Bilingualism: Language and Cognition

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Insights into the neural mechanisms of becoming bilingual: A brief synthesis of second language research with artificial linguistic systems

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Review Article

Cite this article: Morgan-Short K (2020). Insights into the neural mechanisms of becoming bilingual: A brief synthesis of second language research with artificial linguistic systems. *Bilingualism: Language and Cognition* **23**, 87–91. https://doi.org/10.1017/S1366728919000701

Received: 3 February 2019
Revised: 29 September 2019
Accepted: 30 September 2019
First published online: 5 November 2019

Keywords:
second language; artificial language; artificial grammar; event-related potentials

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Abstract

Artificial linguistic systems can offer researchers test tube-like models of second language (L2) acquisition through which specific questions can be examined under tightly controlled conditions. This paper examines what research with artificial linguistic systems has revealed about the neural mechanisms involved in L2 grammar learning. It first considers the validity of meaningful and non-meaningful artificial linguistic systems. Then it contextualizes and synthesizes neural artificial linguistic system research related to questions about age of exposure to the L2, type of exposure, and online L2 learning mechanisms. Overall, using artificial linguistic systems seems to be an effective and productive way of developing knowledge about L2 neural processes and correlates. With further validation, artificial linguistic system paradigms may prove an important tool more generally in understanding how individuals learn new linguistic systems as they become bilingual.

Introduction

Becoming bilingual involves learning the complex structures and uses of a novel language. Explaining how adults acquire new languages is also complex and involves understanding the role of multiple factors, such as the type of linguistic structure, the nature of the input, and learners' linguistic, cognitive, and social profiles. One approach to piecing together this puzzle has been to examine specific factors before addressing questions about their complex interactions. For example, many researchers have focused on the acquisition of second language (L2) grammar by controlling variables, such as prior knowledge of the L2 (e.g., Stafford, Bowden & Sanz, 2012), in order to gain more precise insight into the role of independent variables, such as proficiency (e.g., White, Genesee & Steinhauer, 2012). For both behavioral and neural studies though, testing hypotheses with natural languages often entails inherent confounds: for example, between proficiency and age of acquisition (e.g., Weber-Fox & Neville, 1996). One manner of exerting tighter experimental control over variables and confounds is by using artificial linguistic systems (ALSs), which are language-like systems created by researchers for the purpose of addressing particular research questions (e.g., DeKeyser, 1997; Esper, 1925). The current review provides a brief synthesis of ALS research targeting the neural basis of L2 grammar acquisition by considering the validity of different types of ALSs and the specific contributions made by ALS research to questions about age of exposure to the L2, type of exposure, and online L2 learning mechanisms, with suggestions for future research.

The validity of ALS research for L2

ALSs come in many forms (Ettlinger, Morgan-Short, Faretta-Stutenberg & Wong, 2016; Grey & Tagarelli, 2018), including: (a) artificial grammars, comprised of rule-governed sequences of elements that do not carry meaning; (b) artificial languages, comprised of meaningful nonce words whose use is based on linguistic properties of natural languages; (c) semi-artificial languages, based on a particular natural language into which new linguistic properties are incorporated; and (d) miniature languages, based on a particular natural language but pared down to a finite and small number of words and linguistic structures. Researchers have argued that there are many benefits to using ALSs (Ettlinger et al., 2016; Folia, Uddén, De Vries, Forkstam & Petersson, 2010; Grey & Tagarelli, 2018). First, ALSs allow researchers to control or even eliminate confounding variables in research designs: for example, different amounts of prior exposure to an L2. Second, they allow researchers to manipulate key variables, such as similarity of the ALS to participants' first language (L1). Third, the ALS can be designed so that participants can reach high levels of proficiency in relatively brief amounts of time, which makes them amendable to longitudinal studies. Because of their characteristics and benefits, it has

https://doi.org/10.1017/S1366728919000701 Published online by Cambridge University Press

been argued that ALSs may "constitute 'test tube' models of natural language" (Morgan-Short, Steinhauer, Sanz & Ullman, 2012a, p. 934).

Although there are several benefits to ALSs, one must also consider an important potential limitation – their ecological validity for L2 learning. This may be a particular concern for non-meaningful ALSs, because they do not involve form-meaning relationships found in natural language (Sanz & Morgan-Short, 2005; VanPatten, 1994). Several neural studies, however, provide indirect evidence regarding the ecological validity of both meaningful and non-meaningful ALSs in that they elicit neural processes and correlates similar to those found in natural language studies (Friederici, Steinhauer & Pfeifer, 2002; Morgan-Short et al., 2015; Petersson, 2004; Silva, Folia, Hagoort & Petersson, 2017). This evidence is further strengthened by neural studies that have found shared neural mechanisms within subjects for ALS and natural language (Christiansen, Conway & Onnis, 2012; Petersson, Folia & Hagoort, 2012; Tabullo, Sevilla, Segura, Zanutto & Wainselboim, 2013). Interestingly, a recent meta-analysis comparing neural activation for non-meaningful ALSs and meaningful linguistic systems found several converging areas of activation (Tagarelli, Shattuck, Turkeltaub & Ullman, 2019). Thus, extant evidence suggests that ALS and natural languages at least have some shared neural mechanisms, lending credence to the ecological validity of ALSs.

Another important piece of evidence relevant to the ecological validity of ALSs for L2 learning is whether performance on ALS tasks is related to performance on L2 tasks. For non-meaningful ALS, evidence for a relationship between ALS and L2 learning has not yet been established (for null results in regard to the relationship between artificial grammar and miniature language learning, see Robinson, 2010; Robinson, 2005). For a meaningful ALS, however, Ettlinger et al. (2016) showed that artificial language learning was moderately correlated to a range of L2 Spanish measures. Thus, both behavioral and neural research suggests that meaningful ALS paradigms may be valid models of L2 acquisition, whereas currently only neural research supports the validity of non-meaningful ALSs. Given the larger goal of accounting for successful L2 learning as informed by what learners can do with the language and not only what their brains can do, the current review will focus on research with the strongest ecological validation: that is, research using meaningful ALS paradigms. An important direction for future research, however, will be to further determine the ecological validity of meaningful and non-meaningful ALS paradigms and to consider methodological issues particular to ALSs, such as the use of control groups (Hamrick & Sachs, 2018).

L2 grammar acquisition as informed by meaningful ALS research

Meaningful neural ALS research has focused on specific questions regarding the acquisition of L2 grammar primarily with two brain-based methods. First, in order to examine the neural processes of L2, researchers have employed electrophysiological methods that provide a scalp-recorded measure of the brain's electrical activity related to a cognitive event (Luck, 2014). Particular event-related potentials (ERPs) have been associated with L1 processing (Swaab, Ledoux, Camblin & Boudewyn, 2012), including (a) an N400 effect, which is a negativity commonly associated with lexical-semantic processing that occurs over centro-parietal regions of the scalp around 400 ms after the onset of a word; (b) a P600 effect, which is a positivity often associated with more controlled grammatical processing that occurs over centro-parietal regions around 600 ms after the onset of a word; and (c) a left-anterior negativity (LAN), which has been found around 200–400 ms after the presentation of a word and has been associated with more automatic grammatical processing, although its elicitation is variable across studies and may not always reflect automatic grammatical processing (Tanner & van Hell, 2014; Tanner, 2019). Second, in order to examine the neural correlates of L2, researchers have used functional magnetic resonance imaging (fMRI), which reflects the hemodynamic response evoked by a neural event and thus provides a measure of neural activation (Huettel, Song & McCarthy, 2004). For L1 grammar, neural activation is typically found in the inferior frontal gyrus (IFG), especially in Broca's area, as well as in the superior temporal gyrus (STG), the basal ganglia, and other cortical areas (Ullman, 2006). The typical neural responses from L1 ERP and fMRI research often serve as a basis for comparison for L2 research. Although the current review also adopts this approach, as it is used in the research being reviewed, it is critical that future research reconsider the L1/native-speaker comparison (Bialystok & Kroll, 2017; Ortega, 2018) as L2 learners do not develop into native-speakers of the L2 but rather develop as bilinguals.

Age of exposure

Comparing L1 and L2 neural responses has served as a basis for addressing a central question in L2 regarding whether there is a critical, or sensitive, period for language acquisition (Lenneberg, 1976). This hypothesis was supported by early L2 behavioral (Johnson & Newport, 1989) and ERP (Weber-Fox & Neville, 1996) research with natural languages that examined learners exposed to L2 at different ages. Even when late-learners with high proficiency in a natural language were examined, they demonstrated P600 effects but did not show the more automatic LAN response (Hahne, 2001).

In the first ERP study with an ALS, Friederici et al. (2002) trained learners on the artificial language, Brocanto, to the highest levels of proficiency – 95% accuracy, which is possible to achieve in a reasonable amount of time with an ALS paradigm. After training, learners evidenced both P600 and LAN effects when processing Brocanto phrase structure. Subsequent ALS research with a miniature language based on Japanese, designed "to create an experimental design with a higher degree of ecological validity as compared to artificial language studies" (p. 1231), found that learners showed P600s for phrase structure and case when trained to 75% accuracy (Mueller, Hahne, Fujii & Friederici, 2005). Earlier negativities for phrase structure, and for a subset of case violations after additional training to 95% accuracy (Mueller, Hirotani & Friederici, 2007), showed a distribution across the scalp that differed from native-speakers. However, when tested on familiar words used in training, more native-like negativities followed by P600s emerged (Mueller, 2009).

More recently, fMRI ALS training studies have begun to address whether late-learned L2 grammar can rely on L1 neural correlates and mechanisms. For example, Nevat, Ullman, Eviatar, and Bitan (2017) found activation in IFG for L2 morphology, and Finn, Hudson Kam, Ettlinger, Vytlacil, and D'Esposito (2013) found that the recruitment of IFG predicted L2 learning success. Results from Morgan-Short, Deng, Brill-Schuetz, Faretta-Stutenberg, Wong, and Wong (2015) provided additional

https://doi.org/10.1017/S1366728919000701 Published online by Cambridge University Press

evidence for the involvement of IFG in L2 syntax, although the results also suggested that this may differ by individual. Finally, Weber, Christiansen, Petersson, Indefrey, and Hagoort (2016) found that neural mechanisms operated on known ALS L2 grammatical structures as for known L1 structures. Thus, each fMRI ALS L2 study found results indicating involvement of L1 neural correlates and mechanisms in L2.

Taken together, these studies suggest that L2 learners have the ability to rely on native-like neural processes and correlates, although they may not always fully reflect those of native speakers. Interestingly, the pattern of neural results seems to parallel behavioral research with high proficiency L2 speakers of a natural language who were assessed on various tasks and who showed native-like performance on some but not all measures (Abrahamsson & Hyltenstam, 2009). Overall, some L2 learners seem capable of native-likeness in their performance and in their recruitment of neural mechanisms, but not all learners reach such levels, and late-learners may not be able to evidence native-likeness on all assessments. Whether this pattern of results supports the critical period hypothesis is a matter of debate, but the neural research attests to at least some level of language-related neural plasticity at later ages.

Moving forward, neural ALSs could be leveraged to train L2 learners of different ages to examine potential age effects in the development of native-like processes and correlates, following behavioral research designs that examine L2 proficiency across different aged learners (Birdsong & Molis, 2001; DeKeyser, 2000; Granena & Long, 2013). In addition, both behavioral and neural research should use bilingual populations as a comparison group (Bialystok & Kroll, 2017; Ortega, 2018). Finally, researchers should consider the role of type of exposure or training in achieving fully native-like neural patterns (Mueller, 2006).

Type of exposure/training

A second question addressed by meaningful ALS research is whether different types of exposure affect L2 grammar acquisition differentially. Ample behavioral research has examined this question and an important meta-analysis (Norris & Ortega, 2000) suggested that explicit learning contexts, which provided metalinguistic explanation or direction to attend to grammar, led to greater L2 gains than implicit contexts, which did not provide such explanation or direction, although implicit contexts also led to gains. However, the amount of exposure and the type of practice in primary research was not always controlled in these explicit and implicit comparisons, and it was not known whether these different types of exposure elicited different neural processes.

Adapting the Brocanto paradigm, Morgan-Short and colleagues (Morgan-Short et al., 2012a; Morgan-Short, Sanz, Steinhauer & Ullman, 2010) developed the artificial language Brocanto2 to control amount of exposure and type of practice and to establish grammatical structures (phrase structure and grammatical gender agreement) that differed from learners' L1. Participants were provided with either explicit or implicit training on the language and were tested twice – once when they reached low proficiency during practice (45% accuracy) and once when they completed all training and practice (~90% accuracy). Results indicated that, for phrase structure, explicitly and implicitly trained learners did not differ behaviorally but developed different ERP signatures (Morgan-Short et al., 2012a): The implicitly trained group evidenced N400 effects at low proficiency and a LAN, P600, and late anterior negativity at the end-of-practice. The explicitly trained group only evidenced an anterior positivity and a P600 at the end-of-practice. At retention testing three to six months later, again no behavioral differences were found, but neural processing differences remained (Morgan-Short, Finger, Grey & Ullman, 2012b). For grammatical gender agreement, explicitly and implicitly trained learners also did not differ behaviorally (with the exception of a larger gain for noun-adjective gender agreement for explicitly trained learners) and showed both similarities and differences in their ERPs (Morgan-Short et al., 2010): At low proficiency, only the implicitly trained group evidenced N400s. At end-of-practice, both groups evidenced N400s for noun-adjective agreement and P600s for noun-determiner agreement. Overall, across both phrase structure and grammatical gender agreement, only one behavioral difference emerged between explicitly and implicitly trained groups, whereas several ERP differences were evidenced.

Batterink and Neville (2013) also addressed the question of whether different types of exposure affect L2 neural processing. Learners were explicitly or implicitly trained on a miniature language based on French with a small set of grammatical structures (article-noun agreement, subject-verb agreement, and subject-verb-object word order). Results indicated behavioral advantages for the explicitly trained learners, although a subset of implicitly trained learners also reached high proficiency levels. For the ERP results, processing differences generally did not emerge between the groups when learners with similar levels of proficiency were compared: All learners at high proficiency evidenced P600s for all three linguistic structures, although explicitly trained learners also showed an early negativity for verb agreement.

Overall, the results from Batterink and Neville (2013) are largely consistent with Norris and Ortega (2000) and more recent behavioral meta-analyses (Goo, Granena, Yilmaz & Novella, 2015; Spada & Tomita, 2010) in that explicit training led to better performance and more native-like neural processing, although implicit training also led to L2 learning and native-like processing. In contrast, results from the Brocanto2 studies (Morgan-Short et al., 2012a; Morgan-Short et al., 2010; Morgan-Short et al., 2012b) suggest that explicit and implicit training may not always lead to behavioral differences and that implicit training may lead to a fuller range of native-like ERP effects. The fact that the pattern of results differed between these ALS studies provides a motivation, first, for replication of each study in order to further establish the general validity of the results. Second, future research should examine the factors that differed between the studies, such as (a) the number of lexical items, (b) the pre-practice training, and (c) the amount, type, and spacing of practice, especially when it is theoretically motivated to look at these factors. Fortunately, ALS paradigms are quite conducive to these factors being examined independently and in interaction with other factors.

L2 online learning mechanisms

A third area in which neural ALS research is beginning to make important contributions pertains to our understanding of the online mechanisms that underlie the acquisition of L2 grammar. Note that the studies reviewed above examined neural processing and correlates on post-exposure or post-training assessments and not during learning itself. To the author's knowledge, only two meaningful ALS neural studies have examined L2 grammar

https://doi.org/10.1017/S1366728919000701 Published online by Cambridge University Press

online. Batterink and Neville (2014) examined electrophysiological data that were recorded during training in the miniature French study (Batterink & Neville, 2013). Processing during training was analyzed in regard to ERP effects tied to selective attention (N100) and to successful identification of words (N400). Results implicated a role for selective attention during L2 learning as the N100 successfully predicted performance, whereas the N400 did not. In a different study, Batterink, Oudiette, Reber, and Paller (2014) examined the processing of a semi-artificial language, adopted from Leung & Williams (2012; 2014), with a grammatical rule that was present in the input but experimentally hidden. EEG data were recorded during training and during a nap that occurred half way through training. For learners who reported becoming aware of the rule during training, ERP analyses revealed a post-nap P600, which the researchers attributed to explicit processing. Interestingly, the duration of slow-wave sleep was associated with larger P600s. For learners who reported that they did not become aware of the rule, a post-nap negativity was found, which was attributed to implicit processing.

These studies suggest that the approach of using ALSs to examine the neural mechanisms involved during L2 learning may be particularly informative. Indeed, L2 research has moved in the direction of examining L2 learning mechanisms online using eye-tracking methods (e.g. Godfroid & Uggen, 2013; Godfroid, 2019; Indrarathne, Ratajczak & Kormos, 2018; Issa & Morgan-Short, 2019). Such research often focuses on the role of attention and awareness in L2 grammar learning. Thus, connections between eye-tracking and ERP methodologies related to these factors might provide unique insights to the mechanisms underlying L2 learning. Note that it would be quite difficult for cross-sectional studies or even longitudinal research with full natural languages to provide direct evidence about the mechanisms that support L2 learning because these paradigms invariably test L2 processing at particular points in time. In contrast, longitudinal ALS studies seem quite amenable to testing predictions about the neurocognitive mechanisms that play a role as learning occurs.

Conclusion

Research with meaningful ALSs has examined central questions about L2 grammar acquisition, and results suggest that (a) adult L2 learners can evidence native-like neural processes and correlates, (b) different types of exposure may affect L2 neural processes but do not necessarily do so, and (c) neural mechanisms related to attention may underlie online learning. Overall, using ALSs to test hypotheses in controlled models and then exploring these effects in interaction with other factors and in natural language seems to be an effective and productive way of developing knowledge about L2 acquisition and processing. With further corroboration of the ecological validity of ALSs, the implications of research with these paradigms for natural L2 may be further strengthened.

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