

# 1 Theoretical Background

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## 1.1 Language and Cognition in the Brain

Humans use language to communicate with one another, a unique way of communication that is not found among other species. They are also capable of extremely elaborate abstract thinking, a core ability of the human mind. Language comprehension and production, along with thinking and other higher-order cognitive abilities, are located in a particularly complex part of the human brain, the cortex.

More specifically, a significant part of the cortex, the frontal cortex, hosts ‘cognition’, that is, the ability to orchestrate thought and action (Miller & Cohen, 2001). Memory, spatial skills, and social behaviour are also located in the frontal cortex. Furthermore, the anterior part of the frontal cortex (the prefrontal cortex) is instrumental to the ‘executive control function’, which is associated with abilities such as attentional control (in the mesiofrontal region), response inhibition (in the orbitofrontal region), verbal and nonverbal working memory as well as rule discovery (in the dorsolateral region) (Royall et al., 2002).

Two cortex areas are related to language comprehension and production:

- (i) Broca’s area, which is primarily associated with language production, is located in the left frontal cortex, near the motor cortex (the latter controls language-related muscles such as the muscles of the face and mouth and vocal cords).
- (ii) Wernicke’s area, which is primarily associated with language comprehension, is located in the left temporal lobe near the auditory cortex.

In addition to these two core areas, a wide network of brain regions is required for both language production and comprehension, including regions in the right frontal and temporal cortex, the parietal and occipital lobes, the cerebellum, the basal ganglia, and the thalamus (Fedorenko & Kanwisher, 2009; Pliatsikas, 2019). Studies have also shown that processing sign languages largely overlaps with processing spoken languages, even though there are some differences in the brain areas related to modality (MacSweeney et al., 2008).

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Despite the great proximity of language-related areas with non-linguistic areas in the brain, some researchers argue that these do not fully overlap and specialized sub-areas for language may be distinguished (Fedorenko & Varley, 2016). Similarly, despite the evident association of neural circuits from linguistic and non-linguistic areas in speech production and comprehension, some researchers argue that language-specific and domain-general networks are functionally distinct in the brain (Mineroff et al., 2018).

To date, the precise mapping of brain areas to language processing is not complete as it is complexified by great inter-individual variation (Fedorenko & Kanwisher, 2009). Indeed, the frontal cortex is the part of the brain that is the most dependent on environment and experience, thus resulting in great anatomical variability across individuals. In particular, the frontal cortex is the last part of the brain to mature across the lifespan, reaching full maturity with the end of puberty (Giedd, 2008). It is also the first to deteriorate among ageing individuals affecting, among others, various language skills (Obler et al., 1991; Goral et al., 2011). The neuroplasticity of the brain further complicates the precise mapping of language-related areas and functions. For instance, it has been shown that the adult brain can adapt to new needs through changes in grey and white matter (Fields, 2008; Zatorre et al., 2012; Lövdén et al., 2013). In addition, the human brain has the astonishing capacity to compensate for brain damage to some extent by remapping some of its connections. For example, although language is predominantly located in the left hemisphere among healthy individuals, Vargha-Khadem and colleagues (1997) report fascinating evidence from a young patient who acquired language with the right hemisphere alone.

From an evolutionary standpoint, the cortex is the most recently evolved part of the brain. It is connected to the more ancient parts of the brain: the limbic system that hosts emotion, and the basal ganglia that mediate automatic functions (MacLean, 1990). It is generally admitted that the human cortex and the cortex of non-human primates share many similarities, but that they differ fundamentally in terms of the quantity of neurons and the complexity of connections. Indeed, the two major areas of the human brain involved in language, that is, Broca's and Wernicke's areas, are also found among non-human primates sharing some similarities in structure and functions. However, connectivity differs greatly, as for instance, the white matter fibre tract that can be roughly described as connecting the two language regions is much weaker in non-human primates than it is in humans (Friederici, 2017). This similarity is interpreted by some researchers as evidence that the language areas of the modern human brain most likely initially evolved for other purposes and that only in humans did they evolve an additional communicative function through language. Some researchers therefore argue that language developed gradually using non-language-

specific learning and processing mechanisms of the brain (Christiansen & Chater, 2008). Indeed, the human capacity for speech and language acquisition draws on general cognitive abilities that are also present to some extent in other animals, such as memory, attention, and associative learning. Others argue, however, that the emergence of the language faculty was brief and abrupt, resulting from a minor genetic event (Chomsky, 2006: 176). Empirical evidence from the field of genetics cannot resolve this debate but scientists agree that humans have variants of genes otherwise present in some animals. For example, a variant of the *Foxp2* gene allowed the human brain to take an important step toward the development of language by enhancing the capacity of the human brain for procedural learning (Schreiweis et al., 2014). Moreover, researchers suggest that similarities can be found with more distant animals such as birds. For example, recent research shows that there is considerable behavioural, neural, and genetic similarity between auditory-vocal learning in human infants and songbirds relying on prosody and rhythm (Berwick et al., 2011). Indeed, the role of prosody as a cue for the early acquisition of word order has been demonstrated among infants older than five months, including among bilinguals (Gervain & Werker, 2013). In addition, Abboub and colleagues (2016) demonstrated the key role of prosodic processing in early language acquisition among newborns from monolingual and bilingual backgrounds based on prenatal experience with their native language(s).

From the perspective of language acquisition, two major approaches offer different views on how language develops in humans: the nativist approach and the emergentist or usage-based approach. Skipping the details, the nativist approach considers that language is to a large extent innate and that humans are endowed with a ‘language acquisition device’ (see Chomsky, 2006: 99). However, at present, neuroscientists cannot locate a specific area in the human brain that would correspond to such a device. For example, although evidence from newborns demonstrates a clear left hemisphere dominance for language processing, it does not follow that this is an innate device (Peña et al., 2003). Rather, the hypothesis of an innate language acquisition device strongly relies on the ‘poverty of the stimulus’ argument, asserting that children do not receive sufficient amounts of input to develop language and, in particular, grammatical complexity the way they do. In contrast, proponents of the usage-based approach consider that language is acquired in social interaction using general cognitive capacities that are not specific to language, namely ‘intention reading’, involving joint attention, and ‘pattern finding’ (Tomasello, 2003). This does not imply that specialized language areas are not being developed in the brain as experience increases, but that language abstractions can only be formed through language use. Contrary to the nativist approach, the usage-based approach seeks to demonstrate that infants receive sufficient input

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depending on a combination of three variables: cue availability (frequency), cue reliability (consistency), and cue cost (complexity).

Despite such significant differences between the two approaches in language acquisition, it is uncontroversial that cognitive and language development is about complexification in the infant brain. Scientists have identified several stages of cognitive, behavioural, and language development. For instance, infants start with language comprehension and proceed with the use of gestures and, in particular, pointing, before starting to use language productively. However, the speed with which some of these stages follow one another depends on experience. For example, it has been shown that infants who receive input in two languages maintain a phonological sensitivity window open for several more months than infants who receive input in a single language (Garcia-Sierra et al., 2011). According to the authors, this difference is due to the greater amount of input that bilinguals need to process as compared to monolinguals.

In sum, although the human mind and brain have a universal neurocognitive basis, studies unveil differences depending on environment and experience. Indeed, the neural underpinnings of lower-level and higher-order processes might seem universal, but recent behavioural and neuroimaging research from cultural psychology and neuroscience has revealed significant cultural differences in various domains (see Adolphs, 2010; Ames & Fiske, 2010; Han & Ma, 2014). The fact is that environment and experience constantly shape the brain by changing the size of brain areas, the number of neurons, synapses, and neuronal circuits, and even by altering the genes to some extent. Yet, at present, much of the research on human cognition comes from so-called ‘Western, educated, industrialized, rich, and democratic (WEIRD)’ populations (Henrich et al., 2010). Until recently, 96 per cent of participants in behavioural research publications were from WEIRD countries, although these represent roughly 12 per cent of the world’s population (Arnett, 2008). In particular, in the field of psycholinguistics, Anand and colleagues (2011) point out that only fifty-seven languages (out of more than 6,000 languages) are represented in international psycholinguistic conferences and peer-reviewed journal publications, of which 85 per cent are represented by only ten languages (i.e., English, German, Japanese, French, Dutch, Spanish, Mandarin, Korean, Finnish, and Italian).

Focusing on WEIRD populations, however, is not only biased in that it leaves out a variety of cultures and societies from geographical areas like Latin America, Africa, Southern Asia, and the Middle East, but also disregards the fact that WEIRD populations are quite exceptional from an evolutionary perspective. For instance, pre-industrial populations typically lived in small, kin-based groups, where a variety of adults and sometimes even elder children would be involved in infant care, thus differing markedly in their language

interactions from populations living in industrial societies who typically live in small family units, consisting of parents and siblings, but engage in everyday conversations with a great number of outsiders. It is therefore plausible that by investigating non-WEIRD populations we may gain a better understanding about the way that differences in the interaction environment may shape languages as well as language processing mechanisms.

To conclude, from an epistemological perspective, the present book stresses the need to take into consideration a wider range of empirical data when investigating bilingual cognition. More specifically, I suggest that limited representation of non-WEIRD populations can be overcome in the future by introducing bilingual research practices in the study of endangered languages. Increasing cultural and linguistic diversity in research is even more important for current cognitive models that promote the relevance of language-specific, cultural, and communication factors as discussed in Section 1.2.2. But first, let me start by introducing some of the consequences that the use of more than one language has for cognition and the brain (see Section 1.2.1).

## 1.2 Current Topics in Bilingual Research

### 1.2.1 *How Bilingualism Shapes Cognition and the Brain*

Researchers have now established that the brain of bilingual and monolingual speakers differs in at least two ways: the volume of ‘grey matter’ (Bialystok et al., 2012; Abutalebi et al., 2012; Abutalebi et al., 2013); the microstructure of ‘white matter’ (Luk et al., 2011; Singh et al. 2018). This finding is not so surprising inasmuch as the structure and connectivity of the brain are more generally shaped by the acquisition of new, non-linguistic skills. A well-known example comes from research conducted among trainee London taxi drivers (Woollett & Maguire, 2011). It was found that the brain of those who are successful in the final exam, consisting, among other things in memorizing the map of the city, is characterized by increased grey matter in the hippocampus and changes in memory profile as opposed to the brain of those who fail the exam that does not exhibit such changes. In sum, experience shapes the brain.

However, studies from bilingual and monolingual young adults offer conflicting evidence about the precise brain areas involved in bilingualism, a difficulty that may be due to the great variability in individuals’ experiences, as Luk and Pliatsikas (2016) argue. Indeed, it is now admitted that experience in the use of languages is key to understanding the effects of bilingualism on the brain. The main finding is that differences in the brain structure and connectivity correspond to different types of bi/multilinguals, with differences between immersed sequential bilinguals, simultaneous bilinguals, sequential bilinguals with limited experience in the second language, and multilinguals (Pliatsikas,

2019). Summarizing these findings, the author notes that there is an immediate effect of learning an additional language in local cortical grey matter volume, but that, in the long term and as experience increases, this effect is replaced by white matter, which is responsible for connectivity between neurons, and subcortical restructuring (see Glossary). Pliatsikas further suggests that early language acquisition might simply be a proxy for language use without any significant differences in the stages of neuroplasticity among infants and children on one hand and adults on the other.

This predominantly usage-oriented approach contrasts with nativist theories that propose that the development of language is fundamentally different depending on the age of acquisition: it is assumed to be a subcortical process early in life and a cortical process later in life (Hernandez & Li, 2007). In agreement with this analysis, some researchers argue that genetic variants play different roles in bilingualism. Vaughn and Hernandez (2018), for instance, report that in their study the highest levels of bilingual proficiency were predicted for individuals who acquired a second language early in life when these individuals had the genetic variant A1+, which is associated with higher levels of subcortical dopamine; hence authors conclude that early second language acquisition is a subcortical process. In comparison, the highest levels of bilingual proficiency were predicted for bilinguals who acquired a second language later in life when these individuals had the genetic variant Val/Met, which is associated with cortical dopamine levels that are balanced between stability and flexibility; hence, late second language acquisition is a cortical process.

Similarly, some researchers claim that the mechanisms involved in early simultaneous bilingualism, that is, when the onset of second language acquisition takes place before the age of three, are unique due to maturational constraints. This ‘sensitive period’ is considered to be instrumental for full phonological acquisition, as some studies show that even a small difference in the onset of bilingualism may have a significant effect on the degree and type of acquisition of the second language (Bylund et al., 2019). For grammar, on the other hand, the end of the ‘critical period’ of full (second) language acquisition is associated with puberty when the brain structure and function are significantly modified (see Johnson & Newport, 1989, among others).

Longitudinal studies unveil permanent effects that the long-term use of more than one language has on the brain. DeLuca and colleagues (2018), for example, report that proficient bilinguals who are highly immersed in a bilingual environment exhibit greater plasticity in the cerebellum (a part of the brain that is involved in grammatical processing as well as language and cognitive control). Similarly, researchers have shown that brain plasticity due to the use of more than one language throughout the lifespan is associated with better resistance to age-related grey matter loss in older age, the so-called brain

reserve (Perani & Abutalebi, 2015). Additionally, elderly bilinguals exhibit some ‘cognitive reserve’ which translates into better executive control for the three major functions which are inhibition, attention switching, and working memory (Bialystok et al., 2012). Interestingly, deterioration in brain structure and decline in cognitive performance do not always go hand in hand. For example, bilingual individuals with Alzheimer’s disease who had less well-preserved white and grey matter structure than monolinguals were found to perform similarly in a variety of cognitive tasks (Schweizer et al., 2012). This observation is consistent with the finding that bi/multilingualism delays the onset of Alzheimer’s by four to five years (Bialystok et al., 2007).

This brings us to consider the effects of bilingualism on general cognition, foreshadowing Chapter 7 and, more specifically, the discussion on cognitive costs. Among the most famous effects of bilingualism on cognition is the so-called ‘bilingual advantage for executive control’. This cognitive advantage was reported in several studies via behavioural measures indicating that bilinguals perform faster and better than monolingual control groups in non-linguistic cognitive tasks such as the Simon, Stroop, and Flanker tasks; see Glossary (Bialystok et al., 2004; Marton et al., 2017). Although the executive advantage has not been replicated consistently, this is to be expected given the high inter-individual variability discussed in the previous section and the variety of cognitive tasks used in the various studies. But if there is a bilingual advantage for executive control, how does it arise?

A correlation between executive control and the regulation of a bilingual’s two languages is likely as language processing heavily relies on cognitive control (Fedorenko, 2014). The exact mechanism behind this correlation is not currently fully understood. Nonetheless, Bialystok and colleagues (2012) note that the non-linguistic conflict-monitoring mechanism is easily transferred to the domain of bilingualism where there is a need to select a word in one of the two languages in addition to the selection of a word among competitors which is generally found in language production, including among monolinguals. Indeed, bilinguals need to control:

- (i) The semantic, phonological, and grammatical alternatives in their two languages.
- (ii) Switching from one language to the other depending on the codeswitching habits of their community.

Thus two major cognitive mechanisms may be at play among bilinguals:

- (i) Conflict monitoring (triggered when a stimulus with two cues is associated with two responses, but only the relevant cue must be selected). Conflict monitoring is associated with interference suppression and attentional control.
- (ii) Response inhibition (triggered when a stimulus with a single cue is associated with a major response that must be overruled) (Bialystok et al., 2012).

Crucially, neuroscientists report some functional overlap of brain regions involved in language and cognitive control (see Abutalebi & Green, 2016, for a detailed account). For example, Abutalebi and colleagues (2012) found that language control and conflict and error monitoring in non-linguistic tasks (e.g., a Flanker task; see Glossary) are located in the same brain region, both involving the dorsal anterior cingulate cortex. Coderre and colleagues (2016) confirm the relevance of the role of the left prefrontal cortex and, in particular, the left inferior frontal gyrus, which is active in interference suppression and response inhibition. Several other brain areas seem to play a role in both language control and cognitive control (see the overview in Abutalebi & Green, 2016). These are the left and right inferior parietal lobules (e.g., in attentional tasks and in language selection in bilinguals), the right inferior frontal cortex (e.g., in response inhibition), and subcortical regions such as the left caudate, the left thalamus, the putamen of the basal ganglia (e.g., in cognitive sequence planning and in language selection and switching in bilinguals), and the cerebellum (e.g., in motor and cognitive control, morphosyntactic processing, predictions based on past knowledge, and resistance to speech interference).

Finally, neuroscientists have established that the same neural networks support the use of both of the languages of a bilingual speaker (Indefrey, 2006; Abutalebi, 2008; Golestani, 2016). This overlap could offer a physiological basis to the well-documented observation made by linguists that long-term changes are likely to occur when two languages are in contact. In addition, there is now ample evidence that the two languages are constantly active in the bilingual mind, whether in comprehension or production. Such evidence comes from studies using cross-language lexical priming or lexical decision tasks; see Glossary (e.g., Hernandez et al., 1996; Costa et al., 1999; Kroll et al., 2008). Cross-language structural priming also offers some support for this view (see among others Loebell & Bock, 2003; Favier et al., 2019; and a meta-analytic study confirming structural priming among bilinguals, although to a lesser extent than among monolinguals, in Mahowald et al., 2016). More specifically, in theories that consider processing to provide indirect evidence for the nature of linguistic representations, the cross-language priming data suggest that lexical items and syntactic structures may share some aspects of their representation in the bilingual's mind. One of the interpretations of cross-language structural priming, for example, might be that abstract structural representations can converge between the two languages of a bilingual speaker (Hartsuiker & Bernolet, 2017; also see Torres Cacoullos & Travis, 2018 based on corpus data, and Kootstra & Şahin, 2018 based on experimental data). Again, such evidence is in agreement with dynamic and adaptive models of language and cognition that I introduce in the following section.



### 1.2.2 *Adaptive Models of Language and Cognition*

First, as the term ‘adaptive’ is at the core of this book, I would like to provide a cursory review of adaptationist approaches in science. In evolutionary biology, the mechanism of ‘adaptation’ by means of natural selection captures the idea that biological species evolve rapidly in order to better adapt to a specific natural environment. This theoretical account was elaborated by Charles Darwin in the nineteenth century following the observation of variations in fauna in the Galapagos Islands. Darwin suggested that these variations could be best understood as adaptations to fit the local environment. Adaptation does not have a moral hue: it is neither good nor bad. It is merely a mechanism that takes place under some circumstances. Importantly, adaptation is a process that has to do with the present, not with unforeseen changes that are yet to come. Evolution based on adaptation has since been proved valid by numerous scientific studies, for example, through observation of bacteria rapidly evolving resistance to antibiotics or of insects from one species that split into two (for an accessible overview, see Sapolsky, 2017).<sup>1</sup>

A parallel between evolutionary biology and historical linguistics was already made by Darwin himself (Darwin, 1871). Up to today, methods from biology have been productively applied in the field of linguistics (for an overview, see Atkinson & Gray, 2005). Moreover, the evolution of human language as a biological process raises the question of whether there was biological adaptation of the human brain to language or of language to the human brain (for a discussion, see Conway & Christiansen, 2001, and Evans & Levinson, 2009). In the ‘ecology of language evolution’ framework, Mufwene (2001) supports the idea that languages reflect adaptations to cognition as well as to the social and natural ecologies of humans. For example, in a phylogenetic perspective, modern human languages developed as adaptations to the needs of our ancestors when they expanded their social networks and complexified their social organization. In a developmental perspective, children develop Theory of Mind (i.e., the ability to attribute mental states to others) relatively late (by age four); associated linguistic skills, such as understanding metaphors or irony, follow closely on this development. In a cross-cultural perspective, people with specific activities in local environments develop differing degrees of lexical labels. In an inter-individual perspective, experts acquire a wider range of vocabulary specific to their field of expertise. In sum, language is an adaptive system.

In the present book, the term ‘adaptive’ is more specifically associated with the neurocognitive mechanisms in the mind/brain. The idea that the human brain is adaptive has now been established in the scientific literature. For

<sup>1</sup> Rapid adaptation of some traits, nonetheless, does not preclude the parallel gradual change of other traits (see discussion of punctuated equilibrium vs gradual change).

example, researchers refer to the ‘adaptive parental human brain’ to account for the plasticity of the brain that follows from parental behaviour (Feldman, 2015). Another example comes from the study on London taxi drivers discussed earlier (Woollett & Maguire, 2011). In parallel, several studies, from psycholinguistics and neuroscience, have been developing experience-driven models that focus on the dynamic and adaptive nature of the language and the mind that also take into consideration adaptation. This is expressed clearly in the position paper by the Five Graces Group (2009: 1–2) as follows:

Language has a fundamentally social function. Processes of human interaction along with domain-general cognitive processes shape the structure and knowledge of language. Recent research in the cognitive sciences has demonstrated that patterns of use strongly affect how language is acquired, is used, and changes. These processes are not independent of one another but are facets of the same *complex adaptive system* (CAS). Language as a CAS involves the following key features: The system consists of multiple agents (the speakers in the speech community) interacting with one another. The system is adaptive; that is, speakers’ behaviour is based on their past interactions, and current and past interactions to get her feed forward into future behaviour. A speaker’s behaviour is the consequence of competing factors ranging from perceptual constraints to social motivations. The structures of language emerge from interrelated patterns of experience, social interaction, and cognitive mechanisms.

The Five Graces Group set important research directions by drawing attention to the adaptive characteristic of language. Since the publication of the paper, novel findings have pushed this research agenda even further, among others in the field of bilingual research.

In particular, the adaptive characteristics of the mind and the brain in bilingualism were captured through the Adaptive Control Hypothesis (Green & Abutalebi, 2013). The Adaptive Control Hypothesis holds that bilingual speakers adapt their cognitive system to different real-world, interactional contexts. The model distinguishes between three interactional contexts, defined as patterns of conversational exchanges within a community of speakers:

- (i) Single-language contexts: one language is dominant, the other is used exclusively in a different environment, for example, in interactions with monolingual speakers.
- (ii) Dual-language contexts: two languages can be used in the same conversation.
- (iii) Dense-codeswitching contexts: alternation between two languages is frequent in a single sentence.

These different interactional contexts are associated with different ‘language control’ processes in production and comprehension: the single-language and the dual-language contexts should involve language-task schemas that are in a competitive relationship as there is a need to restrict elements from the