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Neuroemergentism: At the intersection of ontogeny and phylogeny

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When considering how particular features of an organism develop, it is often intuitive to turn to examples of phylogenetic adaptation, or evolutionary change over time. The rapid darkening of peppered moths of industrial-era London provide a compelling case, as light-colored moths became easier for predators to spot in a city increasingly blackened by soot (Cook, 2003). Similarly, it is intuitive that the human brain evolved to allow for functions that would have benefited the survival of our ancestors, such as the ability to see and coordinate movement. What is perhaps less obvious, is how the brain carries out functions that are too new to have been selected for during human evolution, such as precise mathematics and language. In their article "Neuroemergentism: A framework for studying cognition and the brain," Hernandez et al. (in press) review evidence showing that cognitive functions and their underlying neural bases can be best understood by considering both phylogenetic evolution of the brain, as well as ontogenetic development over an individual's lifespan to account for the impact of experience. The authors consider the theories of Neuronal Recycling, Neural Reuse, and Language as Shaped by the Brain, and explain that skills such as reading and numerical processing are made possible by recruiting existing, older neural structures for new functions. They further argue that a comprehensive theory should include consideration of developmental changes over time, and introduce Neuroemergentism as a potential unifying account that seeks to explain how pre-existing elements shaped through evolution are repurposed to meet an organism's developmental needs.

In its conception, Neuroemergentism aims to provide a framework for the study of cognition and the brain. Going forward, the theory would benefit from greater specificity in order to transition from an explanatory account to a framework that generates testable and falsifiable predictions. As a first step towards this goal, we discuss three potential topics for which a Neuroemergentist prism could provide constructive insights: Bilingualism, language acquisition, and language attrition. We consider these three areas in light of data that are already compatible with Neuroemergentism and that could be developed further within its framework.

For bilingualism, there is already substantial evidence that the effects of using multiple languages vary across the lifespan (Bialystok, Martin, & Viswanathan, 2005). For example, differences in executive function between monolinguals and bilinguals have been well documented among young children (e.g., Bialystok, 2001) and older adults (e.g., Bialystok, Craik, & Luk, 2008), but the effects become more tenuous among younger adults (e.g., Salvatierra & Rosselli, 2011). Bialystok et al. (2005) trace this development and propose that effects of bilingualism are less prominent among young adults because they are operating at peak efficiency, leaving little room for variability. Taking a Neuroemergentist approach could complement this work by systematically considering the neurological bases and changes associated with the behavioral data. For instance, increased white matter among bilinguals has been documented for both young children (Mohades et al., 2012) and older adults (Luk, Bialystok, Craik, & Grady, 2011), suggesting that enhanced cognitive abilities may result from better and more distributed connectivity (see Mount & Monje, 2017 for a discussion of experience-dependent myelination). Grey matter density has also been shown to increase with bilingual experience, and is correlated with both age of acquisition and language proficiency (Mechelli et al., 2004). Methodical examinations of change across

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the lifespan can inform us of (1) whether structural differences among groups vary across development, and (2) the extent to which specific structures or functions correlate with cognitive performance at different time points in a person's life. For instance, it may be that the effect of bilingualism on executive function is least pronounced for young adults, in part, because its impact on white matter density is minimal for this age group. Alternatively, even if structural effects of bilingualism are consistent across development, greater connectivity could lead to different types of activity depending on a person's age, available resources, and cognitive demands. Consistent with this hypothesis, neuroimaging has revealed that bilingual experience may lead to potentially more efficient recruitment of neural resources to carry out the same tasks (e.g., Marian, Chabal, Bartolotti, Bradley, & Hernandez, 2014). Different linguistic experiences can lead to both quantitative and qualitative changes to cognitive processes, with consequences that could extend beyond language. For instance, the languages we speak can affect the types of perceptual competition experienced during visual scene processing (Chabal & Marian, 2015), the ability to overcome distracting inputs during audio-visual object search (Chabal, Schroeder, & Marian, 2015), and audio-visual integration (Marian, Hayakawa, Lam, & Schroeder, under review). Experience in one domain (e.g., language) can therefore profoundly alter other domains (e.g., visual perception), consistent with the Neuroemergentist view that cognitive functions operate in a highly interactive manner. By systematically tracking neural and developmental activity in tandem, we can gain a better understanding of their inter-dependence and the ways in which new functions can emerge from, and even influence, the old.

In addition to bilingualism, Neuroemergentism may help reveal the mechanisms driving language acquisition. Our comprehension of the processes underlying language learning could benefit from comparing patterns of brain activity not only across different developmental stages, but across different inputs and learning contexts as well. One example is Boudreault and Mayberry (2006) finding that deaf children with delayed acquisition of sign language experienced long term deficits in language abilities. Comparing the neurological and behavioral activity of children with various ages of L1 acquisition and richness of input could help uncover the mechanisms involved in the attainment of full language proficiency. Furthermore, we may study the interactivity of cognitive abilities by observing the extent to which specific early challenges with language lead to further deficits in both language-related and domain-general function. Such cascading effects for cognition would be analogous to the example cited by Hernandez et al. (in press) whereby deficits with large number approximation among children with Williams Syndrome may emerge from earlier difficulties with sustained visual attention. In addition to observing how different language inputs result in different neural activity, much can be learned by observing cases in which dissimilar inputs result in remarkably similar activity. For example, it has been demonstrated that regions of the superior temporal gyrus (STG) that were believed to be specialized for processing auditory speech are similarly activated when profoundly deaf signers view sign language (Petitto et al., 2000). Petitto and colleagues thus propose that the STG may be initially responsive to input irrespective of modality, but becomes tuned to one modality based on early sensory experiences. Such examples highlight the interactivity of phylogenetic and ontogenetic influences, as the brain evolved to be receptive to language in general, while maintaining the flexibility to organize itself based on the availability of specific inputs. This resiliency is observed even under extreme circumstances, such as in the case of Nicaraguan Homesigners. In the absence of a sign language in Nicaragua, a rudimentary sign language spontaneously evolved, and has become increasingly systematized with subsequent generations (Senghas & Coppola, 2001). The case of Nicaraguan Homesigners provides evidence that languages and language abilities can emerge from a wide variety of environments and inputs. Taking a joint developmental and neuroscience approach may help elucidate the factors that lead to successful or unsuccessful language acquisition based on different learning contexts.

Lastly, a Neuroemergentist approach could yield insights regarding processes involved in language attrition, and the ways they may differ or overlap with those of language acquisition. Learning a new language can be challenging as we become specialized in our native tongue. While young infants can discern sounds of many different languages, they become particularly sensitive to the sounds of their own within the first year (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992). In cases of language attrition, individuals develop a system that is tuned to a particular language, but through lack of use or interfering inputs from other languages, may lose this specialization (Paradis, 2007). Both cases of language acquisition and language attrition are subject to the brain's default patterns of processing being reorganized and reshaped based on experiences and environments. Furthermore, the ease with which languages are both acquired and lost vary across development (e.g., Bylund, 2009; Long, 1990). For instance, individuals adopted into new language environments as young children (e.g., 3–9 years old) can experience what appears to be a total loss of native language ability (Ventureyra, Pallier, & Yoo, 2004), while complete L1 attrition is less likely when the language input is reduced after age 12 (Köpke & Schmid, 2004). This trend is consistent with the notion that brain plasticity decreases over time (Uylings, 2006). However, the fact that abilities in domains ranging from language to music to athletics can be gained or lost throughout the lifespan speaks to the powerful role of experience throughout development. Utilizing a Neuroemergentist approach in the study of attrition, we can observe changes in the system that can result in the loss of an emergent skill (such as loss of a language) as a neural network previously associated with that function becomes repurposed for a new function. It may also be the case that attrition occurs due to changes in the constituent functions for a given process, such as reduced sensitivity to the phonemic boundaries of a particular language (Celata & Cancila, 2010), or due to changes in how different areas are connected, such as a shift in whether a given language relies primarily on procedural or declarative memory (Ullman, 2001). By comprehensively comparing the neurological correlates of language acquisition and attrition over time, we may gain a better understanding of mechanisms driving the development and loss of expertise more generally.

To conclude, although the idea of examining developmental changes in conjunction with neurological activity is not in itself new, Neuroemergentism emphasizes the need for integrative research that systematically tracks the same neural processes and structures across the lifespan. As science becomes increasingly interdisciplinary, Neuroemergentism may provide helpful terminology for discussing neurocognitive functions. In its current form, the theory proposes an explanatory framework that considers both ontogenetic and phylogenetic influences on neurolinguistic phenomena. A goal for the next step would be to develop it into a predictive framework as well. Insights from developmental research may provide direction in the discovery of meaningful neurological activity. Likewise, observed plasticity or crystallization in the brain can provide a map to identify functions that are most affected by our environments and experiences. Just as complex cognition can emerge from combining simpler cognitive functions, the insights gained from bridging disparate methodologies and perspectives can lead us to a greater understanding than the sum of their parts.

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References

Bialystok, E., 2001. Bilingualism in development: Language, literacy, and cognition. Cambridge University Press.
Bialystok, E., Craik, F., Luk, G., 2008. Cognitive control and lexical access in younger and older bilinguals. Journal of Experimental Psychology Learning Memory and Cognition 34 (4), 859–873.
Bialystok, E., Martin, M.M., Viswanathan, M., 2005. Bilingualism across the lifespan: The rise and fall of inhibitory control. International Journal of Bilingualism 9 (1), 103–119.
Boudreault, P., Mayberry, R.I., 2006. Grammatical processing in American Sign Language: Age of first-language acquisition effects in relation to syntactic structure. Language & Cognitive Processes 21 (5), 608–635.
Bylund, E., 2009. Maturational constraints and first language attrition. Language Learning 59 (3), 687–715.
Celata, C., Cancila, J., 2010. Phonological attrition and the perception of geminate consonants in the Lucchese community of San Francisco (CA). International Journal of Bilingualism 14 (2), 185–209.
Chabal, S., Marian, V., 2015. Speakers of different languages process the visual world differently. Journal of Experimental Psychology: General 144 (3), 539–550.
Chabal, S., Schroeder, S.R., Marian, V., 2015. Audio-visual object search is changed by bilingual experience. Attention, Perception, & Psychophysics 77 (8), 2684–2693.
Cook, L.M., 2003. The rise and fall of the Carbonaria form of the peppered moth. The Quarterly Review of Biology 78 (4), 399–417.
Hernandez, A.E., Claussenius-Kalman, H.L., Ronderos, J., Castilla-Earls, A.P., Sun, L., Weiss, S.D., et al., 2018. Neuroemergentism: A framework for studying cognition and the brain. Journal of Neurolinguistics(in press).
Köpke, B., Schmid, M., 2004. Language attrition: The next phase. In: Schmid, M., Köpke, B., Keijzer, M., Weilemar, L. (Eds.), First language attrition: Interdisciplinary perspectives on methodological issues. Benjamins, Amsterdam, pp. 1–43.
Kuhl, P., Williams, K., Lacerda, F., Stevens, K., Lindblom, B., 1992. Linguistic experience alters phonetic perception in infants by 6 months of age. Science 255 (5044), 606–608.
Long, M.H., 1990. Maturational constraints on language development. Studies in Second Language Acquisition 12 (3), 251–285.
Luk, G., Bialystok, E., Craik, F.I.M., Grady, C.L., 2011. Lifelong bilingualism maintains white matter integrity in older adults. Journal of Neuroscience 31 (46), 16808–16813.
Marian, V., Chabal, S., Bartolotti, J., Bradley, K., Hernandez, A.E., 2014. Differential recruitment of executive control regions during phonological competition in monolinguals and bilinguals. Brain and Language 139, 108–117.
Marian V., Hayakawa S., Lam T. Q., & Schroeder S. R.. Language experience influences audio-visual perception. (under review).
Mechelli, A., Crinion, J.T., Noppeney, U., O' Doherty, J., Ashburner, J., Frackowiak, R.S., et al., 2004. Neurolinguistics: Structural plasticity in the bilingual brain. Nature 431 (7010), 757.
Mohades, S.G., Struys, E., Van Schuerbeek, P., Mondt, K., Van De Craen, P., Luypaert, R., 2012. DTI reveals structural differences in white matter tracts between bilingual and monolingual children. Brain Research 1435, 72–80.
Mount, C.W., Monje, M., 2017. Wrapped to adapt: Experience-dependent myelination. Neuron 95 (4), 743–756.
Paradis, M., 2007. L1 attrition features predicted by a neurolinguistic theory of bilingualism. In: Köpke, B., Schmid, M.S., Keijzer, M., Dostert, S. (Eds.), Language attrition: Theoretical perspectives. Benjamins, Amsterdam, pp. 121–133.
Petitto, L.A., Zatorre, R.J., Gauna, K., Nikelski, E.J., Dostie, D., Evans, A.C., 2000. Speech-like cerebral activity in profoundly deaf people processing signed languages: Implications for the neural basis of human language. Proceedings of the National Academy of Sciences 97 (25), 13961–13966.
Salvatierra, J., Rosselli, M., 2011. The effect of bilingualism and age on inhibitory control. International Journal of Bilingualism 15 (1), 26–37.
Senghas, A., Coppola, M., 2001. Children creating language: How Nicaraguan Sign Language acquired a spatial grammar. Psychological Science 12 (4), 323–328.
Ullman, M.T., 2001. The neural basis of lexicon and grammar in first and second language: The declarative/procedural model. Bilingualism: Language and Cognition 4 (2), 105–122.
Uylings, H.B.M., 2006. Development of the human cortex and the concept of “critical” or “sensitive” periods. Language Learning 56 (s1), 59–90.
Ventureyra, V.A.G., Pallier, C., Yoo, H.Y., 2004. The loss of first language phonetic perception in adopted Koreans. Journal of Neurolinguistics 17 (1), 79–91.