The neural basis of language learning: Brief introduction to the special issue

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The Neural Basis of Language Learning

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Brief introduction to the special issue

Language is an essential characteristic of human beings; arguably, a *sine qua non*. It constitutes and expresses culture, often defines history, and reflects who we are. It binds us together, but it also keeps us apart – linguistic diversity and the consequent limitations to communication among people from different countries and cultures is an unfortunate fact of life. To combat this, the European Union has made it an objective of their language policy that "every European citizen should master two other languages in addition to their mother tongue." (goo.gl/3YhIjQ). This makes the fundamental question of how people learn a second (or third or fourth) language – in particular, how the human brain is organized to support second-language learning – of pressing policy concern.

It is well known that the human brain is equipped to learn language early in life. However, new language learning can occur across the lifespan, suggesting adaptability and plasticity. Mounting evidence suggests that a person's specific language experiences play a central role in how the brain comes to be organized. It is still not well known, however, how the native or first language is influenced by learning a second language; how our brains change as we obtain proficiency in a new language; whether learning two languages from birth or later in life has effects on the brain that differ from the effects of learning only one; and what these effects might be.

Understanding how language learning – early and late - occurs in the brain is of particular interest to speech scientists, linguists, psychologists and neuroscientists. In this special issue, we bring together a series of papers that add to our understanding of how the brain's structure and function is shaped by language learning. The papers use behavioral, functional and morphometric approaches either alone, or in combination, to examine learning-related brain changes. This special issue ranges in its examination of different aspects of language processing in first and second languages, from language processing in early development through to adult language contexts, helping to shed light on how different language-learning experiences affect the neurocognitive system. The papers elucidate in what way behaviour, brain function and structure are affected by the acquisition of specific language skills. We include work that examines the neural basis of acquisition of non-native phonetic contrasts (on both the perception and production sides), segmentation rules, novel articulatory patterns, lexicons, grammars, and second language learning more generally, in the context of studying the bilingual brain. We include contributions that have examined these forms of language learning in the normal brain and in situations of language impairment ranging across the lifespan.

The special issue is divided into five sections. The first set of papers explores topics in development focusing on changes in the organization of the language network as children learn their native language (Brusini et al; Asaridou et al; Vissiennon et al). In the next section, we have a series of papers on reading. The first by Jasinska et al continues the developmental theme by exploring how learning to read alters neural circuitry in bilingual children depending on the orthographic transparency of the languages. Rao & Vaid explore orthographic and morphological processing in Hindi and Urdu biliterates. The third section explores novel word learning in relation to word segmentation (Francois et al), learning a novel orthography (Quinn et al), how phonological and semantic representations interact (Savill et al), category learning in normal aging and Alzheimer's disease (Phillips et al) and in a neurocomputational model (Tomasello et al). The fourth section focuses on the memory systems involved in different aspects of language learning (Bartolotti et al., and Nevat et al.) and takes an individual-differences approach to explaining heterogeneity in previous studies. Papers by Kepinska et al., Barbeau et al., and Qi et al. explore the predictive value of measures of native-language processing for later language learning. This section is completed by a review (Wong et al.) proposing a framework of personalized language learning that borrows from a similar approach taken in personalized medicine. The final section describes studies taking novel methodological approaches to measuring phonetic learning (Carey & McGettigan), neuroplastic changes in training in simultaneous interpreters (Hervais-Adelman et al) and reviews changes across the lifespan resulting from bilingualism (Berken et al.).

Section 1: Development.

To comprehend language, listeners need to encode the relationship between words within sentences by categorizing words into their appropriate word classes. *Brusini et al* show how, as early as 18 months of age, toddlers are able to build accurate syntactic category expectations. Electroencephalography (EEG) was used to record event-related potentials (ERPs) in 18-month-olds while they listened to grammatical and ungrammatical sentences in their native French that contained an ambiguous function word. The demonstration of a P600-like response to ungrammatical sentences suggests that online word categorization occurs during comprehension. Such a skill is likely beneficial for future word acquisition.

A longitudinal study of early childhood development by *Asaridou et al* examined the question of whether individual differences in the rate of vocabulary acquisition predicted differences in cortical structure at school age. They found that the pace of vocabulary growth, measured longitudinally from 14-58 months, predicted cortical thickness in the left supramarginal gyrus measured at age 8–10 years old. This area of cortex connects with prefrontal cortical areas via the superior longitudinal fasciculus and is part of a processing stream thought to underpin phonological processing for speech perception and articulation.

The notion of network connectivity was pursued by *Vissiennon et al* in a functional imaging study of sentence comprehension in 3- and 6-year-old children. The study revealed a transition between these ages in the functional connectivity of the left posterior superior temporal gyrus (pSTG) and the left inferior frontal gyrus (IFG) for successful processing of complex syntax. The strength of functional connectivity between pSTG and posterior IFG (BA 44) was greater for the older children compared with the younger children. The study illustrates that although task performance and task-evoked activity in the pSTG did not differ between the two groups of children, the functional network underlying sentence processing is still maturing in this age range.

Section 2: Reading: the effects of learning different orthographies

The impact of literacy acquisition on brain structure and function has been explored in previous studies. Here, *Jasinska et al* examined how learning to read in more than one language can change neural activity patterns depending on the regularity of orthographic to phonological correspondences. They compared Spanish-English and French-English bilingual children aged between 6 and 10 years with English monolinguals. Spanish is transparent with respect to orthographic-phonological correspondence; French less so and English much less so. Using near-infra-red spectroscopy (NIRS), preliminary results indicated greater reliance on left pSTG during reading of irregular words by the Spanish-English bilinguals relative to the English monolinguals.

Orthographic differences were explored in adult biliterates by *Rao and Vaid* for readers of Hindi and Urdu, which differ both in the direction of reading (left-to-right in Hindi and right-to-left in Urdu) and depth of orthography (Hindi is transparent whereas Urdu is opaque). Significant priming was seen in the left visual field for Hindi words that shared form overlap with primes and in the right visual field for morphologically primed words. In contrast, there was no significant form priming in either visual field for Urdu words, but significantly greater morphological than form priming in the left visual field. Because these two languages are almost identical in their morphophonology, lexicon and grammar, the differences in visual field asymmetries (a proxy for preferential hemispheric processing) suggest that word recognition processes can be altered by reading-direction biases and orthographic depth.

Section 3: Learning new words: insights from artificial language learning and modelling

In the first of this series of papers on novel-word learning, the processes of first extracting the word form from the speech signal and then associating it with meaning were explored by *Francois et al* using EEG. Adult participants heard auditory streams of trisyllabic words either with a visual stimulus (word-picture association) or without (segmentation). After learning, the participants listened to the same stimuli but were tested for implicit detection of online mismatches (either audio-visual or audio only violations). The fronto-central negativity (FN400) ERP was observed later in the audio-visual compared to the audio-only learning phases. The two types of violations elicited separate ERPs: MMN/N200 for the audio violations and N400 for the audio-visual (meaning related) violations. These two ERPs indicate separate and parallel processes that can act together to enhance novel-word learning.

In the second paper in this section, *Quinn et al* examined the processes involved in learning a novel orthography (a new print-sound mapping) and naming of novel objects (word-referent mapping). Behavioural data from adult participants confirmed that learning novel visual-verbal associations in reading is distinct from object naming as the former requires componential learning that can generalize to novel word forms whereas the holistic learning involved in object naming does not aid learning of a new object's name. Functional MRI data identified distinct neural systems underlying these two processes, which overlapped with the networks differentially activated by English word reading and real object naming. Activity in posterior ventral occipitotemporal (vOT), parietal, and frontal cortices was increased when reading an artificial orthography compared with naming artificial objects, and the reverse profile was seen for the anterior vOT region. Although trained and untrained novel words elicited similar levels of activity in cortex, reduced hippocampal responses for trained words suggested overnight consolidation of the newly learned stimuli.

Savill et al show also that newly acquired words are more phonologically robust in verbal short-term memory when they have associated semantic representations. They show that new words trained with meaning were more phonologically stable in memory than meaningless items. This demonstration was a test of the "semantic-binding hypothesis" that accounts for the phonological errors made by patients with semantic dementia.

Phillips et al explored semantic category learning in elderly controls and patients with a diagnosis of Alzheimer's disease or mild cognitive impairment. Participants were trained using high- or low-typicality learning sets and with either explicit instructions or implicitly. Patients learned the novel visual category less well than elderly controls. Both groups benefited more from learning with high-typicality learning sets. Whether a condition had explicit instructions or required implicit learning did not affect category learning in either patients or controls. Learning was related to left hippocampal volume in both groups but whereas better learning was related to greater volume in controls, it was related to lower hippocampal volume in patients. The results demonstrate that semantic category learning can be improved when learning materials are highly similar to the prototype.

The final paper in this section by *Tomasello et al.* proposes a neurobiological model of language acquisition that aims to explain findings from patient and imaging data indicating general semantic areas or "hubs" and category-specific cortical regions. This neurocomputational model of human cortical function was used to simulate the time-course of cortical processes involved in understanding meaningful concrete words. The model shows that learning of semantic relationships between symbols and their object or action referents leads to the formation of distributed circuits including connector hub areas bridging sensory and motor cortical systems. Predictions regarding timing of activation in these circuits were compared with real neurophysiological timing data obtained using magnetoencephalography (MEG).

Section 4: Learning a new language in adulthood: memory systems and individual differences

Bartolotti et al used fMRI to explore the first stage of second-language acquisition and cross-linguistic interference in monolingual adults. Newly learned Spanish words evoked activity in the hippocampus in English speaking monolinguals, and this activity was modulated by the presence of an English competitor that shared phonology with the Spanish target word. This finding is consistent with new vocabulary acquisition in a second language being dependent on a medial temporal lobe or declarative memory system.

The notion of multiple learning and memory systems for language is pursued in a paper by *Nevat et al.* This study used fMRI to examine the learning and generalization of an artificial inflectional morphology, which involved affixation to form a plural. In the first training session, affixation activated the head of the caudate nucleus bilaterally. Plural inflection of untrained words (generalization) activated the medial frontal and left inferior frontal cortices but these areas differed in activity in response to using phonological similarity to inflect untrained nouns. The involvement of the striatum and frontal cortical regions is consistent with the idea that procedural memory systems dependent on these structures are involved in early stages of rule abstraction and application.

In the first of a series of papers examining individual differences in language learning, *Kepinska et al* used fMRI to compare individuals with average or outstandingly good language analytical ability during online learning of an artificial grammar (BROCANTO). The group with higher ability performed better on the task during scanning, and recruited more right-hemisphere regions compared with the group of average ability. Proficient acquisition of new language rules indexed by high performance on the artificial grammar learning task and a steeper learning curve was related to specific recruitment of the left angular gyrus.

Relatedly, *Barbeau et al* found activation in the left inferior parietal lobe (IPL) predicted learning of, and proficiency in, a second language after an intensive 12-week language training course. During sentence reading, activity in the IPL was increased following training and correlated with faster reading speed in the second language. Furthermore, IPL activity before training predicted the magnitude of improvement in reading speed following training. These results confirm a special role in language learning for the left IPL, consistent with findings from other studies in this special issue indicating a role for the supramarginal and angular gyri (see *Asaridou et al.*, and *Kepinska et al*.).

Qi et al, used ERP methodology to explore how an individual's native-language ability affects success in learning an artificial language. Greater N400 components for semantic violations in the native language (English) predicted better language learning ability for the artificial language. Specifically, the relationship between N400 magnitude and vocabulary learning was related to better syntax learning. In contrast, the size of the P600 to syntactic violations in English predicted learning of syntax in the artificial language but not vocabulary learning. These findings further support the idea that dissociable native-language processing abilities affect different aspects of learning a new language.

The final paper in this section is a review article by *Wong et al.* presenting a new framework of personalized learning to explain and capitalize on individual differences in language learning. Analogous to personalized medicine, personalized learning would identify genetic, neural, and behavioral predictors of individual differences in learning, and use these predictors to help create optimal teaching paradigms. Examples of such an approach are provided from the domains of motor learning and speech learning; these indicate the promise of this approach for language learning more generally.

<u>Section 5: Exploring neuroplasticity in speech and language learning: new methods, expertise and age-of-acquisition effects</u>

In this last section, *Carey and McGettigan* review the implementation and promise of real-time MRI of the vocal tract to examine phonetic learning. They demonstrate how this can be used in combination with brain fMRI to examine vocal imitation and learning in adult learners. These methods offer new insights into speech learning, and have application for understanding clinical conditions, foreign language acquisition in adults relative to children, and phonetic talent or expertise.

Expertise in multiple and simultaneous language processing was examined by *Hervais-Adelman et al.'s* study of simultaneous interpreters. Trainees in a Master's program for simultaneous interpretation were scanned longitudinally. Cortical-thickness increases were observed in multiple regions consistent with use-dependent plasticity involving audio-motor and phonological processing, as well as in areas involved in executive function and cognitive control. Intense language training resulting in cortical thickening could provide some protection against normal age-related thinning and might underpin the cognitive advantages thought to be conferred by bilingualism.

The final paper in this special issue is a review paper on language learning and bilingualism by *Berken et al*, which examines neuroplasticity and the effects of age at which language learning begins. The review examines some of the existing knowledge about optimal periods in language development, with particular attention to the attainment of native-like phonology, ending with a discussion of nested optimal periods in language development and the different neural pathways to language proficiency taken by simultaneous and sequential bilinguals.

<u>Final thoughts for this special issue</u>

Language learning changes the brain, and such learning can occur throughout the lifespan. The evidence seems to indicate that learning occurs differently in early life and that the concomitant brain changes are both qualitatively and quantitatively different from those related to later learning. The studies featured in this special issue help to shed new light on how the brain is changed in terms of its shape and organisation in association with many different language learning scenarios. We believe that the current issue adds new insights into how language is learned, and how two language systems can be accommodated within a developing and changing system. A recent surge in interest in plasticity related to language learning is reflected in these articles, which make important contributions to the literature. Understanding the structure and function of the brain as it relates to native and second languages should help us to reveal neural systems that mediate language and illuminate the debate about optimal periods for language learning. It is still unclear what quantity or schedule of exposure is necessary for optimal learning; and how this might depend on individual differences. A large question, which is only touched on briefly here, is how our ideas about language learning apply to disorders and to individualized approaches for treatment of language disorders. There are still many unknowns about the extent of brain plasticity, when windows open and close in the brain for learning different aspects of language and how moveable these windows are for learning and success. These remain as challenges for future issues to address.