13
Translation, neuroscience and cognition

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13.1 Introduction

Like any other form of human cognition, the processes targeted in this book are associated with, if not dependent on, specific patterns of brain activity. Of course, as shown throughout the volume, mental aspects of translation and interpreting can be inferred in the absence of neurological evidence. Yet, revealing findings from neuroscience and related disciplines have accumulated over the decades, offering more direct insights on the psychobiological foundations of interlingual reformulation (IR)—namely, translation and interpreting in their various modalities (García, 2019; García, Mikulan, et al., 2016). The present chapter provides a succinct yet comprehensive survey of this interdisciplinary interface, addressing its main methods, topics, findings, implications and challenges.

A few years ago, the neural basis of IR was deemed a “known unknown” for Translation Studies (Tymoczko, 2012). Arguably, however, this is not because critical research is scant but, rather, because it has not been incorporated by mainstream circles in the field. In fact, scientific knowledge on the translating and interpreting brain has been produced since the late 1920s, and it has expanded considerably in the last 25 years (Elmer, 2012; García, 2013, 2015a). Broadly speaking, works on the topic can be periodized in three stages.

First, in the early and mid-20th century, a series of single-case studies on bilingual aphasics showed that translation processes could become variously disturbed following brain lesions, even when other abilities in the native and non-native language (L1 and L2, respectively) were relatively spared. Specifically, Kauders (1929), Veyrac (1931) and Gastaldi (1951) documented three hitherto unknown disorders that compromised verbal and cognitive control mechanisms mediating backward translation (BT, from L2 to L1) and/or forward translation (FT, from L1 to L2)—see Section 13.2.1. In retrospect, the evidence gleaned throughout this period was far from robust, as it was scarce, mostly anecdotal and devoid of apt theoretical frameworks. Moreover, it lacked both systematic translation assessments and detailed neurological and neuropsychological descriptions. However, it paved the way for more detailed examinations of normal and pathological translation processes, and it was eventually resurfaced to inform suggestive hypotheses and models (Fabbro, 1999; García, 2012, 2015a)—see Section 13.2.2.
Then, in the last decades of the 20th century, methodological and technological advances led to significant breakthroughs. The incipient clinical corpus described earlier was considerably broadened thanks to the development of a standardized test including translation tasks (Paradis, 1979), the accumulation of more meticulous case reports (García, 2015a; Paradis, 1989) and the detection of a fourth neurological disorder affecting translation skills (Paradis et al., 1982)—for details, see Section 13.2.1. Also, joint efforts by neurolinguists and translation scholars gave rise to pioneering experimental reports on brain lateralization (Fabbro et al., 1990; Fabbro et al., 1991), functional connectivity patterns (Kurz, 1994, 1995) and evoked hemodynamic activity (Klein et al., 1995; Price et al., 1999) during IR—see Sections 13.2.1 and 13.2.2. At the same time, neurocognitive accounts of translation and interpreting began to emerge in the literature, including compendiums of theoretical reflections (Bouton, 1984; Paradis, 1984), position papers (Fabbro & Gran, 1997) and even full-fledged models of critical mechanisms (Fabbro, 1999; Paradis, 1994).

Finally, since the year 2000, research on the neurocognitive basis of IR has extended in several directions. Behavioural evidence on processing of cross-language equivalents (García, 2015b) and executive skills in simultaneous interpreters (SIs) (García, 2014) has grown in parallel with relevant neuroscientific studies. The latter include assessments of verbal and non-verbal mechanisms through techniques as varied as positron emission tomography (PET) (e.g. Rinne et al., 2000), functional near-infrared spectroscopy (fNIRS) (e.g. Quaresima et al., 2002), event-related potentials (e.g. Proverbio et al., 2004), functional magnetic resonance imaging (fMRI) (e.g. Lehtonen et al., 2005), transcranial direct current stimulation (tDCS) (e.g. Liuzzi et al., 2010), direct cortical stimulation (e.g. Borius et al., 2012), structural MRI (e.g. Elmer, Hägggi, et al., 2014), and scalp-level and intracranial electroencephalographic (EEG) recordings (e.g. Dottori et al., 2020; García, Mikulan, et al., 2016). Indeed, this empirical corpus has become sufficiently large to warrant systematic reviews focused on the neurocognitive correlates of translation directionality, the mechanisms engaged by different translation units, and the anatomofunctional impact of interpreting expertise (Diamond & Shreve, 2010, 2017; Elmer, 2012; García, 2013; Moser-Mercer, 2010). Moreover, a substantial part of the evidence has been jointly interpreted to inform a neuroanatomical model of putative translation routes (García, 2012).

As this recapitulation suggests, research on the neurocognitive basis of IR has been gaining momentum within and outside Translation Studies—so much so that it may be ready to assert itself as a full-blown sub-discipline in the field (García, 2019). The remainder of this chapter provides a comprehensive outlook on this thriving interdisciplinary arena. In Section 13.2.1, an overview is offered of the methods used in existing studies, ranging from behavioural to lesion-based and neuroscientific approaches. Next, Section 13.2.2 considers key findings on the neurocognitive basis of IR, including insights into anatomical, functional and plastic properties of its fundamental systems as well as integrative theoretical models proposed therefrom. Finally, Section 13.2.3 addresses the challenges and opportunities facing the field’s short- and long-term development. All in all, this chapter illustrates the myriad contributions that neuroscience can bring to cognitive translatology.

### 13.2 Core topics

#### 13.2.1 Methods

Research on neural aspects of IR profits from numerous behavioural tasks, which may be used on their own, administered to brain-damaged patients, or combined with neuroscientific
recordings from healthy participants. This methodological repertoire is briefly introduced in the following sub-sections.

13.2.1.1 Behavioural measures

Behavioural measures involve verbal or non-verbal stimuli to which participants must respond following predefined instructions. Outward performance is assumed to reflect the operation of specific target mechanisms, such as those supporting reading, translation or cognitive control—namely, the collection of processes involved in the coordination, selection, inhibition and anticipation of relevant mental operations (Diamond, 2013). Typically, experimental tasks comprise a number of contrastive conditions (e.g. BT and FT) conceived in terms of three types of variables: controlled variables (i.e. factors that are established as similar between conditions), independent variables (i.e. factors manipulated by design in the experiments, such as translation directionality) and dependent variables. The latter are indexed by the participants’ responses, which may consist in oral productions (e.g. translating words out loud), manual actions (e.g. pressing a key to indicate that two words are similar in meaning) or other types of overt decisions (e.g. grabbing a card and choosing which other card it should be paired with). The two most important types of dependent variable are accuracy or number of hits (measures of performance efficacy, typically calculated as the sum or ratio of correct responses) and response time (a measure of processing efficiency, represented by the speed with which the subject responds).

Several behavioural instruments have proven informative for the field. For example, Fabbro et al. (1991) assessed hemispheric dominance for cross-linguistic processing in SIs via a dichotic listening test. Participants listened to a source-/target-language sentence pair, with L1 and L2 sentences delivered to different ears, and decided whether they were similar in meaning. Since initial auditory processes are contralateralized, an advantage for right-ear responses in such a study can be interpreted as a left-hemisphere preference for the process in question, and vice versa.2

Other tasks tap into particular linguistic operations. For instance, overt translation tasks have been used to examine processing differences between BT and FT, as compared with single-language tasks, in professional translators and lay bilinguals3 (e.g. García et al., 2014). Additional aspects of cross-linguistic processing, such as the recruitment of semantic vs. form-level mechanisms, have been assessed through equivalent recognition tasks, in which participants must decide whether pairs of words constitute feasible translation equivalents (e.g. Ferré et al., 2006).4

Behavioural tests can also be used for investigating executive functions, such as inhibitory control (the ability to suppress prepotent responses for successful task performance), mental set-shifting (the capacity to change the dominant cognitive scheme in response to dynamic circumstances) or working memory (the system mediating transient storage of verbal or visual information) (Diamond, 2013). For example, to assess whether information storage skills were enhanced in SIs relative to lay bilinguals, Christoffels, de Groot, and Kroll (2006) asked participants to memorize and repeat increasingly longer lists of words. As in any other word-span task, the number of recalled items was taken to reflect the storage capacity of working memory.5

Although measures of accuracy, number of hits and response time yield reliable information about the final outcome of a process, they are blind to its associated neurological activity. Thus, when considered on their own, behavioural tasks only warrant limited, indirect inferences of neurocognitive mechanisms—for example, faster responses for one task than another can be interpreted as greater strength of the underlying connections (García, 2015b). However, they are essential to understand the contributions of specific neuroanatomical and neurophysiological mechanisms in lesion studies and neuroscientific experiments, as described in the following sub-section.
13.2.1.2 Lesion studies
A powerful approach to identify which brain regions prove critical for specific IR processes consists in administering relevant tasks to brain-damaged bilinguals. Single-case studies allow single dissociations to be established, that is, empirical demonstrations that circumscribed cerebral damage can disturb a given process of interest (e.g. BT) while others (e.g. FT) remain fully or relatively spared. Moreover, joint analyses of two or more cases may warrant the postulation of double dissociations, namely, contrastive patterns in which a lesion to area A compromises function X but not Y, while a lesion to area B yields opposite results (Dunn & Kirsner, 2003).

Both types of dissociation have been observed in individual and integrative analyses of patients featuring translation neuropathologies (Fabbro, 1999, 2001), that is, neurocognitive impairments characterized by selective or differential deficits in IR skills relative to other linguistic processes. As shown in Table 13.1, reports on bilinguals with aphasia and other neurological conditions have revealed four such disorders (spontaneous translation, inability to translate, paradoxical translation behaviour and translation without comprehension), each affording specific insights into the neural basis of IR—see Section 13.2.2.

Lesion studies feature a number of methodological and conceptual caveats (Dunn & Kirsner, 2003). First, as they are “natural experiments”, the specific regions affected differ widely among patients, which limits comparability between studies. Also, the ensuing results may not be directly informative of a region’s functional role in a healthy subject, due to possible disease-related compensatory or otherwise plastic mechanisms. Moreover, since none of the available lesion studies on IR has incorporated in vivo brain recordings, they are blind to the full range of circuits engaged by the tasks and to their interactive temporal dynamics. In addition, single-case studies vary in terms of the subjects’ overall cognitive profile, language combinations, L2 proficiency and age of acquisition, which means that fine-grained generalizations can rarely be derived therefrom. Notwithstanding, dissociations warrant the inferences that (i) certain processes are critically and differentially dependent on specific brain areas and that (ii) two or more cognitive mechanisms (e.g. those subserving BT and FT) are functionally autonomous, in the sense that one can become impaired while the other(s) remain(s) partially or fully functional. In cognitive translatology, interpretations along these lines have informed several lines of inquiry, motivating the rejection of long-standing theoretical postulates (García, 2012, 2015a) and the formulation of explicit neuroanatomical models—see Section 13.2.2.

13.2.2 Neuroscientific methods
Neuroscientific methods allow aspects of brain anatomy and function to be quantified. Moreover, some of them, like tDCS, can modulate neurophysiological activity and influence cognitive performance. In most cases, such measures are combined with analyses of behavioural outcomes in online or offline tasks. If the experiment’s design is adequate, neural differences between two target conditions (e.g. BT and FT) or groups (e.g. SIs and lay bilinguals) can be inferred to constitute key biological correlates of the independent variable at hand (e.g. translation directionality or interpreting expertise). This section describes the generalities of the major neuroscientific methods employed so far to study IR—for a more in-depth treatment, see García, Mikulan, et al. (2016).

First, structural imaging methods (e.g. structural MRI) illuminate features of brain anatomy, such as grey matter density or cortical thickness in a region of interest. In particular, they are useful to assess whether certain experiences or profiles involve plastic adaptations in critical areas. This, for example, has been shown to be the case in studies comparing the volume of executive control regions in SIs and lay multilinguals (Becker et al., 2016).
Second, haemodynamic methods (e.g., fMRI, PET and fNIRS) measure regional blood flow and associated metabolic demands, on the premise that these will increase in regions subserving an ongoing cognitive process. Such tools offer excellent spatial resolution but poor temporal resolution. So, they allow identification of which brain areas are engaged by a given process, but they are not useful to ascertain when that process occurred. Among other things, they have been used to reveal differential neurocognitive mechanisms engaged by BT and FT (Klein et al., 1995; Quaresima et al., 2002; Rinne et al., 2000)—see Section 2.2.

Third, electrophysiological methods (e.g. ERPs and EEG connectivity) tap into fine-grained modulations of electrical brain activity as recorded through electrodes on the scalp. The peak time and amplitude of the signals, as well as their synchronization or desynchronization, warrant inferences on various aspects of an ongoing cognitive process, such as its overall demands, the type of mechanisms it recruits (e.g. syntactic, semantic) or its reliance on integrated or segregated information flows across cortical sites. Although they offer low spatial resolution, these methods are optimal to examine the temporal dynamics of a target process, even before behavioural responses are made. They have been employed, for instance, to identify distinctive demands placed by specific translation units (Christoffels et al., 2013) and to assess the coupling of sensory and articulatory mechanisms in SLs (Elmer & Kühnis, 2016)—see Section 13.2.2.

While these methods are non-invasive, others, like intracranial EEG or direct cortical stimulation, involve incisions, perforations or electrical perturbations in predetermined brain regions to assess the latter’s direct role in a process of interest. Thus, they offer invaluable evidence on the putative basis of specific neurocognitive functions. Since they are only applied on neurological patients during presurgical assessment, they typically offer small time windows to test hypotheses of marginal clinical interest. Despite these caveats, they have been applied to assess the relative independence of translation relative to single-language processes (Borius et al., 2012) and the spatio-temporal dynamics of BT vs. FT (García, Mikulan, et al., 2016) —see Section 13.2.3.

In sum, neuroscientific methods offer critical (and, in many cases, real-time) evidence about the contributions of particular regions or neural mechanisms to specific cognitive processes. Importantly, they can be combined with multiple behavioural tasks designed to target all sorts of mental operations. Relative to other approaches, their application in experiments assessing IR has been limited so far. However, they have been growingly used to such an end in recent years, illuminating numerous topics of relevance for Translation Studies, as shown in Section 13.2.3.

13.2.3 Insights into the translating and interpreting brain

The above-mentioned methods have afforded multiple findings on the neural basis of IR. In particular, convergent evidence warrants preliminary conclusions on four major topics, namely: (i) the contributions of each hemisphere to translation skills, (ii) the neurofunctional organization of putative routes, (iii) the temporal dynamics of task-specific activity and (iv) the impact of interpreting expertise on neuroplasticity. A concise account of these issues is offered here.

13.2.3.1 Hemispheric specializations for interlingual reformulation processes

The two cerebral hemispheres constantly exchange information during any cognitive process. However, some higher-order functions rely more critically on the contributions of one or the other (Stephan et al., 2007). Such forms of functional specialization are well established in the domain of language, with some 90% of the population exhibiting left dominance for basic language skills (e.g. phonological and syntactic processing) (Mazoyer et al., 2016), alongside major contributions of the right hemisphere for multiple verbal and otherwise communicative
functions (Lindell, 2006). A similar pattern seems to characterize neurocognitive mechanisms supporting IR.

The most critical pathways subserving translation processes appear to be left-lateralized. A recent review of translation neuropathologies shows that, in 18 out of 21 cases, the disorders resulted exclusively from left-sided lesions (García, 2015a). Compatibly, Borius et al. (2012) showed that direct electrostimulation of left frontal regions directly inhibited translation processes. Moreover, separate neuroimaging studies offering whole-brain recordings have shown that, relative to other language functions, IR yields activation increases only in the left hemisphere (Klein et al., 1995; Lehtonen et al., 2005; Rinne et al., 2000). This aligns with the view that the neural networks implicated in linguistic processes during translation and interpreting are largely embedded within gross areas supporting more general verbal domains (García, Mikulan, et al., 2016).

However, this does not mean that the right hemisphere is inactive during IR. In a PET study (Price et al., 1999), predominant left-sided activation increases for translation relative to single-language reading were accompanied by bilateral engagement of the anterior cingulate and the basal ganglia. Also, functional connectivity experiments with professional translators (García, Mikulan, et al., 2016) and interpreters (Kurz, 1994, 1995) have revealed significant signal exchanges across both hemispheres during BT and FT. In addition, concreteness effects during translation of cognates have been reported to involve maximal event-related potential (ERP) (in particular, N400) modulations over right centrotemporal sites (Janyan et al., 2009b). Finally, behavioural (including dichotic listening) experiments (Fabbro et al., 1990, 1991; Proverbio & Adorni, 2011) and electrophysiological research (Proverbio et al., 2004) indicate that linguistic processes are less left-lateralized in SIs relative to other groups, with additional imaging evidence pointing to neuroplastic adaptations of right hemisphere regions triggered by interpreting training (Hervais-Adelman et al., 2015; Hervais-Adelman et al., 2017)—for details, see “Neuroplasticity in simultaneous interpreters” below.

In sum, despite an arguable dominance of left-sided regions for IR, relevant neurocognitive mechanisms seem to be widely distributed across both hemispheres, especially in the case of subjects with considerable interpreting expertise. However, these conclusions must be taken with reserve, as the impact of right hemisphere lesions on translation skills remains poorly studied (García, 2015a), available neuroimaging results are not entirely consistent (García, 2013) and behavioural methods may prove sub-optimal to estimate lateralization of functions (Paradis, 1992, 1995, 2003, 2008). More research is thus necessary to fully understand the differential contributions of each hemisphere during IR.

### 13.2.3.2 Functional organization of the systems subserving interlingual reformulation

The available evidence also sheds light on the neurofunctional organization of the systems subserving IR. Broadly speaking, critical hubs include perisylvian (superior and inferior temporal gyri, Broca’s area), extrasylvian (parieto-occipital, superior parietal and supplementary motor cortices) and subcortical (cerebellum, putamen, globus pallidus and insula) regions involved in linguistic and executive functions at large (García, 2013, 2015a). These areas, especially in the left hemisphere, exhibit differential activation increases for translation as compared with other verbal processes (García, 2013), and damage to them systematically disturbs IR skills (García, 2015a).

Some of the mechanisms supporting IR within such regions are partially dissociable from single-language processing skills. Reports on inability to translate and paradoxical translation behaviour (Table 13.1) indicate that the systems supporting BT can remain functional when those involved in L1 production are impaired (and vice versa), and that FT abilities can be spared even when L2 processing is disturbed (and vice versa) (de Vreese et al., 1988; Eviatar et al., 1999;
Compatibly, direct electrostimulation evidence has shown that inhibition of specific left frontal and temporal sites can interfere with single-language production without affecting translation skills (Borius et al., 2012). Of note, cases of translation without comprehension (Table 13.1) suggest that IR systems include a semantically unmediated lexical route, as they show that adequate cross-linguistic equivalents can be found even when relevant conceptual representations cannot be accessed (de Vreese et al., 1988; Paradis et al., 1982).

Moreover, partially autonomous mechanisms seem to be recruited depending on translation directionality. Cases of inability to translate and paradoxical translation behaviour indicate that BT and FT can become differentially or even selectively compromised following brain lesions, and that such patterns can be either transient or stable (Aglioti & Fabbro, 1993; Byng et al., 1984; de Vreese et al., 1988; Fabbro & Paradis, 1995; Nilipour & Ashayeri, 1989; Paradis et al., 1982)—see Figure 13.1A, which displays results from a patient exhibiting inability to translate. Also, evidence from hemodynamic methods shows that FT involves wider activity patterns than BT in frontostriatal regions, such as the putamen (Klein et al., 1995) and Broca’s area (Quaresima et al., 2002; Rinne et al., 2000), suggesting that at least some brain structures play a more critical role in the former direction—Figure 13.1B. In addition, electrophysiological findings indicate that, as compared with BT, FT involves greater participation of the right hemisphere (Kurz, 1994, 1995) and enhanced bilateral frontotemporal connectivity (García, Mikulan, et al., 2016), reinforcing the view that each translation direction recruits partially distinct neurocognitive resources.

Finally, different regions seem to be implicated during IR depending on the translation unit. A comparison of activity patterns during translation of words and sentences suggests that the former rely mainly on temporal regions associated with declarative memory, whereas the latter differentially implicate frontostriatal circuits subserving procedural functions (García, 2013). Indeed, damage to frontostriatal networks disrupts sentence translation more markedly than word translation (Fabbro & Paradis, 1995)—Figure 13.1C. These two broad unit types also differ in their engagement of basal ganglia structures during IR, with words yielding activation peaks in the putamen and the caudate nucleus (Price et al., 1999), and sentences involving hemodynamic

<table>
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<tr>
<th>Disorder*</th>
<th>Principal manifestation</th>
<th>Lesion site</th>
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<tr>
<td>Spontaneous translation (G.-Caballero et al., 2007)</td>
<td>Involuntary and immediate translation of utterances, often accompanied by an inability to translate willingly.</td>
<td>Left hemisphere: frontal lobe, basal ganglia, temporal lobe, parietal lobe</td>
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<tr>
<td>Inability to translate (Aglioti &amp; Fabbro, 1993)</td>
<td>Severe or complete incapacity to translate in one or both directions, even when single-language processes are (relatively) spared.</td>
<td>Left hemisphere: temporal lobe, parietal lobe</td>
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<td>Paradoxical translation behaviour (Paradis et al., 1982)</td>
<td>Incapacity to translate into a language available for spontaneous production, with spared abilities to translate into a language unavailable for spontaneous production.</td>
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<tr>
<td>Translation without comprehension (Paradis et al., 1982)</td>
<td>Preserved ability to translate utterances despite unawareness of the meaning of the source unit.</td>
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* Citations in the first column refer to representative cases of each disorder.

Source: based on García (2015a).
Figure 13.1 Functional organization of the systems subserving interlingual reformulation.  
A. Translation performance of patient E.M. in her first study, including assessments of word and sentence translation in both directions.  
B. Averaged PET subtraction image of cerebrospinal fluid increases in the left inferior frontal cortex for 12 subjects, superimposed upon the averaged MRI scans. B1. Activity pattern upon subtraction of L1 repetition from FT. B2. Activity pattern upon subtraction of L2 repetition from BT.  
C. Translation performance of patient E.M., including assessments of word and sentence translation in both directions.  
D. Time-frequency representations of event-related synchronization and desynchronization (ERS and ERD, respectively) for high-frequency words (D1) and low-frequency words (D2) at one representative electrode position (Cz).

Notes: Panel A: BT: backward translation; FT: forward translation. Panel D: Charts are plotted for the first 700 ms after stimulus onset (3,000 ms) and for the frequency range of 2–50 Hz. The red colour indicates event-related bandpower increases (ERS), and the blue colour represents event-related bandpower decreases (ERD). The frequency bands and time intervals that show ERS/ERD differences between the experimental conditions are highlighted with black rectangles. Note that fully coloured images are available in the digital version of the chapter.

Translation, neuroscience and cognition

increases in the globus pallidus (Lehtonen et al., 2005). Also, which specific neurocognitive mechanisms are recruited during translation depends on more fine-grained linguistic properties of the units at hand. For example, electrophysiological signals over parietal and frontal regions are differentially synchronized and desynchronized for high- relative to low-frequency source words (Grabner et al., 2007)—Figure 13.1D. In the same vein, distinct neural modulations have been observed depending on the level of sublexical (Christoffels et al., 2013; Janyan et al., 2009) or semantic (Moldovan et al., 2016) overlap between source and target items.

In short, IR implicates widely distributed networks spanning cortical and subcortical areas involved in general language functions. Yet, far from constituting an undifferentiated, all-purpose system, those circuits include specific hubs which are distinctively associated with particular directions (BT vs. FT), processing levels (lexical vs. conceptual) and translation units (e.g., words vs. sentences). Beyond anatomical considerations, these mechanisms exhibit particular functional dynamics, as described in the following section.

13.2.3.3 Temporal dynamics of interlingual reformulation

The neurocognitive systems described earlier may involve different temporal dynamics depending on the demands that each instance of IR places on them. In particular, both directionality and the linguistic properties of the translation unit are key modulators of the underlying processes. For instance, behavioural studies in healthy subjects show that BT is typically performed faster than FT—although this effect is typically attenuated as translation competence increases (Christoffels et al., 2006; García et al., 2014; Kroll & Stewart, 1994; McElree et al., 2000)—and that cognate and concrete words are translated faster than non-cognate (de Groot, 1992; de Groot et al., 1994; van Hell & de Groot, 1998; García et al., 2014) and abstract (Christoffels et al., 2003; García et al., 2014; Sánchez-Casas et al., 1992) words, respectively. While these findings, derived from RT measures, reflect differences in the overall period from process onset to behavioural manifestation, EEG methods allow the inner timecourse of IR to be examined.

A number of neuroscientific studies have inquired into the temporal specificities of directionality effects. In an ERP study on word translation, Christoffels et al. (2013) found that FT yielded more positive amplitudes than BT in the P2 component over central and parietal sites, suggesting that each translation direction involves differential neurocognitive mechanisms as early as 200 ms after source-word onset—Figure 13.2A. The same pattern was reported by García, Mikulan, et al. (2016) through direct intracranial ERP recordings in the posterior fusiform gyrus, a region implicated in lexico-semantic processing—Figure 13.2B. Also, the two translation directions differ in their later temporal dynamics (from 400 to 700 ms after stimulus onset). As compared with BT, FT involves less negative-going amplitudes in the N400 component over centro-parietal sites (Christoffels et al., 2013), a modulation that was replicated through direct recordings of activity in the posterior fusiform and the anterior middle temporal gyri (García, Mikulan, et al., 2016). Such findings have been proposed to reflect increased implicit attentional demands by FT alongside more effortful comprehension of source words in BT (Christoffels et al., 2013; García, Mikulan, et al., 2016).

Also, distinct temporal dynamics during IR have been observed depending on specific linguistic features of the translation unit. For example, word frequency modulates synchronization and desynchronization patterns of EEG signals in a period from 200 to 600 ms after source-item presentation (Grabner et al., 2007)—see Figure 13.1D. In addition, relative to control words, interlingual homographs (lexical pairs with similar form but different meanings across languages) are translated more slowly and elicit more negative amplitudes around 400 ms post-stimulus presentation, suggesting additional processing effort (Christoffels et al., 2013). Also, abstract cognates, as compared with concrete cognates, yield N400-like deflections mainly over centro-temporal
Figure 13.2 Temporal dynamics of interlingual reformulation. A. ERP waveforms for interlingual homographs (IHs, grey) and control words (Ctrl, black) for forward translation (FT, dotted line) and backward translation (BT, solid line). B. Intracranial ERP recordings during FT and BT from a proficient bilingual.

Notes: Panel A: In the 150–270 ms window, FT yielded more positive amplitudes than BT at central and parietal sites. In the 300–600 ms window, BT yielded more negative amplitudes than FT over central and parietal sites. The same was true for IHs relative to control words over central sites. For presentation purposes only, the signal was low-pass filtered (10 Hz) and the waveforms were averaged across electrodes of three regions: frontal, central and parietal. Panel B: Activity patterns in the posterior fusiform gyrus showed that, relative to BT, FT yielded more positive modulations in an early (220–250 ms) window and less negative modulations in a late (500–750) window.

sites (Janyan et al., 2009), showing that semantic access during source-word processing operates in a window comparable to that observed during single-language tasks. Moreover, additional ERP evidence indicates that word meaning can be accessed before activation of the target word (Moldovan et al., 2016), although the latter can also be activated automatically and unconsciously during processing of its translation equivalent in a single-language context (Thierry & Wu, 2007).

Overall, high-temporal-resolution methods reveal that well-established behavioural effects are linked to underlying neurophysiological factors. In particular, translation directions and various types of translation unit entail distinctive neural dynamics covering very early and considerably late time windows. The fact that most of these findings could hardly have been obtained without EEG tools highlights the relevance of neuroscience in the development of cognitive translatology.

13.2.3.4 Neuroplasticity in simultaneous interpreters

While most of the evidence reviewed here comes from subjects who are not translators or interpreters, many of the ensuing conclusions are probably generalizable across professionals and non-professionals. However, another line of research has revealed a number of neuroplastic changes associated with expertise in a most demanding form of IR, namely, simultaneous interpreting (Chernov, 2004). These studies complement and extend behavioural research showing that, relative to non-interpreter bilinguals, SIs exhibit advantages in tasks taxing particular linguistic or executive skills (García, 2014; García et al., 2019; Santilli et al., 2018).

First, expertise in simultaneous interpreting entails structural changes in task-relevant areas. As compared with monolinguals, SIs have been reported to exhibit reduced grey matter volume in the left cingulate gyrus, the pars opercularis, the bilateral pars triangularis and the middle part of the insula, arguably reflecting cortical pruning linked to more efficient language control (Elmer, Hänggi, et al., 2014)—Figure 13.3A. Notably, however, SIs seem to possess more grey matter volume than multilinguals in the left frontal pole, a region supporting executive domains (Becker et al., 2016). Though at odds with the previous finding (probably because of methodological factors), this result aligns with the overall view that expertise in SI can induce neuroanatomical adaptations. Indeed, a longitudinal MRI study showed that, after roughly 14 months of intensive practice, interpreting trainees exhibited greater cortical thickness in regions supporting phonetic, tactic and/or executive functions, such as the left planum temporale, the superior temporal and anterior supramarginal gyri, and the right parietal, angular and dorsal premotor cortices (Hervais-Adelman et al., 2017)—Figure 13.3B.

Moreover, SIs seem to be characterized by functional adaptations in critical neurocognitive mechanisms. For example, in comparison to non-interpreters, they exhibit a differential bias towards linguistic stimuli in speech-to-noise tasks, accompanied by distinct modulations of the N400 and P600 components over distributed scalp sites (Elmer, Klein, et al., 2014). Also, during intra- and interlinguistic semantic association tasks, they exhibit greater functional coupling between dorsal stream regions subserving sensory-to-articulation mapping (Elmer & Kühnis, 2016) as well as enhanced N400 modulations for all language combinations but the one corresponding to their professionally trained interpreting direction (Elmer et al., 2010). Furthermore, SIs’ advantages in switching and dual-task performance are accompanied by greater functional connectivity in the left inferior frontal gyrus, a region implicated in verbal and cognitive control functions (Becker et al., 2016). In addition, sustained interpreting practice seems to reduce the recruitment of the right caudate nucleus (a key hub for executive control) during actual simultaneous interpretation sessions (Hervais-Adelman et al., 2015).
Figure 13.3  Neuroplasticity in simultaneous interpreters. A. Grey matter differences between professional simultaneous interpreters and bilingual control subjects (blue, left part of the figure). B. Training-induced cortical thickness changes in simultaneous interpreting students. Regions showing a significant main effect of group in mean per cent annualized cortical thickness change, projected on a canonical inflated white-matter surface. Dark patches represent sulci; light patches represent gyri.

Notes: Panel A: MCC: middle cingulate cortex; ACC: anterior cingulate cortex; MIC: middle insular cortex; AIC: anterior insular cortex; IFG: inferior frontal gyrus; Operc: pars opercularis; Tri: pars triangularis; NC: nucleus caudatus. Panel B: For clarity of display, the clusters having reached significance (at $p < .0001$) are displayed at a threshold of $p < .01$. Colour coding indicates significance level. The asterisk (*) denotes clusters in which the peak reaches whole-brain FDR-corrected significance at $p < .05$. The dagger (†) denotes clusters that reach whole-brain cluster-corrected significance at $p < .05$, with a cluster-forming threshold of $p < .0005$. Bar plots show symmetrized per cent change for both groups at the peak co-ordinates of the cluster. Error bars represent 95% confidence intervals. SMG: supramarginal gyrus; STG: superior temporal gyrus; SPL: superior parietal lobule; IPS: intraparietal sulcus. Note that fully coloured images are available in the digital version of the chapter.

Taken together, these results strongly suggest that the extreme cognitive demands inherent in sustained interpreting practice trigger structural and functional neuroplastic adaptations. These changes are multidimensional, as they are reflected in the grey matter density, cortical thickness, electrophysiological modulations and connectivity patterns of key neural systems supporting relevant verbal and non-verbal functions. Future research along the same lines is essential to further illuminate the neurocognitive impact of expert performance in this and other forms of IR.

13.2.3.5 Neurocognitive models of interlingual reformulation

Despite the accumulation of evidence, neurocognitive models of IR have been advanced very sparsely. The most explicit—and, thus, testable—proposals have been set forth by García (2012), Fabbro (1999) and Paradis (1994, 2009), as described next.

Building on lesion studies and neuroscientific findings, García (2012) has formulated a neurocognitive account of the linguistic systems mediating IR. The model is broadly consistent with the evidence presented in a preceding section, “Functional organization of the systems subserving interlingual reformulation”. In particular, it posits the existence of neurofunctionally independent routes for translation, as opposed to monolingual speech production; BT, as opposed to FT; and form-based, as opposed to conceptually mediated, translation. These routes are claimed to rely mainly on perisylvian and frontostriatal regions of the left hemisphere. Moreover, the model postulates that word and sentence translation are differentially related to posterior networks implicated in declarative memory, and by frontostriatal pathways subserving procedural memory, respectively—clarifying that no translation unit is exclusively reliant on any such circuits. Moreover, while these broad organizational features are assumed to hold for any bilingual, the role of procedural and declarative mechanisms is proposed to depend on L2 competence. This model is characterized by its systematic construction, its inclusion of key constraints regarding the overall organization of bilingual memory, and its reliance on multidimensional evidence. However, it is limited in that it overlooks the role of relevant non-verbal mechanisms and dynamic aspects of online processing.

While the above model is presumed valid for any and all forms of IR, the one construed by Fabbro (1999) is specifically concerned with systems supporting simultaneous interpreting. Still, it aligns with the former in postulating separate routes for BT and FT and in acknowledging the partial functional autonomy of other linguistic systems involved in L1 and L2 processing. In addition, it is more explicit regarding the role of right hemisphere regions (e.g. right pre-motor and temporo-parietal areas) and subcortical structures (e.g. the cingulate gyrus) in prosodic, emotional, attentional and pragmatic functions. Notwithstanding, this model is blind to the distinction between form-level and conceptually mediated routes, and it fails to recognize the differential engagement of specific brain regions depending on the translation unit. Be that as it may, Fabbro’s model constitutes the first and hitherto most comprehensive neurocognitive account of the verbal and non-verbal systems involved in simultaneous interpreting.

Finally, Paradis (1994, 2009) has also relied on neurolinguistic insights to describe cognitive aspects of simultaneous interpreting. Though less explicit in neuroanatomical terms, this proposal also assumes a distinction between conceptually mediated and form-level routes, further positing that each of them supports specific processing strategies. Conceptually mediated mechanisms would be mainly recruited under Strategy 1, which involves decoding the source unit across hierarchically organized linguistic levels (phonology, morphology, syntax and lexical semantics) prior to the construal of a non-linguistic representation. Thereon, the corresponding processing levels in the target language would be traversed in reverse order, leading to the production of the translation proper. On the other hand, form-level mechanisms would be more critical for Strategy 2, which consists in the direct transcoding of units at any hierarchical level of
linguistic processing, in the absence of (non-verbal) conceptual processing. Paradis (2009) adds that Strategy 1 would operate automatically and implicitly, whereas Strategy 2 would be conscious and explicit. Thus, the former would rely mainly on procedural memory, while the latter would more directly depend on declarative memory functions. Still, these hypotheses require experimental testing to be judged for plausibility.

All in all, existing models of the neurocognitive basis of IR are decidedly scant. Also, despite their broad compatibility, they target relatively different phenomena, which precludes fine-grained comparisons among them. Furthermore, since their original formulation, they have not been updated to incorporate the most recent findings enumerated throughout the preceding sections, which leaves open multiple avenues for future works. That being said, they all succeed in advancing falsifiable hypotheses (a cornerstone for any empirical discipline) and in showing that theoretical breakthroughs in Translation Studies can be forged through an interdisciplinary dialogue with neuroscience.

13.3 Recent developments and future directions

In light of the previous pages, rather than a “known unknown” (Tymoczko, 2012), the neuroscience of IR might be better described as an “unknown known” within Translation Studies. Though poorly disseminated throughout the discipline, copious findings have been reported concerning the lateralization, functional organization, temporal dynamicity and plastic adaptability of putative neurocognitive systems. Promisingly, such areas of inquiry have been gaining momentum in recent years, as attested by the very existence of this chapter in the present handbook. Now, as research continues to expand, a number of challenges and opportunities should be prioritized in the field’s agenda.

First, a substantial part of the evidence comes from lay bilinguals, that is, subjects lacking formal experience in translation and interpreting. While some findings (e.g. the partial independence of mechanisms for BT and FT, or the predominance of left-sided regions for verbal processes in both directions) are likely generalizable to all bilinguals, others could be specific to those who have developed expert IR skills. In this sense, neuroscientific studies targeting professional translators and interpreters (e.g., García, Mikulan, et al., 2016; Proverbio et al., 2009), or comparing such populations with lay bilinguals (e.g. Becker et al., 2016; Elmer, Klein, et al., 2014; Hervais-Adelman et al., 2017), are crucial to illuminate questions of more direct relevance to Translation Studies. The challenge for the neuroscience of IR, as it were, is to move from studies on translation and interpreting to studies on translators and interpreters.

Second, it would also be useful to establish modality-specific profiles via direct comparisons between the latter two groups. No neuroscientific study has hitherto examined this issue, so that the literature is moot on which findings are general to expertise in IR as opposed to only one of its subforms. In fact, given the broad differences in the verbal and (more particularly) non-verbal mechanisms involved in translation and interpreting (Schäffner, 2004; Schwieter & Ferreira, 2017), research in this direction might even be highly relevant to understand brain plasticity beyond the particular interests of translation scholars.

Third, efforts should be made to develop more naturalistic designs. As is the case with most experiments in neuroscience, available findings stem from atomistic tasks in which subjects respond to (pseudo-)randomized lists of decontextualized words or sentences. While direct unit-by-unit correspondences certainly play a role in translation (Christoffels et al., 2003; Darò & Fabbro, 1994; Paradis, 1994, 2009), token-based paradigms are blind to the contextual nature of skopes-driven textual processes. Promisingly, new approaches based on behavioural interventions (Trevisan et al., 2017) and hemodynamic recordings (Desai et al., 2016; Huth et al., 2016), as
Translation, neuroscience and cognition

well as analysis of narrative comprehension (García et al., 2017) and production (García, Carrillo, et al., 2016) in brain-lesioned individuals, allow the psychobiological aspects of discourse-level processing to be explored. Though their application in cross-linguistic paradigms abounds in methodological challenges, these and other strategies may inaugurate a tighter rapprochement between neuroscience and Translation Studies at large.

Fourth, multidimensional approaches should be favoured to gain more comprehensive insights into targeted phenomena. Available research has mostly relied on data from individual neuroscientific methods, thus shedding light on anatomical or hemodynamic or electrophysiological aspects—for a notable exception, see Becker et al. (2016). However, any aspect of brain function involves concerted interactions among all such dimensions, as well as several others. To capture such complexities, future studies should integrate measures from two or more of those levels, as is done in other areas of cognitive neuroscience (García-Cordero et al., 2016; Melloni et al., 2015, 2016). Moreover, correlations or regressions could be made between ensuing neurocognitive findings and offline assessments of situated performance (e.g. quantitative estimations of translation or interpreting quality). Major breakthroughs could be attained through these yet unattempted forms of empirical triangulation.

Fifth, the majority of the evidence so far is correlational in nature, which limits the possibility of postulating justifiable mechanistic models. Promisingly, some reports in the literature have circumvented this caveat by either conducting longitudinal studies (Hervais-Adelman et al., 2015, 2017) or employing invasive (Borius et al., 2012) and non-invasive (Liuzzi et al., 2010) stimulation techniques. Both approaches offer a much firmer ground to identify causal links between performance or experience in IR and specific neural phenomena, such as activation patterns or plastic changes. More evidence along these lines would afford an invaluable empirical basis to construct explanatory and predictive models in the field.

Sixth, neuroscientists and translation scholars should work more closely together to promote theoretical cross-fertilization. Current studies have rarely been informed by constructs from the core of Translation Studies. Moreover, most cognitive models of IR have overlooked neurocognitive evidence, an omission that has sometimes resulted in incomplete or inaccurate proposals (see García, Mikulan, et al., 2016). As shown by recent works in other fields, such as systemic functional linguistics (García & Ibáñez, 2016), progress in theory building can be made by overcoming the divide between biological and non-biological approaches to mental phenomena.

Finally, all these developments could contribute to bridging the long-standing gap between theory and practice in Translation Studies. Indeed, neuroscientific works have paved the way for appliable innovations in other language-related arenas, such as the teaching of reading (Dehaene, 2010) or the design of interventions for boosting discourse-processing skills (Trevisan et al., 2017). Though speculative at this juncture, the integration of neuroscience into the central agenda of Translation Studies could foster similar advancements for the teaching and practice of translation and interpreting.

In summary, cognitive aspects of IR can be understood in concrete biological terms. Through a combination of behavioural measures, lesion studies and neuroscientific methods, researchers from within and outside Translation Studies have examined several relevant topics. In particular, results to date indicate that the key involvement of left perisylvian and frontostriatal regions during IR is accompanied by distinct contributions from the right hemisphere. Also, different neurocognitive mechanisms seem to be recruited depending on translation directionality and the linguistic properties of the source segment. Moreover, sustained practice of at least one specific modality (namely, simultaneous interpreting) triggers anatomical and functional changes in critical neural systems. Importantly, some of these findings have been incorporated in descriptive theoretical models, which can inspire new testable hypotheses.
Above and beyond these milestones, possibilities abound for further neurocognitively oriented research with more direct involvement of translation scholars. A profitable path lies open for those ready to tackle the challenge. Hopefully, by disseminating both existing and prospective breakthroughs, this chapter will represent a stepping stone in that direction.

Notes

1 In particular, Part C of the Bilingual Aphasia Test (Paradis, 1979, 2011) includes tasks tapping into cross-linguistic equivalent recognition, word translation and sentence translation, all in both backward and forward directions. All versions of this instrument can be freely downloaded at www.mcgill.ca/linguistics/bat

2 However, see Paradis (1992, 1995, 2003, 2008) for a critique of this approach.

3 The term “lay bilingual” refers to an individual who is competent in (at least) two languages but lacks formal experience in translation and interpreting.

4 For a review of behavioral tasks tapping into cross-linguistic equivalent processing, see García (2015b).

5 For a review of research on executive functions in SIs, see García (2014).

6 Event-related synchronization and desynchronization are two functional phenomena whereby distributed neuronal populations become spatially linked, during a cognitive process, to form transient functional networks. They can be tapped via time-frequency analyses, which enable the detection of spectral power changes across time points and frequency bands in an EEG signal—for details, see Singer (1993).

Further reading

To delve more deeply into the topics of this chapter, the reader may wish to consult the following works.

For detailed accounts of translation disorders following brain lesions:


For more details on neuroscientific methods and their relevance to studying IR:


For examples and discussions of neuroscientific experiments on IR:


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References


García and Muñoz


Translation, neuroscience and cognition


