Linguistic Portfolios

Volume 4 Article 3

2015

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Recommended Citation

Rawski, Jonathan (2015) "Second-Language Phonology Learning and Neuroplasticity," *Linguistic Portfolios*: Vol. 4, Article 3.
Available at: http://repository.stcloudstate.edu/stcloud_ling/vol4/iss1/3

Linguistic Portfolios, Volume 4, Spring 2015 | **24**

SECOND-LANGUAGE PHONOLOGY LEARNING AND NEUROPLASTICITY

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ABSTRACT

Why do adults retain a marked accent in foreign languages? Despite learning and reaching proficiency in other second language (L2) linguistics domains, adults have an extremely difficult time absorbing, recognizing, and utilizing a new phonology. Traditional linguistics and biology hold that a critical period inversely affects language learning ability with age. However, recent advances in brain imaging and knowledge of neuroscience alter this notion. We argue for a separation between language learning and language acquisition. We also present a new model for adult L2 learning, called the Attention Model. This model focuses on linguistic awareness between an L1 and L2, and builds up a new language based on recognition of linguistic form.

1.0 Purpose

Why do adults retain a marked accent in foreign languages? Despite learning and becoming proficient in almost every other aspect of their target language, an adult (or really anyone after puberty) has an extremely difficult time absorbing, recognizing, and utilizing a new phonology. Many language learning textbooks and learning methods recognize this disparity, but glance over it, or ignore it altogether, denouncing it as an inescapable phenomenon.

However, to study the brain properly we begin by asking what tasks it is performing. So in this case we look at what must happen to adjust one's phonology. The shape of the mouth does not change, nor does its phonemic capability apart from learning new phonemes not present in the first language. The auditory system does not change its performance either. So the difference must lie within the brain. This seems intuitive, but it gives a solid basis for where to begin examination.

Knowing that the brain is essentially an information storing and processing unit, the real question comes forward. The brain performs phonologic discrimination already, but it has trouble relearning this task. Why does learning seem to become more difficult? What about learning is changing?

2.0 Neuroplasticity

From an elementary knowledge of neural processes, we discuss how the brain develops behavior; for it does just that: the brain develops over time. Like every other part of the human body, the brain matures throughout life. There are specific neural mechanisms that allow the brain to be a malleable organ. It can change and reshape itself at will based on experience. Although until recently, the belief was just the opposite.

Through the early- to mid-1900s, scientific consensus described the brain as a static organ—that its overall structure remained the same despite developmental patterns. Around 1950, however, psychologists studying neurons noted that growth processes of metabolic change take place in synapses (Hebb, 1949). Through the 1970s research bloomed on this new subject termed "neuroplasticity." The central theme said that as synapses transmit signals repeatedly, they will reorganize and join together to create a more efficient pathway (Pascual Leone et al., 2005).

The last section mentioned that the dendritic spines behave in a "plastic" manner. Plasticity, in a cognitive sense, refers to an ability to change based on repeated patterns. Throughout a neuron's life, it constantly regulates which dendrite spines are being used and which are not. This synaptic pruning reduces the overall number of synapses and recreates its focus to those it uses more. Dendrite spines will shift to connect to neurons that have experienced repeated use. This is captured in Hebb's Law, where "neurons that fire together, wire together" (Hebb, 1949). These repeated patterns create cortical maps in the brain.

The idea of cortical maps models how patterns of neuron interaction become defined through different body actions and behaviors. These behaviors and actions are built through development with world experience. Children, though born with a definite neurobiology, possess very little real cognitive ability to use it. This is simply because they lack significant behavioral experience. As they experience and react to more of the world, their brain focuses and refines itself to cope (Merzenich, 1984).

Whenever a new stimulus is presented to the body, its neural networks have no prior experience routing the stimulus correctly. The stimulus travels along a path and eventually registers in the brain and provokes a response. If this behavior is reinforced through repetition, the cortical structure is strengthened and enlarged. Though this process takes minutes at the individual neural level, Merzenich and Blake (2002) noted that cortical representations can change two to threefold in a day or two when the new behavior is introduced. The changes finalize within two weeks.

However, these changes are not associated with sensory behavior alone. They need learning about the sensory experience, and have a stronger response when the stimuli are associated with reward. As the stimuli-reward relationship becomes more reinforced, the brain starts to develop a behavior: for a given stimuli or goal, perform in a certain way. Human development, especially in infants, requires a huge amount of behavior development. Humans must learn almost immediately how to react in situations they encounter. Every behavior, from breathing to feeling pain to walking, requires a period of neural change. This capacity to adapt implies a plastic nature.

This intense period of neural development does not last forever, though. In the 1970s and 1980s, a window of critical development was documented in children. Children constantly learn the repeated behaviors necessary for existence during specific times. These times are defined by a junction of necessity for the behavior and prior cognitive development associated with the behavior. This can clearly be seen in the area of L1 acquisition.

L1 acquisition generally takes place between ages 5-10 (Lenneberg, 1967). During this time, children have developed the motor control necessary to use their speech and hearing mechanisms, as well as sensory systems to identify multi-sensory concepts. These behaviors, combined with the ever-present need to interact with other humans, yields speech. If for some reason the specific behaviors are not developed correctly, the mind will use what behaviors it does know in order to compensate, or it will not produce speech.

The key with these behaviors is that there is no prior framework to build on. The quadrillion synapse connections constantly engaged in processing information allow children to acquire very specific patterns very quickly. A child has no basis to compare language functions, and as such quickly develops specific controlled behaviors for it. If sound pressure enters the ear, immediately the learned process activates and provokes a response, namely auditory processing. Thus by the end of the critical period, behaviors necessary for life have become so common and expected that they require no conscious effort.

The common timeframe for the critical period decline is the onset of puberty. As synaptic pruning has weeded out many unnecessary synapses, the brain is now a focused organ. But, curiously, though a human is competent in its environment physically and mentally, neither the body nor the brain becomes a static, final product. Indeed, puberty is a second phase of human development, completely different from the first. The body continues to grow, and the mind continues to learn. The methods for this, however, are radically different than in childhood.

This process of maturation is critical in that it indicates an entirely new paradigm of behavior development. This paradigm dictates how processes are to work together, and how the mind regulates how its behaviors will process increasingly complex stimuli. These are metacognitive processes, and require mental functions to execute the goals the brain wishes to accomplish. These are called executive functions.

3.0 Executive Functions

As early as the 1970s, research like Broadbent (1975) and Shifrin and Schneider (1977) drew a distinction between "automatic" and "controlled" processes. Both of these processes required attention to be managed in different ways. Automatic processes, as discussed, have been repeated and practiced so often that they require little or no attention. Controlled processes, then, require significantly more attention, and are often much less frequently used. If a division of labor exists among the two, a process must exist to govern the stimuli that trigger each one. So, knowing that the brain is not a static entity, and that neurally and structurally it changes over time, how does it decide which “behavior train” to follow when given a goal or stimulus? Behaviors like attention and task-switching utilize several different processes at different times and need a metafunction to govern them.

The processes that govern task-switching and other domain-general switching processes have the name “executive functions.” An executive function “controls and manages other cognitive processes…is responsible for processes like executive skills, supervisory attentional systems, or cognitive control” (Elliot, 2011). Early development produces behaviors that are extremely well-trained, but may not be appropriate in a given circumstance. Norman and Shallice (2000) outlined five different areas in which routinely activated behavior would be insufficient:

1. Situations with non-rehearsed responses or with novel action sequences
2. Overcoming strong habitual responses or resisting temptation.
3. Decision-making or planning

4. Dangerous/difficult situations
5. Error correction or troubleshooting

Although these areas involve coordinating a series of localized behaviors, executive functions too are localized in the brain. Executive activity peaks in particular regions of the prefrontal cortex (Alvarez, Emory, & Emory, 2006). These include:

- The anterior cingulate cortex (ACC), which integrates emotional drives and experience, including inappropriate response inhibition, decision making, and motivated behaviors.
- The dorsolateral prefrontal cortex (DLPFC), which handles "on-line" processing of behavior like integrating different cognitive dimensions (verbal and design fluency, planning, response inhibition, working memory, reasoning, problem solving, abstract thinking, etc.).
- The orbitofrontal cortex (OFC) functions in impulse control, set maintenance, and monitoring ongoing/socially appropriate behaviors. It also represents the value of rewards based on sensory stimuli and evaluates subjective emotional experiences.

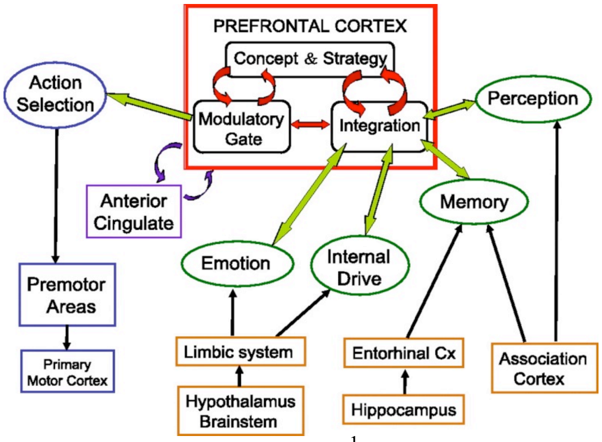

Figure 1[1]

The frontal lobes have multiple connections to other cortical and stem sites; they are a nexus of thought organization. When given a goal or task that contradicts preordained responses, executive functions selectively inhibit the lower-level impulses that yield them. This constraint strategy allows new complicated behaviors to develop alongside or in place of the old, with the executive function determining which train is best in a given circumstance.

Executive function development begins with inhibitory control around 7-12 months, and expands slowly, as the repetitive behaviors set in. However, growth accelerates after puberty, coming in spurts, indicating that they have no critical period. However, children do not apply these processes cross-contextually as they are not fully developed. The major change that occurs in the brain in adulthood is the constant myelination of PFC neurons, which yields amazing processing power. Executive functioning skills reach their peak around age 29, allowing adults

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[1] Retrieved from: Jun Tanji & Eiji Hoshi, "Role of The Lateral Prefrontal Cortex in Executive Behavior Control," *Physiological Reviews*, Published 1 January 2008, 88(1), 37-57. DOI: 10.1152/physrev.00014.2007

to perform some of the most challenging mental tasks (Deluca & Leventer, 2009). Decline sets in very slowly, and brain flexibility (plasticity) does not begin to decline until age 70. Executive functions remain throughout life, and because of them humans can still mentally develop at older ages.

There is a tradeoff in switching development paradigms, however. In the critical period, an abundance of neurons and lack of preconditioning yields a faster cortical mapping rate. This comes at the expense of mature cognitive ability, which cannot be developed using only experience repetition. When this ability gives way to executive function management, the tables turn. Extremely high-order thought becomes possible, but requires a more complex pattern of behavior integration. This yields slower cortical mapping rates, and longer processing time. Executive functions overcome this disadvantage by comprehending overarching concepts and applying them in a top-down model, which takes less time.

4.0 Learning vs. Acquisition

From here it is obvious that behavior development does not plateau when the critical period ends. As discussed, the greatest change comes in the form of a paradigm shift in individual learning strategy. Most disciplines readily accept this change in some fashion. In everyday teaching practice, higher-level educators must recognize that they are training more matured, broader minds.

This brings into focus the critical distinction discussed in the introduction: that of learning versus acquisition. Though often used interchangeably, a striking difference exists when accounting for neuroplasticity. Acquisition refers to behavior development in the critical period. During this time, no prior neural frameworks exist, and any information is initial and readily processed through repetition. However, acquisition may only take place in the critical period, never after.

By contrast, learning refers to behavior acquired after the critical period when executive functions take over. This is because behavior goals here must interact with already developed behavior patterns. Learning, then, is a necessary discrimination process between these new behavior goals and prior behavior frameworks. This presents a unique challenge, as often these goals directly challenge deeply ingrained patterns learned through a different process. These challenges arise when the behavior to be learned and the acquired behavior serve the same function.

Take, for example, the field of mathematics. Early teaching methods rely on simple number recognition, and then applications of simple functions using these numbers. Students learn concepts through rigorous rote practice, not from any high theory. Timed math tests requiring split-second thinking force students to develop simple, low-level response behaviors. These patterns are critical to later mathematical processes and logical thinking in general.

In higher-level classes, the demands of math curricula change. Students must analyze and dissect concepts that constantly utilize their command of low-level operations. However, rather than teach in a rote memorization style as before, teachers present material in an elevated fashion. Abstract theory, applied examples, and discussion precede practice, because they train the executive analytical abilities extensively. Teaching the concepts solely through repeated practice would be fruitless.

The same should then be true for second language learning. When children acquire language initially, it is through extensive experience and repetition of inputs, without any conscious consideration of the underlying theory. Children have absolutely no experience of language before they acquire it. This holds true for both L1 and L2 acquisition. The two languages are completely independent behavior patterns, which happen to serve the same function. They are acquired using the same neural process

Language learning, by contrast, involves integrating another language into a predefined mental framework. The learner's mind has ample experience with L1, and may have higher-level knowledge of L1 through education. Any L2 learning must not change the process underlying L1, while developing an equal framework that responds to different linguistic inputs and outputs. This is a sizable task, to be sure, but not an impossible one. In L2 learning, executive functions isolate each function involved in speech, and inhibit reaction unless the input matches the L2. This is how the brain reteaches every linguistic concept.

Nowhere is this focused retraining more necessary than in learning phonology. Whereas most linguistic spheres govern only underlying representations, phonology is unique in that underlying mental forms depend on speech/hearing processes, and vice versa. Phonological structure cannot form without proper input from speech/hearing processes, and speech/hearing processes have no use in language without underlying forms.

Any L2 phonology learning, as a conscious process, must create a neural network that:

1. Recognizes a sound input in an L2 context
2. Differentiates it from the same input in an L1 context
3. Applies that differentiation to speech processes

The key part here is differentiation. Sounds may exist (or not) in multiple environments in an L1 and an L2. The learner's task then is to group the impulses that exist in the L2, and create a system for discriminating between them. Prator (1967) proposed the following phonological correspondence hierarchy, with difference between languages directly correlating with learning difficulty:

Level 1: No difference
Level 2: L1-L2 convergence (at least 2 items to 1)
Level 3: L1 feature absent from L2
Level 4: L1 item has a different environment in L2
Level 5: No similarity between L1 and L2 item
Level 6: L1-L2 divergence (1 item to at least 2)

This hierarchy represents the range of categories that an L2 item may fall into.

These levels are not just assigned randomly, however. The hierarchy may apply only if there is prior knowledge of the phonological parameters that differentiate sounds. Note that an L1 item does not follow this hierarchy because prior knowledge is not required in behavior acquisition. A learner's mind, with developed or developing executive functions, is perfectly primed to make these distinctions. The executive functions take the phonologic concepts of feature, place, and manner, and combine them with analogical processes to route the sound through a new L2 framework.

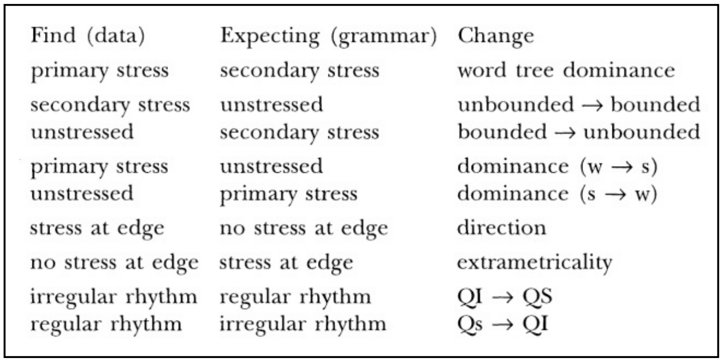
This new L2 framework does not develop as quickly as the existing L1 framework, as noted above. Because of the necessary executive integration step, inputs require more time to map. But in the meantime, in a defined learning environment, output behaviors are required. The L2 system must be able to output before attaining native-like fluency. Learners thus create an interlanguage, a unique mix of recently learned L2 features influenced by L1 features. While the interlanguage phonology can and will vary between learners, as L2 proficiency improves the L1 influence will diminish.

An individual's unique interlanguage is motivated by phonological markedness. In specific language phonologies, markedness describes the degree of difficulty in producing an output faithful to the input given (Prince and Smolensky, 1993). The central tenet of this theory applies to an interlanguage, but varies slightly. In an interlanguage the input comes from the L2 item, and the remaining influence an L1 behavior holds determines its markedness.

These notions, however, merely describe the process of change. They do not reflect the executive functions' differentiation process. How then does discrimination happen in L2 learning? Considering the number of parameters proposed to describe a linguistic system, determining *what* to reset is far from trivial. A learner cannot just treat L1/L2 sound cues as irreparably separate, like an acquirer. Therefore the differentiation must not come from individual cues, but their linguistic parameters. The cue/parameter relationship can be conceived of in a model by Dresher and Kaye (1990):

If you find x where you were expecting y, change parameter z.

Many phonological parameters are well-documented in most of the world's languages. Archibald (1998) gives some examples of possible cues appropriate to particular stress parameters, shown below in Table 1. The stress relationship illustrated there is but one of many phonological parameters that guide production. The learner's central task, then, is to draw that relationship based on L2-L1 comparisons. This task cannot be solved by forcing repeated processes onto a learner, yet this is precisely what many L2 curricula do.



Find (data)	Expecting (grammar)	Change
primary stress	secondary stress	word tree dominance
secondary stress	unstressed	unbounded → bounded
unstressed	secondary stress	bounded → unbounded
primary stress	unstressed	dominance (w → s)
unstressed	primary stress	dominance (s → w)
stress at edge	no stress at edge	direction
no stress at edge	stress at edge	extrametricality
irregular rhythm	regular rhythm	QI → QS
regular rhythm	irregular rhythm	Qs → QI

Table 1: L2 Stress Parameters

This central inefficiency is the core of phonological difficulty in L2 learners. Drawing a complex mental relationship is an integrative task that cannot rely solely on practice and repetition. Yet this is precisely how many current L2 learning curricula operate. While almost every other discipline recognizes the students' ongoing development of high-level thought, language learning curricula stand alone as anomalies in the education spectrum.

The reasons for this are obvious, but completely unintentional. Due to typical lags between research findings and changes in actual educational methods, many of today's language learning programs are based on cognitive research that is horribly outdated. The methods used by many public and private institutions, as well as individual and computer-based methods, to teach pronunciation stem from research done in the late 1900s. At that time the critical period was a huge discovery, and educators latched onto it and implemented systems designed around it.

But these educators were merely basing their tactics on the research available. As mentioned earlier, many learning scientists and language researchers fail to make the critical distinction between acquisition and learning. They use the terms interchangeably, and so many aspects of learning research are misbranded as acquisition. This usage comes from language researchers' lack of understanding of current neuroscience research. Their theories about L2 learning are based on an assumption that post-critical period language development must try to emulate children's strategies as closely as possible.

Our current knowledge of neuroplasticity firmly disproves this research. We now know that forcing a learner to draw relationships solely through practice is inefficient and ultimately unsuccessful. Parameter discrimination can happen, though, in a way that is as competent in L2 as in L1, and in some ways more so. The critical difference is that the parameter must be shown in a multifaceted and integrated manner. Learners can grasp abstract theories, apply them, discuss, and practice, but focusing on only one aspect will not produce optimal results in a learner. Nor will bombarding a learner with a new phonology all at once. This strategy may have worked for a child whose sole cognitive ability in life involved constantly drawing relationships based on experience, but a learner is not an acquirer. L2 learners require additional information to take advantage of their new mental abilities. But this is not a disadvantage; far from it. When presented with concepts in a multifaceted way, in the right order, learners have the capability to process this information quickly and more completely than ever.

5.0 Pedagogical Implications

Any theory, however true, remains only a theory without methods of application. There are uses for pure theories: they describe the natural and abstract world, allow for concrete models from which further inquiry develops, and allow propositions to be checked. But they do nothing. A theorized answer to scientific inquiry may arrive at deep structure, but it remains formal. This is the constant problem with artificial languages: they describe properties of language only in a fixed environment that is designed to arrive at a foregone conclusion. They are fixed representations. Theories do not directly change anything: they merely influence new methods.

In that spirit, I have used the correlation between neuroplastic paradigm shifts and L2 phonology to create a new method of L2 phonology education. This method uses as its core the process described above, and seeks to integrate parts of current learning methods which reflect this process's existence. I call this method the Attention Model. Its name stems from the emphasis on constant awareness of forms presented to the learner in successive manner. The emphasis here will be on phonological learning, but the model works in all linguistic domains, and for maximum effectiveness should be applied to each level of linguistic knowledge.

With phonology, the first step in this process is the L2 learner's phonologic awareness of both L1 and L2 forms. Unless awareness is attained, the learner is doomed to an education based on rote memorization without deep understanding. How is this awareness realized? We have evidence from previous methods in Archibald (1998) and Lado's Audiolingual Model (Lado, 1964). This dialogue-based program has one applicable tenet: that listening must precede any output. But I contend that this listening must be guided. A learner must listen actively, and be prompted to compare sounds in the L2 with those in the L1. All other parts of the utterance are unimportant here. By actively looking for relationships, the learner recognizes parameter differences internally and cements them.

After this period of guided listening, the focus can then move to a discussion of the differences each student noticed. Students can compare what they observed with the observations of others, and be corrected by the teacher. At this stage, a further dimension is introduced: physical phonological awareness. Any student of phonetics and phonology can relate the helpfulness of knowing the actual articulation differences in speech. Take the phonemes /r/ (L1) and / ɹ / (L2). The former is a lateral approximant and the latter a lateral flap. However, this distinction is easily lost on most students, and physical examples must be shown. The teacher can have the students produce /r/ and hold it, while the teacher gives a short description of what the mouth is doing. Then, the task is repeated with the / ɹ /. Again, the student is forced to develop a difference awareness of a parameter, but this time using a motor process.

This process is slow, but going through it incrementally allows for learner-driven contrastive analysis of the type that usually only exists in formal environments. However, here it results from integrated awareness and practice. From individual phonemes, the teacher can then start building segmental units, by building pairs (CV, VV, CC, etc.), trios (CVC, CCV, etc.), and so on. Again, by incremental building, a student gains basic understanding that will last throughout the learning process.

6.0 Conclusion

With such promising results from a bottom-up integration method, I believe the same success can be achieved in L2 pronunciation and reading fluency in children and adults. I have only explored this method here in a phonological sense, but there seems to be no barrier to its success in other linguistic domains. Approaching the study of language learning from a cognitive basis, as well as with a theoretical linguistic basis, will provide a more integrated and ultimately more successful pathway to language learning for any individual anywhere with access to it.

About the Author

Jonathan Rawski is a graduate student of Cognitive Science at the Higher School of Economics in Moscow. He earned a BA in Linguistics from the University of Minnesota in 2013.

Recommendation: Dr. Ettien Koffi has recommended this paper for publication. He is a professor of Linguistics at St. Cloud State University and can be contacted at: enkoffi@stcloudstate.edu.

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