Neuroimaging of simultaneous conference interpreters

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Introduction

This chapter focuses on one form of conference interpreting, namely, simultaneous interpreting. It is a complex cognitive task that demands the concurrent execution of multiple processes, at least listening, comprehension, repackaging a message from one language to another (while continuing to process incoming speech), speech production, and self-monitoring. This depends upon the deployment of an array of linguistic and cognitive control mechanisms that must coordinate the various brain systems implicated in handling these tasks. The way in which this is achieved is of profound interest to scientists working on a range of topics spanning language, cognitive control and expert performance.

Simultaneous interpreting has become a focus for research among cognitive neuroscientists interested in the neurobiology of multilingualism, as it offers a unique insight into the cerebral networks engaged by what has been termed extreme language control (Hervais-Adelman et al. 2015b; Obler 2012). Examining the neural basis of this extremely challenging activity elucidates the brain mechanisms implicated in multitasking processes, and in the exceptional ‘language-juggling’ that a simultaneous interpreter must carry out in the course of their work. This chapter provides an overview of what is currently known about the cerebral underpinnings of these processes, and will discuss the insights that studying simultaneous interpreting from a neuroscientific perspective can give us for better understanding the neural implementation of human language.

Figure 34.1 presents a schematic illustration of the processes implicated in simultaneous interpreting and their inter-relationships. This is not intended to be a formal model of the interpreting process that supplants existing proposals (which are covered elsewhere in this volume, e.g. Riccardi, Chapter 27, and in e.g. Daró & Fabbro 1994; De Groot 2000; Frauenfelder & Schriefers 1997; Gile 2009; Moser-Mercer 1997; Seeber 2011). It forms a basis for the conceptual representation of the relationships between the processes highlighted in the chapter. Throughout this chapter, the focus is on cognitive and linguistic control processes. These tap a limited set of cognitive resources, and it is assumed that to successfully interpret requires optimising the use of those resources in order to best manage and coordinate the
processes that underpin the task. This has parallels with the formulation of the task presented in Gile’s Effort Model (Gile 2009), a comprehensive discussion of which is beyond the scope of the chapter. In examining the impact of interpreting experience on the brain, the underlying premise is that an experienced interpreter has acquired mastery over the mechanisms that are necessary to control their languages in a manner that is compatible with interpreting.

In order to provide the reader with the requisite background, there follows a brief primer on the methods of cognitive neuroscience that have been used to investigate simultaneous interpreting and are referred to later in the chapter.

**Selected methods of human neuroimaging**

Mapping the neural correlates of simultaneous interpreting can provide insights into more than simply the brain areas involved in a task. If carefully interpreted, it is possible to draw inferences about the relationship between the neural substrates of simultaneous interpreting and other tasks. In particular, as this relates to the question of multilingual control. Simultaneous interpreting requires the control and coordination of an extensive array of resources, at the...
heart of which are those required to juggle two languages—to comprehend one and to speak another. By identifying the brain areas implicated in these processes and considering their roles in other cognitive processes, it is possible to provide insights essential for generating models of multilingual control that can accommodate this atypical multilingual scenario.

**Electroencephalography (EEG)**

Electroencephalography is the recording of electrical brain activity by means of sensitive electrodes placed on the scalp. It is prized for high temporal resolution, recording brain activity continuously in real time, and is therefore valuable for examining the timecourses over which cerebral processes occur. Modern EEG systems with a large number of electrodes also provide sufficient information to crudely localise (within a few cm) the cerebral sources of electrical activity recorded at the scalp, providing insights into which brain areas are responsible for processes at a particular instant.

EEG is silent and portable, but (due to its sensitivity to electrical fields) is easily disrupted by movement of the participant (including blinking and eye-movements), since muscles produce electrical fields many orders of magnitude greater than neuronal activity. EEG is therefore only of limited use in investigations involving speech production. When employed to investigate simultaneous interpreting, it is constrained to experiments using covert, rather than overt, output. EEG was nevertheless used for the first published neuroscientific investigation of simultaneous interpretation (Petsche et al. 1993).

**Positron emission tomography (PET)**

Positron emission tomography is a technique that records the decay of radioactive tracers. In an experimental setting, this allows examination of the brain’s metabolic activity by injecting a volunteer with ‘radiolabelled’ glucose. The labelled glucose is preferentially diverted to brain regions that are most in need of energy, i.e. those that are most active. The radiolabelled glucose undergoes decay and the emitted radiation is detected by the PET scanner, and the sources of elevated levels of radiation are identified, revealing which brain areas are most engaged during the recording period.

PET is of restricted utility experimentally, as it is an invasive technique, and a single session allows the acquisition of only a small amount of data, due to decay of the tracer, which becomes undetectable in barely a few minutes. Consequently, PET has been more or less supplanted by magnetic resonance imaging in experimental settings, although it has an advantage over EEG of being insensitive to electrical signals generated by muscles during articulation, in principle, allowing it to be used for experimental paradigms in which an overt response is required (e.g. Rinne et al. 2000; Tommola et al. 2000).

**Magnetic resonance imaging (MRI)**

Magnetic resonance imaging is a non-invasive tool for visualising brain anatomy and function, *in vivo*. MRI uses strong magnetic fields and radio waves to generate images, without recourse to ionising radiation (unlike PET).

Neuroanatomical studies employ MRI protocols producing high-resolution morphological images or protocols that provide fine-grained anatomical information about regional microstructural properties of the brain, which can be used to infer neuronal organisation. Comparing the neuroanatomy of simultaneous interpreters and non-interpreter bilinguals (e.g. Becker et al.
2016; Elmer et al. 2014) can provide hints that interpreting experience results in change to specific brain areas, implying (but not proving) a role for these areas in the task.

MRI can also be used to image brain function. A brain area activated in response to a stimulus or a task will exhibit higher blood flow than a less active one, due to the metabolic demands of the active neurons, which are met by increasing the supply of blood. MRI provides high-resolution images of the brain (at the scale of millimetres or better) but acquiring them is cumbersome. An MRI scanner is a large, expensive device requiring considerable infrastructure. Furthermore, MRI scanning is extremely noisy. Consequently, any study of simultaneous interpreting that aims to use spoken source material must consider this, and work-arounds must be employed. Functional MRI (fMRI) only provides information at low temporal resolutions, limited by the speed of neurovascular coupling (the speed with which blood-flow responds to the metabolic demands of increased neural activity, which is on the order of 3–6s). Furthermore, the quality of data recorded by MRI is very sensitive to movement, even small displacements of a participant’s head (e.g. speaking) during the acquisition of a scan can cause substantial signal loss, although the gravity of this can be reduced by careful study design. Despite these technical difficulties, fMRI has been used to investigate the brain areas involved during simultaneous interpreting tasks (e.g. Ahrens et al. 2010; Elmer 2016; Hervais-Adelman, Moser-Mercer & Golestani 2015; Hervais-Adelman et al. 2015).

The human language network, in brief

This section provides an outline of the cerebral basis of spoken language³ that suffices to permit the reader to situate the results of the reviewed literature (a thorough and accessible introduction may be found in Kemmerer 2014) and to appreciate the functional diversity of brain areas implicated in language and bilingual language control. Such an account inevitably entails the presentation of a substantial quantity of neuroanatomical labels. Figures 34.2 and 34.3 provide an overview of the loci of the brain areas referred to below.

![Lateral Surface of the Left Cerebral Hemisphere](image)

*Figure 34.2* Illustration of the approximate location of Broca’s and Wernicke’s areas in the left cerebral cortex. The co-ordinate system depicted in the figure labels the cardinal axes that are typically used to situate brain regions in the neuroscientific literature.
No introductory description of the cerebral basis of language is complete without a brief historical overview covering the first systematic modern observations of the relationships between localised brain lesions and language impairments. Such insights began to proliferate in the nineteenth century, thanks to the work of neuropsychologists investigating aphasias—disorders of language.

In 1861, physician and anthropologist Pierre Paul Broca visited a patient named Leborgne at the Hôpital Bicêtre in Paris. Leborgne suffered from severe impairment to his verbal communicative ability. He was known as *Tan* due to his inability to utter any other word. However, his comprehension was unimpaired. Shortly after Broca’s visit, Leborgne succumbed to a gangrenous infection, allowing Broca to conduct an autopsy, during which he noted that Leborgne had a cerebral lesion, at a locus he described as the “third left frontal convolution” (Broca 1861). Broca continued to examine speech disorders and published a series of case studies in which lesions to this area produced similar speech production deficits (Broca 1865). The brain region he identified is the *left inferior frontal gyrus* and is to this day often referred to as *Broca’s area*.

Shortly after the publication of Broca’s findings, Carl Wernicke, a Prussian neurologist, began to pursue research into speech disorders caused by brain disease. In his post-mortem studies of the brains of individuals suffering from language impairments, he found that not all speech disorders were caused by damage to the left inferior frontal region implicated by Broca. In particular, he found that receptive language deficits, rather than productive ones, resulted
when an area of the left posterior temporal cortex was damaged (Wernicke 1874). This region is still frequently referred to as Wernicke’s area.

Wernicke developed a model of language processing and, with subsequent elaboration by aphasiologist Ludwig Lichtheim, the “Wernicke-Lichtheim” model was born (Lichtheim 1885). This model contained a “motor centre” (Broca’s area), an “auditory centre” (Wernicke’s area) and a “concept centre”, and proposed that connections between these centres were critically important to speech comprehension and production.

The roles of Broca’s and Wernicke’s areas have since been discovered to be more complex, diverse and less specific than initially proposed. It has become clear that what is referred to as Broca’s area encompasses multiple functionally-distinct territories separately serving phonological, semantic and syntactic processing in both speech comprehension and production (e.g. Friederici 2012; Willems et al. 2016). Moreover, the labels Broca’s area and Wernicke’s area are neuroanatomically only approximate, and there is no unanimous agreement as to their definition among cognitive neuroscientists of language (for a review and discussion of this issue, see Tremblay & Dick 2016).

A considerable body of evidence now implicates numerous additional brain areas in language processes (extensively reviewed in Price 2012), and the effort to characterise the role of the neuroanatomical subcomponents of the language network is ongoing.

According to the influential model of the neural architecture of speech processing by Hickok and Poeppel (2007), speech comprehension implicates the bilateral superior temporal lobe (associated with auditory and phonological processing), alongside a network of areas comprising the left inferior frontal cortex (akin to Broca’s area, implicated in semantic and combinatorial processes for building meaning), the left inferior temporal cortex (involved in lexical access), the left anterior temporal cortex (involved in semantic representation and the organisation of semantic information). Speech production (for extensive reviews on the neurobiology of human speech production, see, for example Eickhoff et al. 2009; Hickok 2014) depends upon a similar set of brain areas as comprehension (especially those associated with the higher-level linguistic aspects of formulating a spoken message, which are analogous to those implicated in comprehending a spoken message) with the addition of sensorimotor cortical regions and left premotor cortex, the anterior insulae (Ackermann & Riecker 2010) and the cerebellum—implicated in speech motor planning and execution.

The brain areas listed above, barring the cerebellum, are located in the cortex, the outer layer of the brain, which is typically considered the site of higher behavioural and cognitive functions. However, the human brain contains more than the cortex and many structures that will be referred to later in this chapter are “subcortical” (i.e. they are found deeper inside the brain). In contrast to cortical structures, they are often simplistically described as being instrumental in the regulation of behaviour, emotions, memory and learning. Nevertheless, subcortical structures are also important in speech perception and production, contributing substantially to diverse functions, such as articulation and grammatical processing (Kotz & Schwartz 2010; Lieberman 2000). The subcortical structures discussed below are the basal ganglia, in particular, the putamen and the caudate nuclei. These structures are bilateral, with a homologue in each hemisphere.

**Bilingual language control**

Bilingual language control refers to the cognitive process required to deal with the co-existence of multiple languages, and their attendant conflicting lexical, semantic and syntactic processes.
in one brain. The necessity for a particular apparatus to be available to deal with this becomes clear in the light of the fact that, far from being segregated, a bilingual individual’s languages are always, even in a monolingual context, co-activated—in spoken word recognition (Marian et al. 2003), in visual word recognition (Dijkstra 2005) and in word production (Kroll et al. 2006). As Grosjean memorably entreated: “Neurolinguists, beware! The bilingual is not two monolinguals in one person” (Grosjean 1989: 3).

It is evident that mechanisms must be at work to enable the use of one language in preference to another. Numerous psycholinguistic models have been developed to account for various issues in bilingual cognition, such as how the bilingual lexicon is organised to allow word recognition (Dijkstra & Van Heuven 2002), or production (Kroll et al. 2010). At the heart of these models lies the need to control competing languages, wherever they may interfere with one another, by a process of selection and inhibition that involves moderating the relative ‘activation’ of one language in contrast to another.

Neurofunctional accounts of bilingual language control

In 1986, David W. Green proposed a highly influential framework for speech control in bilinguals. Green based the development of this framework primarily on a synthesis of neuropsychological data, citing clinical observations of polyglot individuals who had suffered brain damage that caused them to have impairments in producing or comprehending some, but not all, of their languages. Such cases provide evidence that there are separable neural substrates for speech production and perception (supporting the notion that these are subsystems of the global language system), and that separable neural subsystems support different languages. Based upon the implications of these observations, Green elaborated a conceptual model focused on the idea of control, specifically, inhibitory control. This provides a mechanism for enabling one language to be used in preference to another. This model has since been extensively revised, incorporating additional evidence, resulting in numerous iterations of a comprehensive neurofunctional account of the mechanisms of bilingual control (Abutalebi & Green 2016; Calabria et al. 2018).

Bilingual control processes act on brain regions implicated in speech production and comprehension, interfacing with these structures to enable multilingual individuals to use the desired language, by adequately regulating interference from the language not in use. This is coordinated by a cortico-subcortical network that overlaps with non-linguistic control mechanisms. A number of structures are implicated in this complex control activity:

The anterior cingulate cortex (ACC) and pre-supplementary motor area (pre-SMA) are particularly associated with tasks involving language switching and selection in multilinguals. They are also seen to be implicated in conflict monitoring in monolingual individuals, in monolingual tasks.

The prefrontal cortex (PFC) is a large subdivision of the brain, which is consistently associated with cognitive control. The left PFC is often seen to be involved in tasks that require bilingual control. Green and Abutalebi (2013) describe the role of the PFC as conflict resolution. They divide this construct into response selection in the left PFC and response inhibition in the right PFC. They also point out that the right PFC is involved in domain general inhibitory control.

The inferior parietal lobules (IPLs) are linked to the control of attention. In the context of bilingual language control, this implies driving language selection. Abutalebi and Green (2008) suggest that the left IPL functions to bias selection towards the language in use and the right IPL towards the language not in use.
The left caudate nucleus in bilinguals is associated with language control, in particular, switching between languages (in monolinguals it is associated with the control of lexical interference). The left putamen is similarly involved in language control tasks. Both of these structures are also implicated in domain general inhibitory control, albeit in subtly different ways—the caudate nucleus is typically associated with cognitive control, which might be considered to be deliberate, while the putamen is associated with lower-level action control, which might be said to be more “automatic” or “habitual” (Grahn et al. 2008).

The cerebellum is intimately interconnected with all the regions of the language control network, although its precise function in the domain of language processing is not yet fully elucidated. One suggestion is that it helps resolve inter-language conflict (Filippi et al. 2011).

These areas, illustrated in Figure 34.3, constitute a bilingual language control network, which provides the necessary influences on the core language network to allow language selection, in a fashion that is responsive to the demands of the environment.

**Bilingual control in simultaneous interpreting: a unique multilingual communicative context**

In the case of interpreting, a model of the organisation of the bilingual language system that is predicated exclusively upon a global inhibition of one language or another is not feasible. Green (1986) addressed the issue of translation and suggested that inhibition is possible at multiple loci, which he refers to as internal and external. Internal being suppression of retrieval of words and external being the suppression of words at the production stage. In a further development of this model, Green and Abutalebi (2013) put forward the Adaptive Control Hypothesis (ACH), which aims to account for bilingual control in the diverse modes in which multilingual individuals communicate. Different contexts are presumed to call upon different functional subsystems of control and therefore, different neuroanatomical regions.

A monolingual context, wherein the interlocutors have only one common language at their disposal (or where they elect, or are obliged, to use only one) demands goal maintenance (speaking in the desired language) and interference control (to suppress the competing language). A dual language interactional context demands both these control processes and more—the speaker must be responsive to the arrival of a new interlocutor (salient cue detection), who may need to be addressed in a different language (requiring selective response inhibition to cease the ongoing activity), and then to begin using the appropriate language (requiring task disengagement and task engagement, i.e. halting output in one language and initiating output in another). A further multilingual context, code switching, is also covered by the ACH. Here, two (or more) languages known to the interlocutors are freely used, exercising another control process, namely, opportunistic planning, characterised as using whichever means most readily come to hand in order to achieve a goal. The demands of deploying these control mechanisms on a regular basis are thought to progressively hone them, rendering them more efficient and enabling multilingual individuals to communicate seemingly as effortlessly as their monolingual counterparts.

Simultaneous interpreting represents yet another category of multilingual communicative context, one in which both the source and target language must remain actively accessible, while the language of production must be rigorously controlled. This scenario clearly has similarities with the dual language and dense code-switching contexts. We will now focus on the available neuroimaging evidence that can cast light on how simultaneous interpreting is implemented at the neural level, and how the control mechanisms it requires relate to those of other forms of bilingual control, and cognitive control.
The neural basis of simultaneous interpreting

Investigations using neuroimaging methods during a simultaneous interpreting task have provided insights into the cerebral loci that are implicated. The relatively small quantity of research published to date has addressed the important question of which structures are implicated in the task and has begun to offer answers to such questions as what is the effect of directionality in simultaneous interpreting and what is the effect of expertise.

Outlining the cerebral network of simultaneous interpreting

The first investigation to provide insights into the neuroanatomical substrates of interpreting was carried out by Rinne et al. (2000). They used PET to examine brain activation in eight Finnish professional interpreters as they carried out Finnish to English and English to Finnish interpreting tasks, as well as Finnish and English shadowing. Because shadowing and interpreting both require listening to and processing speech as well as producing speech (with all that this entails for accessing phonological, lexical, syntactic, mnemonic and attentional resources), comparing the pattern of brain activity elicited by interpreting with that elicited by shadowing (i.e. subtracting out the correlates of shadowing) yields an image of brain areas that are more involved in interpreting than shadowing. This “subtractive logic” enables conclusions to be drawn about the relative recruitment of brain areas in the service of a particular task—if an area is more significantly active during an interpreting task than a shadowing task, it may be concluded that it has a role that is specific to the interpreting task, presumably relating to the multilingual nature of the task. Rinne et al. (2000) subtracted L2 shadowing from L2 to L1 interpreting in order to delineate the areas implicated in interpreting to L1 that are not involved in processing the L2 input. Similarly, they compared L1 shadowing with L1 to L2 interpreting to isolate brain areas involved in interpreting but not involved in processing L1 input. In both these cases, the significant differences between the tasks reflect the additional demands of processing the source for conversion to the target message and any associated multilingual control demands (not present during shadowing).

Interpreting into L1 recruited left premotor cortex and left dorsolateral frontal cortex. Interpreting into L2 recruited left ventrolateral prefrontal cortex, left inferior temporal gyrus and the cerebellum. These areas are involved in processes such as lexical retrieval, working memory, morphosyntactic and semantic analysis (see Hodzik & Williams, Chapter 26, in this volume).

In a study of similar design, Elmer (2016) used fMRI to compare interpreting into both a native and non-native language with shadowing in a group of five professional simultaneous interpreters. Elmer’s analysis was limited to brain areas already implicated in bilingual language control and, within these, showed significant engagement of the pars triangularis of the left inferior frontal gyrus (a portion of Broca’s area known to be involved in speech production and semantic processing) during interpreting into both L1 and L2 and the left anterior insula (an area associated with articulatory control and inhibitory control) during interpreting into L2. Unfortunately, the small sample is cause for concern, as the results may not be replicable (Hervais-Adelman et al. 2018), but the observed effects of interpreting direction are nevertheless of interest.

The effect of interpreting direction

In the history of simultaneous interpreter training, there has been a long debate regarding the “best” direction for interpreters to work (discussed at length in Godijns & Hinderdael...
2005). Should they work from their L1 into their L2, allowing them to leverage their putatively superior comprehension of the source message? Or should they work from an L2 into their L1, potentially sacrificing some subtlety in comprehending the source in favour of a potentially more refined output in their L1?

Cognitive neuroscience cannot provide an answer to this, since the qualitative question of what is best ultimately resides with service users. Cognitive neuroscience may, however, provide some insights into the resources used. The studies by Rinne et al. (2000) and by Elmer (2016) suggest that more cerebral resources (assessed by the extent of brain territory significantly recruited by the task) are called upon when interpreting into the non-native language. This may indicate that the task is more effortful, although the precise reason for this is unclear. There are several potential explanations—either the demands of formulating the output in the second language are greater than formulating in the first, or the demands of inhibiting the first language, in order to produce the target accurately in the second language are greater. This may relate to the interpreters’ command of the L2 in comparison to the L1, which may be lesser. In the absence of data on their relative mastery of the two languages, this is only a speculative suggestion. A third possibility is that the interpreters in these studies had a habitual interpreting direction, which they trained in and practise professionally, namely, L2 to L1, rendering L1 to L2 interpreting more challenging than its more usual counterpart. This raises the question of the impact of experience on the pattern of brain activation observed during a simultaneous interpreting task.

**The impact of experience on the brain network of interpreting**

The two studies described above examined professional interpreters with considerable experience—5–20 years in the case of Rinne et al.’s (2000) study and 4–22 in the case of Elmer’s (2016). Two fMRI studies of simultaneous interpreting have been carried out in which participants were novice or untrained interpreters. In contrast to the participants in the studies above, these participants had not had the opportunity to develop automaticity in interpreting, and thus the results of these studies provide a different type of insight into the network of brain areas involved in simultaneous interpreting—they can help to show the extent of the brain network involved, absent learned strategies or specialisation.

Ahrens, Kalderon, Krick and Reith (2010) carried out a small exploratory fMRI study, in which six interpreting trainees either interpreted into their native language or produced speech freely while listening to a story in a second language. They reported that interpreting, compared to free speech, preferentially recruited bilateral motor cortex, the pars triangularis of the left inferior frontal gyrus, the bilateral superior temporal lobe, the left inferior postcentral gyrus, the left fusiform gyrus, the left cuneus, and the right cerebellum. This is consistent with a network of brain areas involved in speech planning and production, semantic processing, auditory processing, lexical access and attentional control.

Hervais-Adelman, Moser-Mercer, Michel and Golestani (2015) also used fMRI to examine the neural basis of interpreting in novices. Fifty participants, some of whom were about to begin a master’s course in simultaneous interpreting (and had no prior experience with SI) executed an interpreting task from a second language into their native language. They found a broad range of brain areas to be significantly more engaged in interpreting than in shadowing. Key areas involved were the pre-supplementary motor area, the premotor cortex, the left inferior frontal gyrus, the anterior insulae, the caudate nuclei, and the cerebellum. Intriguingly, this composes a set of brain areas implicated in linguistic processes (as discussed above) but also known to have other, domain general cognitive control functions. The pre-supplementary
motor cortex is implicated in self-monitoring and error detection (Nachev et al. 2008), while the anterior insulae, alongside their role in speech production and vocal motor control (Ackermann & Riecker 2010; McGettigan et al. 2013), are implicated in task switching and attentional control (Nelson et al. 2010).

Interestingly, these two studies of inexperienced individuals reported more extensive brain activation during interpreting than did the studies previously discussed. This is consistent with the idea that expertise, or practice (see Moser-Mercer, Chapter 28, in this volume), promotes the development of efficient cerebral strategies for executing tasks, that consequently place lesser demands on cognitive resources. The studies described above are not directly comparable with one another, as they use differing tasks, and in the cases of the studies by Rinne et al. (2000), Elmer (2016) and Ahrens et al. (2010) have rather small sample sizes, but they provide circumstantial evidence that expertise may indeed reduce the extent of brain activation (in terms of the number of distinct neuroanatomical areas significantly recruited) in response to the trained task. This question was, however, directly addressed by Hervais-Adelman, Moser-Mercer and Golestani (2015).

In a follow-up to the study described above, they invited the same participants to undergo a second fMRI scanning session 15 months after the first. In the case of the interpreting trainees, this coincided with the end of their master’s programme. They analysed the patterns of brain activation during interpreting in the now finished interpreting trainees and the non-interpreter participants, as controls. By comparing these, they were able to determine whether any changes to the functional network of interpreting had occurred that could be attributed to training. They showed that training in interpreting significantly reduced activation in one brain area—the right caudate nucleus. As described above, the caudate nucleus is a structure associated with cognitive and language control. This suggests that, after completion of a master’s in simultaneous interpreting, trained participants make fewer demands upon the right caudate nucleus to carry out this task. One possible interpretation of this finding is that, with increasing interpreting expertise, the cognitive and language control demands of the interpreting process decrease, requiring less input from the right caudate nucleus. This may contribute to releasing cognitive resources to enable the interpreter to improve their delivery, consistent with the benefits of expertise-driven automaticity of the task.

Managing simultaneity in simultaneous interpreting

One of the most unusual features of simultaneous interpreting as a multilingual communicative context is the fact that the interpreter must simultaneously process an incoming speech stream in a source language and produce a speech stream in the target language (see Bartłomiejczyk & Stachowiak-Szymczak, Chapter 2, in this volume). This presumably requires the application of control at two conceptually different levels—to minimise cross-linguistic interference during comprehension and to minimise it during production. Hervais-Adelman, Moser-Mercer and Golestani (2015) attempted to elucidate the neural basis of the different levels of control. In order to do so, they focused on finding the brain areas that support the “simultaneity” of simultaneous interpreting. They performed an analysis in which they correlated the level of brain activity during an interpreting task with the duration of the period for which the participant simultaneously produced speech and heard the source message, on a sentence-by-sentence basis. They reported that the bilateral putamen and the cerebellum, as well as the left superior parietal lobule (implicated in the control of attention) and the medial orbitofrontal cortex (often seen to be activated in cognitively demanding tasks), showed significant modulation of activity as a function of the duration of overlapping input and output. They interpret their results as
indicating that the caudate nucleus is involved in the overarching task demands of the bilingual scenario (the global requirement to maintain two lexico-semantic sets active), while the putamen is implicated at a conceptually lower-level, mechanistic level of control over the output (the speech production processes themselves).

The impact of simultaneous interpreting experience on brain structure

Structural investigations provide only indirect evidence regarding the neural substrates of a task—they do not provide direct evidence for the engagement of particular brain areas. Comparing brain structure across groups incorporates all between-group differences of simultaneous interpreting, which may not be exclusively the language control aspects (e.g. regularly listening to long speeches or producing speeches for protracted periods). Due to this limitation, this category of studies is discussed selectively and in brief; an extensive discussion is presented in Hervais-Adelman and Babcock (2019).

A number of investigations have been carried out that support the view that there are structural adaptations of the brain as a function of simultaneous interpreting experience. Elmer et al. (2014) demonstrated reductions in volume of a number of brain areas associated with bilingual language control (the left and right prefrontal cortices, the anterior cingulate gyrus and the caudate nuclei, bilaterally), the magnitude of which correlated with cumulative interpreting experience. The authors argue that this reduction reflects an adaptation of the structures to interpreting practice, such that they become more efficient, i.e. they are tuned in such a way as to meet the demands of the task with fewer neural resources. However, another study (Becker et al. 2016) reported that simultaneous interpreters had greater brain volume in an area of anterior left temporal lobe, compared to consecutive interpreters and translators. Findings in professional musicians have shown similarly heterogeneous patterns of regional volume reductions and expansion as a function of expertise (James et al. 2014).

Longitudinal investigations of the structural consequences of simultaneous interpreting practice can provide slightly more certainty that the between-group differences are truly attributable to simultaneous interpreting practice. Hervais-Adelman et al. (2017) examined the changes in brain structure after 15 months of simultaneous interpreting training, and found that areas associated with attentional control, phonological processing, audio-motor integration and working memory thickened in the trainee interpreters compared to a non-interpreter multilingual control group who were engaged in other post-graduate studies. Babcock (2015) examined changes in regional brain volume after a 2-year training in simultaneous interpreting, compared to a 2-year translation programme, and revealed a larger decrease in volume after translation training compared to interpreting training in the bilateral putamen, the right caudate, the left superior temporal lobe, and the left supramarginal gyrus (among other areas). Considered with respect to the result from Hervais-Adelman et al. (2017), these results support a preservation or enhancement of the grey matter in the left temporal and parietal cortical regions after training in interpreting. Van de Putte et al. (2018) examined changes in inter-areal connectivity in the brains of trainee interpreters after nine months of training, in contrast with trainee translators. They employed a network-based analysis and revealed that two functional networks were enhanced in the interpreting students. They label these as control networks, the first incorporating basal ganglia and prefrontal areas associated with domain-general and language-specific cognitive control, and the second incorporating the cerebellum and supplementary motor area, also associated with language control.
The structural data are heterogeneous, but implicate several regions predicted by models of multilingual language control, including the basal ganglia, and frontal areas, as well as areas associated with lexico-semantic processing (the supramarginal gyrus, the anterior temporal lobe and the parietal lobe). However, the time-course of these expertise-related adaptations of the brain is not yet known, but research in other fields suggests it is unlikely that there are linear relationships between expertise and volumetric or morphological brain changes (Lovden et al. 2013). This is likely to contribute to the current heterogeneity of the literature.

**Conclusion**

The investigation of simultaneous interpreting from a neuroimaging perspective has provided data that further underscore the extent to which the demands of bilingual language control are met by brain networks that are not specialised in language but, rather, are implicated in domain general cognitive control. The cognitive consequences of interpreting expertise have already proven to be a subject of considerable academic interest (recently reviewed by García et al. 2019). Understanding the neural basis of interpreting and its consequences for the brain provides evidence (albeit circumstantial) that there is an intersection of cognitive control and language control during interpreting.

Although the functional neuroimaging data are relatively scant and results diverse, there is some convergence pointing to a particular role for prefrontal, pre-SMA, cerebellum and basal ganglia structures, consistent with the bilingual language control network put forward by Calabria et al. (2018). The unique properties of simultaneous interpreting, namely, the necessity to control linguistic interference at the level of both comprehension and production, in a continuous, rather than merely punctate manner, have been partly characterised by the above studies. Mapping the data onto the schematic representation of simultaneous interpreting in Figure 34.1 is not trivial. The following is a suggestion based on the functional data, which will surely be refined and may even be superseded as more studies are carried out in future:

1. language management during simultaneous interpreting is the province of the left inferior frontal gyrus, caudate nucleus and the pre-SMA;
2. the motor control demands of interpreting that are specific to the multilingual context are handled by the putamen and the cerebellum;
3. attentional control, enabling monitoring of source and target streams, calls upon the anterior insulae and parietal areas.

The research to date suggests that interpreting direction may have a considerable impact on the cerebral resources recruited to execute the task. However, this remains confounded with expertise. There is typically (in the population samples implicated in the studies reviewed above) a habitual direction of interpreting, and further investigations are needed to determine whether what has been observed results from greater facility in one direction than the other that derives from practice, or because of the intrinsic balance of activation of the two languages (with the L1 being more difficult to suppress than the L2, as suggested by Meuter & Allport 1999). Further, the impact of language asymmetry in interpreting has been of considerable interest to scholars of TIS (translation and interpreting studies) but has yet to be systematically explored by cognitive neuroscientists. There remain several avenues for exciting research that are still to be pursued, which will help shed light not just on interpreting, but on the underlying mechanism of bilingual language control.
An important issue that this chapter has not addressed is the implication of these data for practitioners and students of simultaneous interpreting. Currently, the data show that the brain is modified as a function of acquiring expertise in simultaneous interpreting, and that the patterns of change are consistent with an increasing automaticity of the process. It is not possible to directly conclude from the data which subcomponents may be more automated, but the functional changes in the right caudate nucleus after training reported by Hervais-Adelman, Moser-Mercer and Golestani (2015) point to a reduction in the central coordination demands of the task, possibly emerging alongside the development of improved language management strategies (see Riccardi, Chapter 27, in this volume). Other findings suggest a global reduction in the extent of brain activation required to achieve the same task with experience (Elmer 2016; Rinne et al. 2000; Tommola et al. 2000), which is often interpreted as a reflection of globally reduced cognitive demand.

Although insights from simultaneous interpreting may be highly relevant to an adjacent discipline, namely, consecutive interpreting, these two tasks differ substantially, in particular as regards the demands of managing overlapping input and output speech streams (necessary in simultaneous but not consecutive) and the memory demands of retaining potentially lengthy discourse in consecutive but not simultaneous interpretation. A comparison of the neural bases of these two tasks would be a welcome addition to the literature, yielding insights into the way the different demands are managed and providing additional information on the coordination of the multiple linguistic and cognitive systems implicated in such challenging bilingual endeavours.

If there can be only one conclusion from the data featured in this chapter, it is that practising the interpreting task is key to developing the degree of control required simultaneously across the multiple levels of the bilingual language system. Practice is vital to driving the cerebral changes that result in automaticity, liberating cognitive resources from the extraordinary demands of language management results in a greater availability of cognitive resources that can be devoted to matters of style, accuracy and performance.

Notes

1 This approach is inherently one of cognitive decomposition, which may be somewhat controversial or unsatisfactory (see, e.g. Setton 2001. “Deconstructing SI: a contribution to the debate on component processes”). It is espoused here for pragmatic, rather than ideological, reasons, as it allows for a preliminary mapping of component processes onto neural substrates, necessary at this relatively precocious stage in the study of the neuroscience of simultaneous interpreting.

2 An investigation using only covert output leaves open the possibility that the participant is not engaging with the task, and does not allow validation of their intended targets. Furthermore, one feature of simultaneous interpreting that is especially challenging is the need to monitor one’s own production of the target while continuously monitoring the source stream. This aspect cannot be investigated in conditions that do not allow production.

3 Reading and writing depend upon similar substrates, albeit with the engagement of visual rather than auditory processes. However, a discussion of the cerebral basis of reading is beyond the scope of this chapter, which focuses on oral-oral interpreting.

4 The brain is an approximately symmetrical structure divided into a left and right cerebral hemisphere, in which most neuroanatomical features have a homologue in each hemisphere. Neuroanatomical labels therefore specify left or right, indicating the hemisphere in which a region is situated. Typically, when no hemisphere is indicated, left and right homologous areas are intended. However, some labels, such as “Broca’s area” can specify a particular, lateralised region, in this case, in the left hemisphere.

Further reading

References


Becker, Maxi, Schubert, Torsten, Strobach, Tilo, Gallinat, Jürgen & Kuhn, Simone 2016. Simultaneous interpreters vs. professional multilingual controls: Group differences in cognitive control as well as brain structure and function. Neuroimage 134, 250–260.


Neuroimaging simultaneous interpreters


