Editorial: A Special Issue of Brain & Language

The Bilingual Brain: Linguistic and non-Linguistic Skills

Jubin Abutalebi, Marco Tettamanti & Daniela Perani

Faculty of Psychology, Vita-salute San Raffaele University

Nuclear Medicine Unit and Division of Neuroscience, San Raffaele Scientific Institute

Milan, Italy.

Since the mid-nineteenth century, brain scientists have been trying to give a specific identity to language and its functions among the different parts of the brain. With the advent of newly developed functional neuroimaging and electrophysiological techniques in the last decades, we are now able to trace an identikit of the neural correlates of linguistic processes. The particular issue of language and brain mechanisms becomes more intriguing though, if we consider the adaptive capacity of the human brain to acquire and use more than one language. We refer to this crescent field as the "Neuroscience of Multilingualism". The origins of this research field may be dated back to early accounts of selective loss and recovery in bilingual aphasia (Pitres, 1896), which gave rise to vivid discussions concerning potential different brain locations for multiple languages. Unfortunately, since its inception, functional neuroimaging and electrophysiological work on bilinguals has been motivated by the same 'localizationist' questions that dominated for decades the bilingual aphasia literature: whether multiple languages are represented in overlapping or separate cerebral systems. In addition, neuroimaging data on this issue have often been influenced by possible biases, such as the lack of information on the age of acquisition, the degree of proficiency and the degree of exposure to a given language in the experimental subjects. These variables have been indeed shown to exert profound influences on the neural processing of a second language (L2) (Perani, Paulesu, Sebastian-Galles, Dupoux, Dehaene, et al., 1998; Wartenburger, Heekeren, Abutalebi, Cappa, Villringer, & Perani, 2003; Perani & Abutalebi, 2005).

In this Special Issue of Brain and Language, we present a series of papers that provide an ultimate glimpse on the research progresses that have been so far achieved in the field of the brain correlates of bilingualism. We do not only focus on linguistic processes but also on extra-linguistic processes since bilingualism may also be influenced by or exert effects on other cognitive processes. We are particularly fond of having brought together contributions from different research groups who also use different techniques and methodologies to investigate the bilingual brain, i.e., from psycholinguistics up to

modern neural connectivity techniques, from the study of bilingual patients to the study of healthy bilinguals.

In this Special Issue, the reader will acknowledge that investigations into the neural basis of bilingualism do not solely focus on how two or multiple languages are represented in the brain, but rather on how these languages are acquired and how they are processed. It is important to consider that language is a most complex function that encompasses numerous sub-processes, including the recognition and articulation of speech sounds, the comprehension and production of words and sentences, and the use of language in pragmatically appropriate ways. Underlying and interacting with these processes are also the functions of memory, attention and cognitive control. All contribute in more or less combined ways to our ability to process language and multiple languages together. In the case of multilingualism, these interactions may even become more complex because the brain has to deal with two or more languages, some of which can be relatively weaker (in terms of proficiency or exposure) than the others. A nice example is provided by the contribution of Hernandez (this Special Issue) who observed increased activity in brain areas devoted to memory, somatosensory processing and emotion during a dual language task (switching between languages during picture naming) in early bilinguals, but not in a single language condition. Hence, the author (Hernandez, this Special Issue) suggests that in bilinguals, the processing of the two languages may be also mediated by neural systems that are not typically associated with language.

Indeed, one of the strongest messages that we, as Guest Editors, want to propose here in this Special Issue is that, especially in the domain of bilingualism, the full set of neural representations engaged by a particular language should not be just equated to core linguistic processes, such as syntax or phonology, but may very well also entail auxiliary cognitive processes, such as memory or attention. As an example, we would like to cite those neuroimaging studies who compared an L2 that is processed with a relatively low proficiency to an L1 (see for review, Perani & Abutalebi, 2005). The observation is

that, generally, a "weak" second language (L2) is processed through brain mechanisms that may in part differ from those underlying first language (L1) processing. However, on a closer look, the main neural differences are found outside the classical language areas, such as the more anterior parts of the left prefrontal cortex and the anterior cingulated cortex, just to name a few (see for review, Abutalebi & Green, 2007). In that case, it would be erroneous to state that an L2 has a different language representation in the brain than L1. One has to properly interpret the additional brain activity that "supports" the processing of a weak L2. For instance, the additional prefrontal activity may index a more cognitively controlled processing for L2 than for L1, which should be ideally processed in a more automatic manner. Likewise, when processing a weaker language, more attention and cognitive control mechanisms may be in need, which in turn may be correlated to the specific activity in the anterior cingulated cortex. In all these cases, differences in regional neural engagement reflect auxiliary cognitive processing effects, rather than language representation per se. This striking finding was described by Abutalebi, Brambati, Annoni, Moro, Cappa & Perani (2007) even for the case in which the native language was the "weaker" language.

Consider, as another example, the complex process of L2 acquisition. The available evidence indicates that an L2 seems to be acquired through the same neural structures responsible for L1 acquisition. This observation extends to grammar acquisition in late L2 learners contrary to what one may expect from critical period accounts (Abutalebi, 2008). Indeed, in her review paper, Kotz (this Special Issue) clearly points out that for syntactical processing the critical period hypothesis plays less of a significant role than initially discussed in the literature and that L2 proficiency may be a driving factor influencing peak and extent of brain activity concerning functional neuroimaging studies. As Kotz states in her paper, the same conclusion holds on when considering neurophysiological investigations such as ERPs studies.

A further aspect that was traditionally regarded as particularly sensitive to critical

period factors is phonological processing. Consider the case when late learners have to acquire L2 phonetic contrasts that are not present in the learners' L1. Several studies have demonstrated a close correspondence between L1 and L2 acquisition with respect to the recruitment of subsidiary and classical linguistic neural structures for phonologic processing. Critically, these structures, including the left Heschl's gyrus (Golestani, Molko, Dehaene, Le Bihan, & Pallier, 2007) and the left parietal lobe (Golestani, Paus, & Zatorre, 2002), exhibit a high degree of individual variability regarding white matter volume, and possibly white matter connectivity, with faster L2 phonetics' learners presenting greater volumes than slower learners. In this Special Issue, the article by Golestani and Zatorre further demonstrates that the behavioral individual variability that parallels the neuroanatomical variability between faster and slower L2 phonetic's learners is: i) specific to speech sounds as opposed to a more general capacity extending to non-speech tones; ii) related to long-term memory category representations of the phonetic contrast. These findings are entirely compatible with a recent electrophysiological study (Diaz, Baus, Escera, Costa, & Sebastián-Gallés, 2008).

In general, we may summarize that L2 acquisition may be considered as a dynamic process, requiring additional neural resources in the early stages, such as a greater cognitive control and attention demands as indexed by prefrontal, subcortical and cingulated activity (Abutalebi & Green, 2007). It is worth underlining, that the same network may be responsible for determining language recovery in the case of bilingual aphasia, as postulated by Green & Abutalebi (2008). In a novel experimental approach, Abutalebi, Della Rosa, Tettamanti, Green & Cappa (this Special Issue) provide such evidence in a follow-up study of a bilingual aphasic. The authors combined fMRI and Dynamic Causal Modeling to examine the effects of specific language treatment on the representation and control of language areas during the course of recovery. Improved performance in the treated language was associated with increased activation in language areas, while Dynamic Causal Modeling indicated increased connectivity of the language

control networks for the recovered language, hence, emphasizing the role of areas such as the anterior cingulated cortex, the basal ganglia and the prefrontal cortex in bilingual aphasia. The research field on the more clinical aspects of bilingualisms is not only restricted to aphasia, but also to various developmental language disorders such as primary language impairment (PLI). In her contribution, Kohnert (this Special Issue) provides an overview on PLI and compares non-linguistic features (such as perceptual-motor tasks and higher-level symbolic tasks) of the PLI population to normally developing monolinguals and bilinguals. The author reports that many children with PLI show subtle nonlinguistic deficits, thus providing a new theoretical and empirical window to characterize PLI performance. Furthermore, Kohnert (this Special Issue) outlines that bilingualism may complicate the identification of PLI in linguistically diverse learners. The author defines relative language experience as a factor determining the diversity among learners. Finally Kohnert shows that linguistically mediated language tasks favored typically-developing children who had longer experience with the target language, even when compared to the relatively proficient L2 speakers, a finding that is also reported by Bialystok (this Special Issue).

On a different front, also in the field of neural network modeling, a large body of research has been recently devoted to the study of multilingualism. Dominey, Inui, and Hoen (this Special Issue) report a newly developed neural network model, implementing analog time coding in neural signaling, that simulates a cortico-striato-thalamo-cortical loop, in which the cortical component is represented by the left inferior frontal cortex. This prefrontal-subcortical model is based on the assumed striato-thalamic role in the control of associative lexical-syntactic binding at the level of the left inferior frontal cortex. The neural network model by Dominey and colleagues is shown to reliably perform a validated syntactic comprehension task (Caplan, Baker, & Dehaut, 1985), and – with a crucial focus to multilingualism – to successfully extract and apply syntactic rules in an artificial grammar learning task, mimicking the performance observed in human adults (Gomez &

Schvaneveldt, 1994).

However, once the L2 learner gains sufficient L2 proficiency, this additional brain activity reflecting auxiliary language processing effects may become less necessary and hence, the pattern of brain activity of L2 is expected to converge towards that of L1. At this stage one may suppose that L2 is processed in the same fashion as L1, as psycholinguistic evidence points out (Kroll & Stewart, 1994). A direct testing field for such neural convergence may be given by so-called adaptation paradigms (see Chee, this Special Issue). Adaptation paradigms are those by which a pair of identical stimuli elicits a smaller neural response than a pair of dissimilar stimuli. Hence, it may be suggested that once an L2 is processed in a similar fashion to L1, the neural response for L2 will be similar to that of L1. Chee (this Special Issue) suggests that the use of these adaptation paradigms would be very fruitful in the field of L2 acquisition.

It is thus remarkable to this regard that a very strong line of recent psycholinguistic research suggests that due to this early engagement of attention and cognitive control resources, bilingual subjects develop a unique capacity to solve conflicts in non verbal tasks. For instance, Bialystok and Feng (this Special Issue) even provide evidence from two separate behavioral investigations, in children and adults, respectively, that bilinguals may compensate for weaker language proficiency (i.e., lower vocabulary size of bilinguals as compared to the vocabulary size of monolinguals) with a higher load on executive control mechanisms.

To this regard, it is important to underline, that the executive control mechanisms referred to are the very same responsible for the specific ability of bilinguals to chose to speak in one language rather than another without (too much) interference from the latter. This strongly implies the intervention of selection mechanisms. There is some evidence that these selection mechanisms may be part of, and improve selective attention mechanisms which would lead to benefits, not only in language control, but also in non-verbal tasks. Some studies have in fact linked bilingualism with better attention and control

mechanisms as compared to monolingualism. Examples of such studies are: i) the study by Bialystok, Craik, Klein, and Viswanathan (2004), which uses the Simon task to ascertain whether the bilingual advantage seen in childhood persists into adulthood and helps to attenuate the effects of aging on executive control; ii) the study by Costa, Hernandez and Sebastian-Galles (2007), which uses the ANT task (attentional network task) to show that bilinguals have more efficient alerting and executive control networks compared to monolinguals (see also Bialystok & Feng, this Special Issue).

The spectrum of non-verbal cognitive functions, which seem to be advantageously modulated by multilingualism, can be extended beyond executive functions, as demonstrated by the unique case of bimodal bilinguals, i.e. subjects fluent in both a spoken and a signed language. Bimodal bilinguals offer a unique perspective on the interplay between non-verbal functions and L2 acquisition, because their two languages exploit distinct sensory-motor systems for comprehension and production. Emmorey and McCullough (this Special Issue) examined the neural correlates of facial expression recognition in bimodal hearing English-American Sign Language bilinguals in a fMRI study that was designed as a follow-up of a previous comparable study investigating unimodal deaf signers and hearing non-signers (McCullough, Emmorey, & Sereno, 2005). Altogether, the results of these two fMRI studies indicate that, in bimodal bilinguals, facial expression recognition is supported by a less left lateralized pattern of superior temporal cortex and fusiform gyrus activations than that of unimodal deaf signers, but still more bilateral than the right lateralized pattern displayed by unimodal hearing non-signers. In other words, the extensive load on facial expression recognition experienced by bimodal bilinguals during native sign language acquisition appears to modulate the functional organization of the posterior temporal lobes, a phenomenon that possibly underlies the superior performance on face recognition tasks in signers compared to non-signers. Along similar lines, the paper by Kovelman, Shalinsky, White, Schmitt, Berens, Paymer, & Pettito (this Special Issue), which also addresses the issue of bimodal bilingualism, reports novel

evidence on a bimodal dual-language use paradigm. Remarkably, the authors employ an innovative technique, i.e. functional Near-Infrared Spectroscopy, to compare bimodal bilinguals to unimodal bilinguals and monolinguals during a naming task. Interestingly, the neuroimaging results revealed that bilinguals in the bilingual mode showed greater signal intensity within posterior temporal regions ("Wernicke's area") than in the monolingual mode.

These results suggest that, on a macroscopic temporal scale, bimodal dual-language use relies on posterior brain areas coding for the phonological, sensory and visual processing required by these two communication forms. However, on a more rapid temporal scale, bimodal dual-language use involves a continuous switching between sign language and oral language. Future research will have to specifically tack the question of whether bimodal bilinguals employ the same or different language switching neural mechanisms that have been described in bilinguals speaking two verbal languages (for a review, see: Abutalebi & Green, 2008; for experimental evidence, see: Abutalebi, Annoni, Zimine Pegna, Seghier et al., 2008; Hernandez, Dapretto, Mazziotta, & Bookheimer., 2001; Wang, Xue, Chen, Xue, & Donga, 2007).

In conclusion, as illustrated in the present Special Issue, the technological advances in the field of functional neuroimaging and neurophysiology, combined with major developments in the field of psycholinguistics and cognitive science, have played a crucial role in our actual understanding that the bilingual brain is a "special brain". The authors of the various papers have elegantly outlined how the present state of affairs related to the bilingual brain was achieved by means of such an integrated, multidisciplinary approach. So far the progresses, from its beginnings with Pitres observation on bilingual aphasia, have been quite impressive and in the future this will hopefully translate into the formulation of more powerful and overarching theories. As for future directions, researchers should put more effort on extended longitudinal investigations addressing the natural course of L2 acquisition (i.e., follow-up studies in L2 teaching classrooms). To

date, the course of language acquisition has mainly been documented for specific components (such as grammatical rules or a limited lexicon) using experimental conditions where language acquisition is generally achieved in a short time period (e.g. Tettamanti, Alkadhi, Moro, Perani, Kollias, & Weniger, 2002; Musso, Moro, Glauche, Rijntjes, Reichenbach et al., 2003). Of course, these studies are highly informative (see Opitz and Friederici, 2004) but they do not represent the natural course and environment of L2 acquisition and so may not reveal the real-life mechanisms (see Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, & Molinaro, 2006 for pioneering work to that regard).

Likewise, we underline that there is an apparent lack of interest towards one of the factors that crucially influences the neural basis of L2 processing: the relative exposure towards a language. Language exposure has been often cited to be one of the most important factors determining selective recovery in bilingual aphasia (see Paradis, 1998), and two of our own fMRI investigations have shown that exposure rather then proficiency may determine specific activity patterns in the bilingual brain (Perani, Abutalebi, Paulesu, Brambati, Scifo et al., 2003; Abutalebi et al., 2007). Hence, we encourage researchers to control for, and consider specifically the exposure in the study of the bilingual brain as a fundamental model of brain plasticity (see Perani & Abutalebi, 2005). As a third points, we would like to stimulate researchers to perform more cross linguistic studies such as comparing linguistically distinct languages such as Indo-European languages vs. Ural-Altaic languages, African languages, and even indigenous languages spoken in more isolated areas of the world (Papua New Guinea, Amazonia). Such studies may also provide a glimpse on the evolution of the human brain and of language functions.

We very much hope that the reader will enjoy the comprehensive coverage of the present Special Issue treating "brain & language" issues inherent to the field of bilingualism.

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