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Lessons learned from brain responses: The second language learning experience

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ABSTRACT Learning a second language (L2) is a complex process that undoubtedly involves the acquisition of a complex implicit linguistic system. Lexical entries, their features and forms, complex syntactical and phonological systems as well as rules on the pragmatic use of language have to be acquired. The acquisition process itself involves numerous sub-processes that interact at every stage of learning the second language. Learners develop sensitivity to regularities in the absence of verbalizable knowledge, which can be traced in brain responses. *Event-related potential* (ERP) responses like the P600, N400 and especially the *early left anterior negativity* (ELAN), which are produced within a few hundred milliseconds after syntactic and semantic violations, are most likely not the result of conscious thought processes. Thus, it seems that grammatical form-meaning connections, grammatical categories, chunking and statistical learning in orthography, phonology and syntax are learned implicitly. When acquiring a second language, we form recognition patterns, e.g., for the speech sounds and the grammar specific to the newly acquired language. Research has found evidence for native-like brain responses after very little exposure in classroom settings. It is still controversial which role language analytical ability (the specific ability for learning languages) plays in this process, which is often named as one of the components of language aptitude. Moreover, we still do not know how implicit linguistic systems are acquired. In the following, I will take a closer look at brain responses during language processing and factors associated with second language acquisition, such as perceptibility, prosody-syntax integration, letter-sound integration and pragmatic communication ability. By shedding light on some recent developments in second language acquisition research, I will make an attempt to connect brain research to language learning and teaching.

KEYWORDS brain responses, event-related potentials, language learning, second language acquisition, theory of mind

1 LANGUAGE APTITUDE AND COGNITIVE PROCESSING

In light of modern theories on second language acquisition, which view the process of second language learning as one driven by cognitive processes also involved in other mental activities, language aptitude is seen as a complex construct that comprises cognitive and perceptual abilities that predispose individuals to learn well or rapidly (see, e.g., Doughty et al., 2010). The existence of potential connections between individual differences in language aptitude and cognitive style are usually taken into consideration as well (see also Dörnyei & Skehan, 2003). Studies investigating individual differences in cognitive abilities in relation to brain function tend to focus on the neural efficiency hypothesis. Their main aim is to explain the mechanisms underlying high cognitive skills (see, e.g., Nussbaumer, Grabner, & Stern, 2015; Prat & Just, 2011). In these studies, cognitive ability tests are used to measure mental processes in laboratory experiments, using reaction times, error rates and other indicants.

Recent research distinguishes between cognitive aptitudes for implicit and explicit learning (see, e.g., Linck et al., 2013; Morgan-Short, Steinbauer, Sanz, & Ullman, 2012). Implicit memory and implicit inductive learning ability are attributed to aptitude for implicit learning, which is characterized by the absence of conscious intention to learn and conscious attribution of any noticed change to the effects of learning. Explicit induction and rote learning are typically attributed to explicit learning aptitude. These attributions are in line with dual-process theories of cognition that claim that individuals operate using two separate systems: a conscious, analytical, rule-governed and slower system, which is explicit, and a nonconscious, holistic, associative and faster system that is implicit (see, e.g., Epstein, 2008; Witteman, van den Bercken, Claes, & Godoy, 2009).

The two main information-processing styles proposed by dual-process theories in cognitive psychology, namely the *rational-analytical* and *experiential-intuitive cognitive style* (see Pacini & Epstein, 1999), can be related to implicit and explicit cognitive abilities. Recent research suggests that there seems to be a relationship between rational-analytical profiles and explicit aptitude, as well as between experiential-intuitive profiles and implicit aptitude (Granena, 2016). These results can be interpreted as support for the existence of qualitatively different types of cognitive processes that underlie rational-analytical and experiential-intuitive cognitive styles. Second language learners preferring an experiential-intuitive cognitive style tend to rely on intuition and holistic thinking as an approach to information processing, whereas second language learners showing a rational-analytical style have a tendency to rely on logic and analysis as an approach to information processing. In several studies, preference for an analytical cognitive style correlated positively with scores on psychometric intelligence, explicit associative learning and working memory (Kaufman et al., 2010; Pretz, Totz, & Kaufman, 2010). Studies by Woolhouse and Bayne (2000) show that subjects with a more intuitive style learn covariations in an implicit learning task more accurately.

Kepinskaa, de Roverb, Caspersa and Schillera (2017) investigated whether the neural basis of *Artificial Grammar Learning* (AGL) differs between highly and moderately skilled learners. The results of their study suggest that highly skilled learners performed better in proficiency tests than moderately skilled learners and engaged more neural resources in the right hemisphere, especially in the right angular/supramarginal gyrus, the superior frontal and middle frontal gyrus and the posterior cingulate gyrus. SLA (*second language acquisition*) research has found that learning proficiency correlates with the training-induced increases in the strength of the structural connectivity between the right inferior frontal gyrus and caudate (Hosoda, Tanaka, Nariai, Honda, & Hanakawa, 2013).

Undoubtedly, working memory and short-term memory play a crucial role in second language acquisition as well as in the processing of linguistic input. Working memory represents a control system with limits on both its storage and processing capabilities and has access to phonemically coded information. Many linguists assume that it is controlled by a rehearsal buffer which is responsible for the limited memory span and allows for the manipulation of stored information (see Mandler, 2013). Working memory enables us to navigate complex cognitive tasks such as comprehension, learning and reasoning and is involved in the development of *wh-questions* in English (see Wright, 2010). Cognitive processes involved in performing these tasks include the executive and attention control of short-term memory, which permit the interim integration, processing, disposal and retrieval of information. It is well-known that short-term memory has very limited capacity, which means that language learners can keep only a certain amount of information in their short-term memory before it disappears again, so that new information can be stored (see Juffs & Harrington, 2011; Martin & Nick, 2012; Paradis, 2004; VanPatten, 2002).

2 EVENT-RELATED POTENTIALS: DISCOVERY OF DISSOCIABLE LEARNING ABILITIES IN ADULTS

As we have seen in section 1, individual differences in language aptitude have been researched extensively and associated with success in second language learning. However, little research has explored how native-language processing affects second language acquisition success. This is made possible by measurements of brain responses that can help shed light on how first and second languages are neurally processed and what crucial differences exist between them from a cognitive perspective. In the following section, I will review relevant studies that address different types of brain responses to the learning of vocabulary, syntax, non-native sound contrasts and prosody. The aim of this chapter is to highlight how language proficiency impacts language cognition and what lessons can be learned for second-language teaching.

2.1 Neuroimaging: Measuring brain responses

Various types of neuroimaging techniques are commonly used in the psychological sciences, which can measure different indirect neuronal response types from which conclusions can be drawn as to the cerebral involvement of specific cognitive tasks, such as speech processing. Electro-physiological methods, which are able to directly measure the electric activity of nerve cells, focus on temporal aspects of brain processes and involve electrodes which are applied to the head *electro-encephalography* (EEG, see Swaab, Ledoux, Camblin, & Boudewyn, 2012). Positive (P) and negative (N) voltage deflections are measured in reaction to external or internal events (*event-related potentials*, ERPs) of which some are of particular relevance for neurolinguistics (for instance P600 or N400, see Qui et al., 2017). Magneto-encephalography (MEG), on the other hand, exploits magnetic fields that are generated by neural activity. By contrast, hemodynamic neuroimaging methods, such as fMRI (*functional magnetic resonance imaging*), detect changes in cerebral blood flow and thus allow inferences regarding the location of brain activity (Small & Burton, 2002). The introduction of a novel stimulus in a homogenous sequence of stimuli (e.g., a voiced plosive appears in a series of unvoiced plosives), leads to *Mismatch Fields* (MMF), an abrupt change in cognitive engagement which indicates that participants neurologically distinguish between new and old stimuli (Pulvermüller & Shtyrov, 2006). Taken together, neuroimaging methods are valuable tools to study how the human brain processes first and second language(s).

2.2 Vocabulary and syntax

Research in L2 (second language) acquisition of morphosyntax is primarily concerned with mental linguistic representations. *Acquisitionists* and cognitive linguists are interested in whether mental representations are similar in L1 and L2 ultimate realization or whether they are maturationally conditioned to be different (see Tsimpli & Dimitrakopoulou, 2007; White, 2003). Research results indicate that the ability to learn syntax and vocabulary are dissociable and thus not strictly linked. A recent study by Qi et al. (2017) demonstrates how native language and second language abilities are intertwined concerning morphosyntactical structures. In fact, ERP measurements from native language processing can be used to make predictions about a person's success in learning an artificial language. Qui and colleagues first recorded N400 and P600 values while native speakers of English were judging the acceptability of English sentences, followed by recording them when they were learning an artificial language. Results showed a double dissociation between native-like ERP responses and their relationship to the learning of the novel, artificial syntax and vocabulary. Generally, the N400 effect is related to lexical/semantic processing (see Hagoort, Brown, & Osterhout, 1999; Kutas & Federmeier, 2011), and participants who exhibited a greater N400 effect when processing English sentences were overall more successful in learning the artificial language. The P600 effect only predicted future success in morphosyntactic but not in vocabulary learning. Qi et al.'s results suggest that neural predispositions related to native language processing can help with learning another (in this case artificial) language.

L2 research has always been interested in how speakers acquire and regulate more than one language in both production and comprehension (see Abutalebi & Green, 2007; Prior & MacWhinney, 2010; Rothman, 2015). Some components appear to be specifically related to syntactic processing in contrast to lexical-semantic processing. As noted above, syntactic violations consistently elicit P600 effects which are assumed to reflect syntactic integration (see Kaan, 2007). However, with increased proficiency, responses to morphosyntactic violations appear to become more native-like. We also find studies that observed hemispheric changes (from right to left) with increased L2 proficiency (Xiang et al., 2015). Thus, increased proficiency in a language leads to neural re-organization of linguistic processing which subsequently becomes reflected in brain activity in response to linguistic cognition.

2.3 Neural evidence for perceptibility and prosody-syntax integration

Learning a second language involves the establishment of mappings between familiar speech sounds and new phoneme categories. The phonological relatedness of the language that is learned compared to the learners' native language influences the perceived similarity but may also cause problems. For instance, language learners may face difficulties when allophones in the native language represent phonemes in a second language, such as /d/ and /ð/ which are allophones in Spanish but different phonemes in English (see Barrios, Namyst, Lau, Feldman, & Idsardi, 2016). Learners have to overcome native language mappings in order to form new phonological relations between familiar phones. Barrios et al.'s results suggest that even for late learners, phonological relatedness may not cause persistent difficulties, at least in advanced learners. It seems as if L2 learners are able to make use of cues in the input they get to establish new mappings between familiar phones. Barrios et al. provide MEG evidence from two experiments they conducted, during which they measured sensitivity and pre-attentive processing of three listener groups (L1 English, L1 Spanish and advanced Spanish late learners of English). Spanish and English natives developed greater sensitivity for non-word pairs distinguished by phonemic contrasts than for pairs showing allophonic contrasts. However, Spanish late learners of English developed sensitivity to all contrasts, meaning they succeeded in establishing new mappings, which can be considered a very positive second language learning effect.

Ideally, second language learners should be able to develop automatic speech processing of phonetic contrasts. Unfortunately, classroom experience does not lead to linear improvements in phonetic discrimination and thus, learning a second language should be accompanied by targeted phonetic training in the L2. A useful tool for phonological practice can be mismatch fields, which are created by presenting a deviant stimulus within a series of homogenous stimuli. MMF data are used to prove automatic processing of sensory-derived information. Whenever the derivation is processed in a similar way irrespective of the physical parameters of the stimulus per se, researchers assume that automatic processing is going on. Hisagi et al. (2016) investigated second language learning effects and focused on second language vowel duration contrasts in English learners of Japanese. MMF findings suggest that targeted training of L2 phonology is necessary to allow for changes in the processing of L2 speech contrasts to happen at an automatic level.

The role of prosodic information in sentence processing is an aspect that is very often neglected in L2 instruction (however see, e.g., Anderson-Hsieh, Johnson, & Koehler, 1992; Trofimovich & Baker, 2006). Neurocognitive studies in that area are rare as well. In one of the few studies that have been conducted, Hed (2016) tested the perception and production of the Swedish word accent-grammar association in L2 learners of Swedish using EEG. Based on findings from previous research, she started from the assumption that L1 speakers of Swedish use Swedish word accents to make predictions about linguistic segments that appear in sequential order within a word, for instance affixes. In her study, L2 learners of Swedish received special training in order to practice this accent-suffix association. In a perception test, valid and invalid accent-suffix combinations had to be discriminated and subsequently, participants were trained to use accent as suffix predictors more extensively. However, the participants did not re-process ungrammaticality and tended to rely mainly on the suffix itself. Unlike L1 speakers, the L2 learners did not yield longer response times when confronted with ungrammaticality in the post-test. Here, no P600 effect was found.

Similarly, Nickels and Steinhauer (2016) investigated prosody-syntax integration contrasting ERP data from German and Chinese learners of English. They found that L1 background and L2 proficiency influence the processing of prosody-induced *garden path effects* which are created by grammatically correct sentences that start in such a way that readers' most likely interpretation will be incorrect because they are lured into a parse that yields a clearly unintended meaning. Using such sentences, Nickels and Steinhauer provide interesting data on complex interactions between L1 background, prosodic structure and morphosyntactic processes. An important lesson from these studies is that prosody should be a focus in L2 instruction.

2.4 Brain responses to letter-sound integration in second language reading

Successful reading in alphabetic languages requires the correct integration of letters and sounds, and evidence from ERP studies shows that native language background has an important influence on brain responses to letter-sound integration. Yang Z. et al. (2016) found that Chinese learners of ESL (*English as a second language*), whose mother tongue has a morphosyllabic system in which each character corresponds to one syllable, have great difficulties in integrating letters and sounds in the alphabetic language English during early stages of reading. Chinese ESL learners' ERP responses were shown to be different from those of native speakers and from those of native Korean ESL learners who acted as their control groups (Korean also uses a phonological spelling system): native Chinese speakers performed slower compared to the native Korean ESL learners. Yang Z. et al.'s findings provide a significant contribution to SLA reading research as they help to understand brain mechanisms involved in second language reading. From this, implications for the teaching of reading to speakers of non-alphabetic languages can be gathered.

Most researchers agree that reading in a foreign language is an interactive process in which L2 readers bring a unique set of past experiences, emotional and mental processes, and individual levels of cognitive development to the reading process (see, e.g., Britt, 2013; Kennedy, 2000; Koda, 2005; Snowling, 2010). Readers also apply reading strategies from their L1. Naturally, reading in a second language involves accessing the meaning of words in the new target language. In agreement with the *Revised Hierarchical Model* by Kroll and Stewart (1994), L2 learners first access the meaning of L2 words via L1 while advanced learners access meaning directly. Ma, Chen, Guo and Kroll (2017) tested this hypothesis in an ERP study with English learners of Spanish. They used a translation recognition task, in which participants were asked to judge whether English words were the correct translations of Spanish words. The researchers measured the performance of learners in a task where they had to reject distractors that were related to the translations in form or meaning when a long (750 ms) or short (300 ms) SOA (*Stimulus-Onset Asynchrony*) separated the two words. Their findings show that late learners also access the meaning of second-language words directly in comprehension, thus seemingly contradicting the Revised Hierarchical Model. When time was limited, learners showed semantic access without translation mediation. Furthermore, the study provides evidence for the fact that the meaning of an L2 word is accessed prior to the L1 translation equivalent.

Contrary to the findings of the studies mentioned above, Yang, Wang, Bailer, Cherkassky and Just (2016) claim that there is commonality in neural representations of sentences across languages. They were able to predict brain activation during Portuguese sentence comprehension using an English-based model of brain function. Their computational models are capable of predicting *Neurally Plausible Semantic Features* (NPSFs), thematic role markers to neural activation patterns (assessed with fMRI), and activation levels in a network of brain locations. The English-based model predicted fMRI patterns for Portuguese sentences in both monolinguals and bilinguals. In addition to that, the sentences from two languages were decodable from the same set of 38 brain locations.

3 THE SOCIAL BRAIN: PRAGMATIC COMMUNICATION ABILITY AND THEORY OF MIND

In order to become proficient users of an L2, learners have to acquire the ability to use language in context. The development of some form of pragmatic communication ability goes beyond the understanding and expressing of basic word meanings and the production of grammatically correct forms. In order to become pragmatically competent speakers, learners have to be able to understand other speakers' intentions, interpret speakers' feelings and attitudes, differentiate speech act meaning, evaluate the intensity of a speaker's meaning, recognize sarcasm and joking, and be able to respond appropriately. It is quite common that pragmatic communication deficits occur at the initial stages of SLA when learners are not familiar with appropriate registers or are lacking intercultural experience.

To date, research has not yet succeeded in establishing a widely accepted standard framework for the assessment of pragmatic competence, social adjustment, social functioning and social cognition (see, e.g., Ebstein, 2011; Fiske, 2010; Striano, 2009). Since this assessment depends on interpretative attitudes and embeddedness in cultural practices, this will continue to present a major challenge in the future. Proponents of Grice's (1957) position claim that any kind of pragmatic processing is about inferring the intentions that underlie the speaker's utterance. According to this view, pragmatic processing is associated with the derivation of both primary and secondary meanings and can be seen as a cognitive capacity that is inherently rooted within *Theory of Mind*, that is, the capacity to attribute and reason about mental states (see Premack & Woodruff, 1978). Many researchers such as Kissine (2015) criticize the alleged modularity of pragmatic processing inherent in Grice's model and view pragmatics as being dependent on language-independent contextual factors that can, but need not, involve Theory of Mind. They see pragmatics as a language-specific metacognitive process that may unfold at an unconscious level without involving any kind of meta-representation. In support of this idea, Kissine (2015) refers to data showing that, from a very young age, children can make use of contextual cues to interpret and produce communicative behavior, even though they have not mastered a full understanding of all layers of Theory of Mind.

According to Sperber and Wilson (2002), pragmatic processing is underpinned by a specific cognitive module which is responsible for the interpretation of communicative behavior. This cognitive module is grounded within a more general Theory of Mind and has an independent developmental trajectory. Wellman, Cross and Watson (2001) proved that verbally demanding versions of first-order Theory of Mind tasks (e.g., false-belief tasks involving other people's false beliefs) prove difficult for typically-developing children below the age of four. There is consensus among researchers that children are not capable of attributing second-order mental states (e.g., understanding that a belief about another person's belief can be false) until the age of seven (see Leekam & Prior, 1994).

Pragmatic communication deficits have been documented in patients suffering from schizophrenia. Schnell et al. (2016) investigated irony comprehension and the underlying brain activity in patients with schizophrenia. Using fMRI techniques, they succeeded in revealing the brain networks involved in social cognition and non-compositional processing, which refers to the processing of meaning that cannot be inferred from the meanings of the individual words. They were able to identify an area with an integrative role, which is responsible for pragmatic meaning construction, and their results are in line with the idea of a hypothesized meta-module of pragmatic comprehension.

Pragmatic processing is guided by a scale of interpretative strategies that require different developmental stages of Theory of Mind. As outlined by Kissine (2013), *egocentric relevance* does not require any Theory of Mind since it is entirely based on egocentric considerations of accessibility, and the child is not able to understand other people's points of view; *allocentric relevance* requires at least implicit first-order Theory of Mind, as it is based on an understanding of other people's perspectives. It is similar to egocentric relevance, but it rules out contents that are incompatible with the speaker's perspective. Essentially, the *Gricean, sophisticated interpretation* becomes available only when second-order Theory of Mind is operational.

Explicit pragmatic instruction to facilitate the development of pragmatic competence should find its way into the SLA classroom. Foreign language learners need to develop new representations of pragma-linguistic and socio-pragmatic knowledge and can be instructed on the strategies and linguistic forms by which specific pragmatic features are performed and used in different contexts (see Bardovi-Harlig, 2013). This can be done, for instance, in online learning environments where Hong et al. (2017) investigated the effect of online gaming on brain connectivity. Their results revealed that after twelve weeks of online English education, the children showed improved connectivity between Broca's area and the left frontal cortex as well as between Wernicke's area and the left parahippocampal gyrus and the right medial frontal gyrus. In addition to that, changes in the pragmatic scores correlated positively with the average peak brain activity in the left parahippocampal gyrus.

4 CONNECTING BRAIN RESEARCH TO LANGUAGE LEARNING AND TEACHING

This final section aims at critically assessing the current state of neurolinguistic data on language acquisition and processing and will discuss how they might inform us with respect to developing appropriate teaching methods for the ESL classroom. Research in the area of neurolinguistics has developed dramatically over the past few years, providing us with a wealth of exciting and promising findings. In particular, the field of neuroplasticity research has produced data about the ability of the brain to structurally change in relation to input from the environment (Shaw & McEachern, 2012). The theory that the brain loses plasticity for language learning past a critical period during early childhood has been challenged, and today we know that the brain undergoes continuous change and is able to form new synapses well into adulthood (see also

Kong-Insam and Resnik in this volume). Brain structures can change in response to direct mental effort and thus language learning as a complex cognitive ability can be recommended, for example, in order to delay the onset of the Alzheimer's disease.

Our brain has to undergo cognitive adaptation processes in order to accommodate the L2. It recruits existing regions used for the L1 but can also make use of adjacent areas of the cortex. We know from neuroimaging studies that an actual structural shift takes place in the brain in response to acquiring an L2 as an adult (Mechelli et al., 2004). We can rely on declarative memory or explicit knowledge and thus SLA teachers should provide learners with strategies to tap into knowledge from their L1.

The importance of selective attention should be taken into account in ESL teaching as well since we know from brain response studies that when we pay attention to certain things, our neurons become active and strengthened, which ultimately results in an increase in our knowledge and awareness. Thus, output and input enhancement can be achieved by drawing learners' attention to what is missing in their developing systems (see Izumi, 2002). This might even motivate learners to become more active with their input processing (VanPatten, 2003). Possibilities for active interaction should be part of every language class because it has been proven that interaction promotes L2 acquisition.

Finally, it has long been known that learners need to be provided with ample opportunities to practice and repeat. From neurolinguistic findings it is known that practice is critical if newly acquired language should move from the short-term memory into the long-term memory. By performing language exercises, learners can strengthen relevant synapses and thereby improve their language skills. In receptive and productive exercises and activities, students should be exposed to routines and familiarized with conventionalized language forms to support them in the development of communicative competence in their L2 (see Rosas, 2018; Yorio, 1980). This can be achieved by activities focusing on fluency, providing respective feedback and by familiarizing students with turn-taking queues, pause fillers, set phrases and expressions that make them sound more natural to native speakers. Creating a motivating and relaxed classroom atmosphere will also help to increase their confidence and language proficiency (see Mercer, Gkonou, & Tatzl, 2016).

5 CONCLUSION

No doubt, our understanding of the developmental processes of language learning has increased enormously over the past two decades. Research has found neurolinguistic evidence for grammatical development, letter-sound integration, dissociate learning abilities and prosody-syntax integration, to name only those areas that have been addressed in this chapter. Although the nature of the mental realization of language learning processes has become more transparent, we are still a long way from fully understanding it. Much research still needs to be done in order to get a clearer picture of the factors relevant for language learning, which is a highly individual process involving a complex interweaving of psychological factors. Nevertheless, we should make use of opportunities for cross-fertilization across the disciplines of cognitive linguistics and second-language research. Ideally, we should envisage a symbiotic relationship for mutual benefit with the ultimate goal of creating linguistically and neuro-linguistically informed, evidence-based pedagogies for second language teaching.

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