gives the answer to the previous stimulus, you can easily detect the effect we are looking for: switching languages takes longer, and you may even get a laugh when the participant makes mistakes or gets stuck. You may notice this even more so if you try this experiment on a participant whose command of the second language is not very high.

What have we observed with this task? First, that the participants are more efficient naming trials in which the language repeats (repetition trials) compared to those in which the language changes (switch trials). This is the effect and cost of language-switching tasks, that is, the time it takes to say the word in question is different in each of these two types of trials, which shows that switching from one language to another takes longer and demands a behavioural effort. Nothing surprising so far. But is this switching cost the same for a bilingual's two languages? Consider that you are doing the activity described above in his first language, Spanish, and in another in which he is rather less competent, English. Take a guess: Do you think it will be more costly for him to switch from his dominant to non-dominant language (from Spanish to English) or vice versa? Do not respond quickly, take your time … When I describe this experiment to my students, the vast majority guess incorrectly. The cost of language change is greater when we must switch into the dominant language (in this case, Spanish) than when switching into the non-dominant language (English). In other words, the cost of change is asymmetric: its magnitude is greater for the dominant language than for the non-dominant one (what we call 'asymmetrical language-switching costs'). The paradox, therefore, is that switching into what is easier for us is actually more costly than switching into what is more difficult for us. If you guessed it, well done – and if not, do not worry, I did not guess it right the first time either.

You now know that experimental psychologists are experts in designing experiments that yield amazing results, but what in the world does this pattern mean? Well, this asymmetry has been used repeatedly to support the idea that linguistic control of two languages is based on inhibitory processes. That is, when we want to speak in a language we have to put processes into play that reduce the activation of representations of the other language, and as such, decrease the possible interference that these representations would cause when we want to focus on the language in use. But inhibiting one language may have effects on subsequent trials in which we have to use it. That it is more costly to switch from the non-dominant language to the dominant one implies that the amount of inhibition applied to each language is different. So, if I have to say the name of what a drawing represents in my non-dominant language, I would apply a lot of inhibition to my dominant language to prevent intrusions. If then in the next trial I am asked to switch, it will be quite costly given that I will have to recover from all the inhibition applied in the previous trial. The inhibition applied to the non-dominant language would be less and, therefore, it would cost less to recover from it in subsequent trials. So, the magnitude of the switching cost would be greater when I switch to my dominant language versus to the non-dominant one. In fact, this asymmetric cost phenomenon is not unique to linguistic contexts, and also has been observed in attentional activities that do not involve language use at all. So the fact that it costs us more to return to an easier task when doing two tasks at the same time suggests that this is a property of the cognitive system, and not only of the linguistic system.

You might ask what happens with more balanced bilinguals, that is, those who master the two languages at a similar level. Suppose that the asymmetry of the magnitude of language-switching cost should be relative to the difference in inhibition applied to each language. The greater the discrepancy between the level of competition between the two languages, the greater the inhibition applied to the dominant one.

Therefore, smaller differences in dominance between the languages should show less asymmetry. To make it clearer, the most balanced bilinguals should show the same amount of switching cost for both languages. In fact, that's what we found a few years back in our laboratory when balanced-bilinguals of Catalan-Spanish and Basque-Spanish participated in the task: it cost them the same to switch into one language as the other. These are true jugglers.

LINGUISTIC CONTROL IN THE BRAIN

As we have seen, some bilinguals show difficulties in language processing because of brain damage. The most common pattern is that both languages have a similar deterioration that occurs at the same time. However, there are cases in which brain damage seems to affect not so much the linguistic representations, but the voluntary control that the patient has over them. It's as if the patient is unable to focus attention on one of the languages and instead mixes them up involuntarily. Studying this verbal behaviour and its relation to damaged areas of the brain has been laying the groundwork for a better understanding of the neuronal circuits responsible for linguistic control in bilingual individuals. In fact, more and more studies are investigating how lack of linguistic control contributes to the loss of the ability to process language, something that goes well beyond examining damaged representations. In other words, the information would still be there and the problem would be how to access this information. If this is true, the case of the Formula 1 driver Fernando Alonso would exemplify such a loss of linguistic control.

Perhaps the most complete model on this subject is the one proposed by Jubin Abutalebi and David Green just over a decade ago in an article published in the *Journal of Neurolinguistics* (see Figure 2.4). They argued that different areas of the brain are involved in several aspects related to linguistic control. Of particular relevance to this skill are certain subcortical areas, such as the caudate nucleus. A deterioration in this area results in what has been called 'pathological language change' or a mixture of languages. Consider, for example, the case described by Peter Marien and his collaborators in their study of a ten-year-old boy who suffered from language problems due to a cerebral haemorrhage. The boy's first language was English, but he had learned Dutch at the age of two and a half and had been communicating with his friends and at school in Dutch. A few days after the haemorrhage, the child had problems with spontaneous language in both languages, that is, it was difficult for him to maintain a conversation. The most notable side effect was that he seemed to have lost the control of his languages and thus mixed them involuntarily.

Neuroimaging tests showed abnormal blood flow in various brain regions (what in medical terms is called 'hypoperfusion'), including in the caudate nucleus of the left hemisphere. This abnormal blood flow caused these regions to work inefficiently, which created problems for the child. Fortunately, six months later, blood flow had returned almost to normal in the frontal zones and in the left caudate nucleus, although not in other areas of the brain also related to language processing. After those six months, the child stopped unintentionally mixing English and Dutch. He still showed certain linguistic problems in both languages, especially regarding fluidity, but he no longer mixed them. The authors interpreted the relationship between the boy's symptoms and his brain damage as evidence that the frontal and subcortical areas (the caudate nucleus) are responsible for linguistic control in bilingual individuals. There are many cases of patients with brain damage in subcortical structures who show poor control of languages and we now have enough evidence, including from studies with patients suffering from Parkinson's disease, that such structures seem to be closely related to linguistic control.

These observations have laid the groundwork for the design and interpretation of a good number of studies that have explored different aspects of language control using neuroimaging methods among healthy speakers. These studies have employed different types of tasks, most of which involve the need to exercise linguistic control, such as the switching task described in the previous section. Without going into too much detail, these studies show that linguistic control is exercised through the use of a brain network that involves frontal, prefrontal, and parietal areas along with the anterior cingulate gyrus and the caudate nucleus.

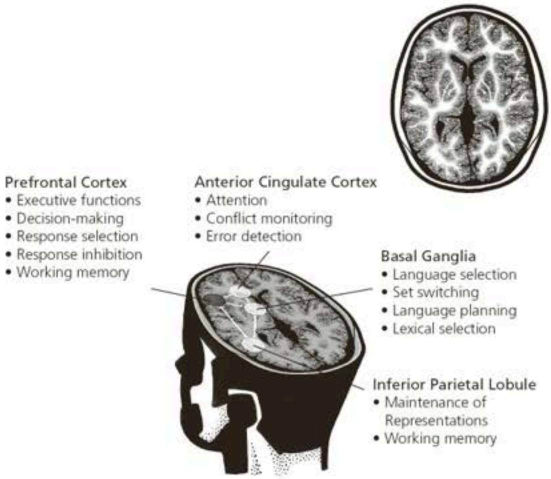

Figure 2.4. The brain network responsible for linguistic control in bilingual speakers, using the model of Abutalebi and Green (2007).

We also have information about what happens when we interfere with the functioning of some of these areas through the intraoperative stimulation that we described earlier in this chapter. For example, in a study conducted by Antoni Rodríguez Fornells at the Bellvitge Biomedical Research Institute, it was observed that an interference with the normal operation of medial and inferior areas of the frontal region affected the verbal behaviour of two patients in a language-switching task similar to the one described above.

One of the central questions about the functioning of linguistic control in bilingual individuals has to do with the extent to which it involves processes and areas of the brain belonging to the domain-general executive control system. It is difficult to find a good definition of the ‘domain-general executive control system’, but let’s put it this way: executive functions are those that we put into play when we want to do something without getting distracted. It’s a little more complicated than that, but for the time being this definition suffices. These control processes are triggered continuously and allow us to maintain the goals we want to keep active in our mind, as well as ignore stimuli or information that can interfere with the appropriate behaviour to achieve them. If you have seen the movie *Finding Nemo*, you may remember Dory, the blue fish that accompanies Nemo's father on his search but continuously gets distracted and confused. Dory lacks some important parts of the executive control system like working memory.

In the case of linguistic control, the goal is to speak in the desired language and the distracting information is the language that is not being used. Given this parallelism, it is reasonable to think that linguistic control processes use the resources of the domain-general executive control system. However, the behavioural results that we have at present from neuroimaging studies indicate that although there is some overlap, it is only partial. We will return to this question and discuss it in more detail in Chapter 4.

FORGETTING THE FIRST LANGUAGE

Most studies on bilingualism seek to understand the acquisition processes and use of a second language. To put it another way, scientists, and I dare say most people, are interested in understanding how one goes from being monolingual to bilingual or how one grows up being bilingual. The latter makes sense, because it's quite common. However, some researchers have asked a question that is somewhat related to the previous one and can tell us a lot about how we learn … and unlearn: What happens when one language replaces another?

This is a topic that has to do with what we call 'first-language attrition'. There are numerous works that have explored how the acquisition of a second language affects the use of the already established first language. The patterns of interaction between the two languages are complex at all linguistic levels. In many cases one language is not replaced by another, but peculiarities can be seen in the use of the dominant language.

I had the opportunity to observe these interactions first-hand when I lived in Boston and was conducting experiments on bilingualism in the Cognitive Neuropsychology Laboratory directed by my mentor, Alfonso Caramazza at Harvard University. In addition to posting ads all over campus to recruit bilingual Spanish-English participants for my tests, I was also looking for participants informally at the many parties organized by my Latino friends. You know, life isn't just about science. Between margaritas, mojitos, and too much Salsa music for my taste, I more or less managed to explain the type of studies that I was carrying out. My goal was clear: I had to get their emails or phone numbers to contact them a couple of days later, when their attentional abilities would be more in tune. The important thing was to get the contact. As expected, when I called them the following Monday with the intention of setting up an appointment to perform the experiment, many of them reacted with surprise and claimed to have no idea what I was talking about, and in many cases didn't remember who I was (some even refused to remember having been at the party at all, but that's another story). Although I have to admit that this strategy for recruiting participants was unconventional, it worked and I managed to carry out my post-doctoral experiments.

I tell you this not because it was strange to meet young people who, even though their first language was Spanish, had a clear dominance in English, but rather because they were enrolled in courses in Spanish as a second language, that is, courses for native speakers of English. When I was talking to them, I could notice the effect that English had on their Spanish, both at the grammatical and lexical levels and even at the phonological level. The two languages were interacting in such a way that one was 'eating' the other. Several reminded me of some Catalan speakers who immigrated to Mexico when they were young as a consequence of the Civil War, and who spoke in Catalan with Mexican prosody, a very curious and endearing thing. This effect of the learning of one language over an already established one shows the plasticity and dynamic nature of our brain.

The number of children who are adopted by caregivers who speak a different language is considerable. Without thinking too hard, I can name about ten acquaintances who have adopted children from Russia, China, Vietnam, or Ethiopia, and none of these acquaintances knew (or know) the languages spoken in these countries. In many of these cases, the children no longer have contact with their first language and become immersed in a second (or third) language. There is no doubt that this situation entails a loss of skills in the dominant language, but are there any traces left in the brain of the first language once they reach adulthood? Or is the cerebral plasticity such that these adoptees will completely forget what used to be their first language for some months, and in some cases for a few years? Can the brain forget a language?

These studies are difficult to carry out, and perhaps because of this, there are only a few of them. In one of these studies directed by Christophe Pallier at the Institut National de la Santé et de la Recherche Médicale (National Institute of Health and Medical Research) in Paris, eight Korean adults were selected who had been adopted by French-speaking parents. The age of adoption varied from three to eight years of age, which meant that these children had already acquired Korean when they left their native country. Nevertheless, they all claimed to have completely forgotten their mother tongue and to have had no problems learning and using French. The authors asked these participants to perform several tasks in which Korean came into play. For example, they heard a series of recorded phrases in several languages that were typically unfamiliar to French speakers (e.g. Japanese, Korean, Polish). The participants were asked to say whether they believed that each of these phrases belonged to Korean. In another one of the exercises they were shown a written word in French followed by a recording of two words in Korean. The participants had to decide which of them corresponded to the translation of the French word. The performance of the adoptees in these activities was compared with that of another group whose mother tongue was French but who had no experience with Korean; that is, a kind of control group. The hypothesis was clear: if the adoptees maintained some kind of knowledge of their mother tongue (Korean), unconscious or indirect as it may be, their accuracy would be greater than that of the other group.

The results did not confirm this hypothesis; in fact, the accuracy was identical for both groups. Korean had disappeared from their mind, even among those who had had quite a bit of experience with and exposure to the language (i.e. eight years). The authors went a step further and decided to analyse the brain activity of the two groups during a task involving Korean. After all, even though their behavioural performance did not show traces of the lost language, maybe their brain activity would. In this task, the participants heard a series of recorded phrases while their brain activity was recorded. When analysing the brain activity of the French participants (the control group) while listening to French or Korean, there was greater activity in the classic areas related to language when the sentences were reproduced in French. This makes sense because these individuals had no previous contact with Korean. How did the brain respond among the adoptees who previously did have contact with the Korean? It was exactly like the French participants. That is, the brain of those adults who had grown up with Korean for several years and those who had grown up without Korean reacted in the same way. It was as if none of them had ever learned it. The group of adoptees had forgotten their mother tongue.

However, another study conducted by Jeffrey Bowers at the University of Bristol yielded a surprising result. The study explored the ability of adults whose mother tongue was English to learn a phonological contrast that exists in Zulu and Hindi but not in English. Remember that in Chapter 1 we talked about how our ability to discriminate between sounds that we are not exposed to in our environment diminished by the age of one. Some of the adults had had contact with the two languages during childhood, but at the time of the experiment they claimed to have lost all knowledge of them. A control group was composed of native English speakers who had no experience with Zulu or Hindi. The question was whether those who had used those languages during childhood could 'relearn' the phonological contrast faster than those in the control group, which would suggest that there was still a trace of that language in their brain. The results of the study were clear. At the beginning of the sessions, the two groups showed equally poor performance and it was difficult for them to differentiate the sounds. This reaffirmed the idea that the group of participants who had been exposed to those languages had lost all knowledge of them. However, as the test advanced, the group with previous experience with Zulu or Hindi was able to discriminate between the sounds more efficiently than the control group. These results suggest that the group with previous experience with Zulu or Hindi had maintained some knowledge, at the phonological level in this case, of a language they had stopped using many years ago. Their brain had saved some of that experience from childhood even though they were not aware of it.

Considering these results, it is premature to conclude that a language can be completely forgotten after it is no longer used. But these studies are important because not only do they provide us with information about the interaction between languages, but also about brain plasticity, and even how we forget language.

We have come a long way in this field, but we still have much to discover. If we could analyse the mechanisms that the most wonderful animal in evolution, the Babel fish, uses when it translates all languages, this task would be much easier. Unfortunately, Douglas Adams took this secret with him, although apparently engineers are trying to decode it.[fn4]