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INTRODUCTION

Language, plasticity, and learning

Challenges at the forefront of research^{*}

Michèle Kail and Frédéric Isel

CNRS, UMR Structures formelles du langage | Université Paris
Nanterre, CNRS, UMR Modèles, Dynamiques, Corpus

Two central themes lie at the cutting edge of research on language plasticity: the organization and development of language-related neural networks, a collection of regions in the brain jointly engaged by language processes, and the status of various forms of variability in adaptive mechanisms of language learning.

1. The language network and connectivity

1.1 The language network in adults

All domains of cognitive function require the integration of distributed neural activity in the whole brain, considered as a complex system integrating and segregating nodes (brain regions) and node collections (structural connections or functional relationships) (van den Heuvel & Sporns, 2013). The study of complex brain networks has been stimulated by the advent of network science (Bullmore & Sporns, 2009). It is commonly agreed that some subsets of the brain are more strongly and consistently engaged in language processing than other regions, which support other mental processes. Fedorenko and Thompson-Schill (2014), for example, proposed that the language network plausibly includes a functionally specialized ‘core’ and a domain-general ‘periphery’, a distinction borrowed from

* This special issue aims to follow up the interdisciplinary work and challenging discussions which took place during the Research Network Seminar of the GDR ADYLOC (GDR CNRS 3195) on 5–6 November, 2015, in Paris. The ADYLOC Research group (led by Maya Hickmann and financed by the CNRS between 2009 and 2015) united research from a large number of specialists around the topic *Languages, Oral Language and Cognition: Acquisition and Dysfunction*. The goal of this seminar was to address the links between language acquisition and learning, neural plasticity, behavioral flexibility, and human learning. Given the quality and relevance of the presentations, some of the topics were selected for this special issue.

other areas of neuroscience. Converging evidence from functional neuroimaging studies on adults has shown that, while syntactic and semantic processing both involve a left-lateralized fronto-temporal network, each function seems to be supported by segregated regions in the brain (for a review, see Wu, Vissienon, Friederici, & Brauer, 2016). However, some regions, such as the left inferior frontal gyrus, contribute to the *unification* of information from language with concomitant non-linguistic information, such as co-speech gestures (Willems, Özyürek, & Hagoort, 2005). Crucially, despite the central role of Broca's area in the *unification* of language information, it is not necessarily a language-specific area, nor does it serve only one linguistic function. Consequently, Broca's area can be viewed as both a domain-specific and a domain-general cortical area.

Three kinds of connectivity are now available for study: structural connectivity at the anatomic level, functional connectivity, measuring statistical dependency between neuronal activations, and effective connectivity, measuring causal interaction for tasks and information flow. Effective connectivity tends to reconcile structural and functional approaches (Sporns, 2013). Functional connectivity makes it possible to study functional networks in the absence of cognitive tasks, also known as resting state connectivity. It has been shown that these cerebral networks of the resting state evolve according to experience during the learning of new knowledge and the adaptation of behavior in the face of environmental constraints.

1.2 The developmental language network

The study of functional brain network development is still in its infancy. Unfortunately, most of the studies are not longitudinal, which would be the best way to capture how and to what extent the changes of the network depend on the ongoing learning in a bidirectional way.

In a recent review article, Skeide and Friederici (2016) proposed that the functional specialization and structural maturation of the language system could be described in two main developmental stages. The *developing bottom-up language processes*, from embryos' experiences of speech in utero to the first three years of life, when the infant rapidly acquires bottom-up abilities (phonological, lexical, and emergent syntactic), are primarily implemented bilaterally in the temporal cortices. The *top-down language processes*, from age 4 to adolescence (semantic and syntactic relations), emerge gradually and slowly. It is only after the age of 10 that Brodmann Area 44 (in the left inferior frontal cortex) reaches its functional selectivity and structural connectivity to process complex syntax. According to the authors, these developmental

trajectories into adulthood are related to the functional specialization of the left inferior frontal gyrus and the left posterior superior temporal gyrus, and to the maturation of their structural connection via the arcuate fasciculus. However, a question remains open concerning the transition between these two developmental stages.

While substantial progress has been made in uncovering the development of the neural basis of phonology, lexicon, semantics and syntax, the neural basis of emerging pragmatic abilities remains to be explored. Similarly, despite extensive crosslinguistic behavioral studies, the underlying neural structures implicated in early lexical learning remain largely unknown, especially the relevant connections of the developing language network. In a recent study, Ekerdt, Kühn, Anwender, Brauer, and Friederici (2020) investigated white matter plasticity as children learned novel pseudo-words during a three-week training session. The authors provided the first evidence for white matter plasticity following word learning in 4-year-old children.

1.3 The language network in L2 and bilingualism

Neuroimaging studies on second language acquisition (SLA) have set out to understand how multiple languages are represented in the brain (Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001). Two central questions addressed in this field are whether L1 and L2 share the same neural bases and involve the same language network(s). The available neuroimaging evidence indicates that L1 and L2 are processed by the same neural devices. The neural differences in L1 and L2 representations are only related to the specific computational demands, which vary according to a range of factors, such as the age of acquisition (AoA), the degree of mastery, and the level of exposure to each language (Perani & Abutalebi, 2005). Interestingly, the finding that the two language systems of bilingual speakers rely on similar neural networks has led to new questions about the link between the language networks and the executive control network. The latter network includes the left caudate nucleus, the anterior cingulate gyrus, and the middle frontal gyrus (Abutalebi et al., 2012). Recent neuroimaging studies have examined the specific and joint contribution of L2 AoA, proficiency, and usage as continuous variables. For example, Sulpizio, Del Maschio, Del Mauro, Fedeli, and Abutalebi (2020) conducted a resting-state functional connectivity investigation of the relevant brain networks. Their findings support the assumption that the bilingual experience is a continuous and multifaceted phenomenon that may impact brain plasticity by modulating the functional connectivity both within and between language and control networks. Rossi, Cheng, Kroll, Diaz, and Newman (2017), using diffusion tensor imaging (DTI) with a picture naming task, provided evidence that L2 learning constitutes an experience that can lead to rapid structural

neural changes. They showed that variability in the age of L2 acquisition has important consequences on the utilization of pathways involved in both L1 and L2 processing.

2. Variability and variations in plasticity of language learning and processing

At the neural network level, variability is generated by adjustment of the excitation/inhibition balance, continuous interaction and competition across large neural populations, changes in attention and arousal levels.

2.1 Intra-individual variability in L1 and L2 learning

Intra-individual variability is one of the emblematic concepts of dynamic systems. Dynamic Systems Theory (DST) (van Geert, 2010; van Geert&Verspoor, 2015) assumes that novel, complex forms of behavior emerge from the interaction of the components of the system and the environment. Some hypotheses (Evans, 2007) adopt a dynamic systems approach to the study of development: the outcome of the process comes from the cooperation of the multiple heterogeneous parts of the system, producing coherent complex behavior. This process, known as *self-organization*, is a dynamic process and continuous in time. The notions of *stability* and *instability* are central in the conceptualization of behavioral patterns within DST. The *emergence* of behaviors is synonymous with developmental change. According to DST, *intra-variability* is especially significant during periods of rapid development, as previously shown by Thelen and Smith (1994), when the learner tries out new strategies or modes of behavior that are not always successful and may therefore alternate with old ones.

For example, Bassano and van Geert (2007) address the nature and shape of developmental changes in French children's progression in utterance length (MLU measure) as an index of the increase in syntactic development from one word (holophrase) utterances, to two- and three-word (combinatorial) utterances, then to four-word and longer (grammatical) utterances. Two child corpora (from 1;2 to 3;0 and 2;0 to 3;0) were analyzed using statistical simulation method. Of the complex results, we would like to highlight one crucial contribution – the analysis of intra-individual variability and its link to transitions from the dominant holophrastic stage to the combinatorial stage of language, and the emergence of syntactic constructions. The results all show evidence of two critical peaks of variability in the gradual development of grammar in very young children, with the corresponding transitions, which entail two qualitative discontinuities. Behind the notion of the continuity of early grammatical development, a dynamic model of the data reveals that

there is an underlying process which is clearly discontinuous. However, local discontinuities and a global continuity of the developing language system are not incompatible.

2.2 Inter-individual variability in L1 and L2 learning

Why does inter-individual variability in early L1 processing matter?

Marchman and Fernald (2008) used *the looking while listening* paradigm (LWL) for a longitudinal study of the dynamics of emerging lexical and grammatical comprehension in English-learning children aged 15, 18, 21 and 25 months. Individual analysis of growth curves showed that children who were faster and more accurate in online comprehension at 25 months were those who showed faster and accelerated growth in expressive vocabulary and more multiword combinations throughout the second year. This effect was also observed at an age younger than 18 months (Fernald & Marchman, 2012). Moreover, the authors investigated the predictive validity of real time speech processing in a substantial group of 'late talkers' from 18 to 30 months in a comparison with typically developing children. The results showed that those late talkers who were more efficient in word recognition at 18 months were also more likely to 'bloom', showing more accelerated vocabulary growth over the following year compared with late talkers who were less efficient in early speech processing. This finding provides an illustration of developmental plasticity. One important implication of this research is that time-course measures of comprehension in very young language learners could be useful in improving early identification of children at risk for persistent language delays.

Inter-individual variability in L2 adults

Like Grant, Fang, and Li (2015), Chai et al. (2016) conducted a resting-state fMRI with a training paradigm to provide evidence of the considerable variability in an individual's ability to acquire an L2 during adulthood. Using data from English speakers before they took a 12-week intensive French immersion course, the authors investigated whether inter-individual differences in intrinsic resting state functional connectivity were related to a person's ability to acquire an L2. The authors were able to show that an individual's intrinsic functional connectivity within the language network could predict the capacity (measured by spontaneous speech and reading speed) of the participants to learn the L2 French. Combined fMRI data on L2 word learning converge to show that it is possible to use patterns of neural activity to differentiate 'good learners' from 'poor learners'. Moreover, it seems that, even before any training, the activity of some brain regions (e.g. superior temporal gyrus) differs between individuals and could therefore be used to predict the ability to

learn words in a new language. A final remark with respect to the two selected themes concerns the relative scarcity of crosslinguistic investigations supporting neurocognitive results devoted to developmental and adult plasticity and the need to look at typological constraints to avoid a potential questionable (low) validity. It is worth mentioning, however, that Bornkessel-Schlesewsky and Schlewsky (2009) took up the issue of a *neurotypological approach*, i.e. the relation between the typology of arguments and their neural correlates, to study online processes of language comprehension.

3. An overview of the contributions

The two themes addressed in this special issue, namely the organization and development of the language brain networks, and the status of various forms of variability in adaptive mechanisms of language learning, have begun to open up a promising avenue for a deeper understanding of the underlying mechanisms and processes of language development, language learning, bilingualism, language use and their dynamics. All six articles of this special issue focus on variability and variations in language learning.

In the first article, starting from the emblematic work of E. Bates and P. Kuhl, **Michèle Kail** identifies some issues in early and late plasticity that have improved our understanding of the neuro-behavioral dynamics of cognitive change throughout language acquisition. One key finding is that cognitive plasticity is not optional but intrinsic to development. The developmental crosslinguistic research on online sentence processing run by Kail shows that variability is observed in the patterns of *cue cost* components according to the monolinguals' language typology. Around age nine, whatever the language, the shift towards the adult pattern indicates an efficient adaptive processing. This occurs slightly later in bilinguals who exhibit original patterns with interactions between cue cost components from childhood, suggesting a specific processing system. In older French adults, cue cost variability is mediated by processing speed which preserves online syntactic abilities but reveals plasticity limits in Alzheimer patients.

Plasticity is also observed in the brain during L2 vocabulary acquisition, as presented in the article by **Frédéric Isel**. The author reviews a series of functional and structural magnetic resonance imaging studies on the brain changes induced by learning new L2 lexical units. Isel highlights a central finding, that linguistic experience is able to sculpt brain structures even in short-term laboratory training lasting only a few weeks. The second salient finding reported by Isel is that inter individual variability may already exist in the intrinsic activity of specific language regions in the brain before any language learning program. The

consequence of this neurofunctional variability on L2 learning is discussed.

Kroll, Takahesu Tabori and **Navarro-Torres** extend the discussion on plasticity by postulating that not only L2 but even native language can change under the influence of linguistic experience and sensitivity, which can vary as a function of the context in which languages are used. Importantly, Kroll and colleagues show that significant plasticity in language learning can be observed beyond early childhood, and that variation in language experience has been shown to influence both language learning and processing. Kroll and colleagues revisit how the native language may be more open than previously understood to the dynamics of language experience, using bilingualism as a unique means to reveal L1 adaptations to the active use of a second language. Such adaptations concern not only language learning itself, but the neuro-processes that support it.

Barbara Köpke also reviews discoveries showing that brain plasticity induced by language learning in adults can be found even in a short time scale. Köpke focuses particularly on the possible links between brain plasticity and L1 attrition in adult bilinguals. She discusses recent neurocognitive studies of re-exposure to L1 in formerly attrited immigrants. The studies suggest that changes linked to attrition as well as recovery from attrition are only captured in online tasks such as naturalistic conversations or experimental settings. With respect to brain plasticity, time scales differ with age, and children and adults have different needs concerning input and exposure.

In a methodological contribution, **David Birdsong** offers analytical procedures to study types and loci of variability in L2 attainment compared to L1, with special attention to learner factors, including L1 and L2 dominance that might condition such variabilities. The availability of such fine-grained procedures of variability analyses in L2 learning constitutes methodological progress as ultimate attainment is typically more heterogeneous among L2 learners than among native speakers.

Finally, **Scalise, Stahnke**, and **Müller** bring production data on the acquisition of grammatical subjects in French based on a longitudinal case study of a trilingual child aged 2;8–3;2, who simultaneously acquired French, Italian, and Spanish. Linguistically, the issue of variation was approached here by means of the null-subject property, which is expressed differently in these three languages. Critically, the authors show that production strategies vary depending on whether the children are monolingual, bilingual or trilingual. The trilingual child shows an acceleration effect. The authors interpret their results in light of a parameter setting account that has to take into consideration the typological specificities of the language being acquired.

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