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Neuroemergentism: Response to commentaries

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We would like to thank our commentators for the very constructive and informative discussion they have engendered. We were uniformly pleased with how well they took to the various themes presented in our synthesis. Although the comments were wide ranging, they can be placed into roughly four categories: 1) general theoretical considerations, 2) specific components of processing, 3) implications for bilingualism and 4) neural computational components. In some sense, the commentators discussion of our views almost reads like a conversation amongst themselves. In our response, we give form to the theoretical and empirical points that arose.

1. General theoretical considerations

In our piece, we note how Dehaene and colleagues have reduced their views to a particular brain area (the visual word form area) which is recycled from basic multimodal operations of matching visual and auditory footprints of a particular event or object (S. Dehaene & Cohen, 2007; Stanislas Dehaene & Cohen, 2011; S. Dehaene & Dehaene-Lambertz, 2016). However, Dick and Krishnan (2018) point out that Dehaene's views may be out of sync with the actual findings. For example, some experiments have shown the VWFA is less responsive to orthographic patterns from a person's language than to those from another language. Similarly, the fusiform face area (FFA) no longer shows increased activity for faces when people are asked to identify single objects in a category. In their view, the FFA and VWFA are dedicated to a particular set of processes on which a category rests. They are NOT modules dedicated to the processing of particular content per se. They also point out the ways in which expertise may influence auditory processing. In short, Dick and Krishnan (2018) argue for the notion that specialized processing may emerge from systems that perform relatively rudimentary processes and over time are recombined into greater wholes, one that is consistent with the Neuroemergentism framework presented in our article.

The danger of reductionism is also pointed out by Tachihara and Goldberg (2018) who ask why it was necessary to propose a specific term such as Neuroemergentism. In their view, a general Emergentist view applies nicely to so many phenomena. A similar point is also brought up by MacWhinney (2018) who presents a very broad overview of what a cognitive landscape would look like at multiple levels. In his commentary, he notes how processes can operate at a number of scales with the slowest being population genetics. Some processes are even faster, such as one-trial learning that occurs via the hippocampus. MacWhinney (2018) shrewdly points out a number of places where Emergentism fits in with existing theories, for example, that it actually might be consistent with recursion, a hallmark of Chomsky's view on what is unique to human language (Chomsky, 1966, 1975). MacWhinney (2018) also acknowledges the need to consider more focused versions of Emergentism, such as the one we describe with regard to Neuroemergentism. In his view, the most important point is that a theory make testable predictions, (see Marian and Hayakawa, for further discussion).

The search for a more focused and falsifiable version puts us at a crossroads. Whereas general Emergentism may be appropriate for a wide-range of phenomena, it becomes difficult to falsify if everything can be described in a theory. On the other hand, if a theory becomes too focused it is likely to miss some aspect of naturally occurring phenomena much like Dick and Krishnan's criticism of the VWFA and Neuronal Recycling. Hence, MacWhinney (2018) as well as Tachihara and Goldberg (2018) feel that our agreement on

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Emergentism is good news for the field. What is the bad news? We now have a lot of work to do at multiple scales in order to more accurately define how Emergentism operates. Neuroemergentism seeks to achieve this goal by focusing on the neurocomputational level using a developmental approach. However, doing so is likely to lead to us missing some phenomena that operate at other levels and in other domains of inquiry.

2. Scales of operation

The theme of scale brought up by MacWhinney (2018) is further elaborated by Isbilen, Christiansen, and Chater (2018). The Neuroemergentist account as presently constructed considers dynamic processing from an ontogenetic perspective but not from a temporal processing perspective. Isbilen et al. (2018) provide compelling evidence that language processing in particular is subject to temporal constraints. Furthermore, these constraints are likely to be a significant part of the reason language takes the form that it takes, a point further emphasized by the authors. D'Souza and D'Souza (2018) make a similar assertion with regard to language. In their commentary, movement from one individual to another and from one generation to another leads to modifications that improve communication. The authors cite examples of ways in which artificial languages are adjusted across time to better suit people's communicative abilities. Isbilen et al. (2018) make this point as well when supporting their chunk-and-pass model of language processing. This model involves clusters of decipherable information that can be processed more efficiently in a system with processing bottlenecks. D'Souza and D'Souza (2018) offer the example of how processing efficiency is changing the world's most spoken languages, English, Mandarin Chinese, and Spanish, toward a preferred subject-verb-object order relative to other less widely spoken languages. The use of this preferred order would suggest that as a language becomes more and more widely spoken it will adapt to grammatical forms that are more easily interpreted by humans.

D'Souza and D'Souza (2018) also expand on a neurocognitive account of development by considering the body as a source of constraint. For example, infants who have short arms view any grasped object across almost the entire visual field. Compare this to adults whose longer arms allow them to look at a grasped object while still seeing other objects in their visual field. Hence, as the arms lengthen across development, a transition will occur from a world dominated by single objects to one that is integrated with other objects in a person's environment. Both commentaries bring up interesting and important points with regard to the limitations of any framework or theory, including Neurocomputational Emergentism. The sensorimotor hypothesis of Hernandez and Li (2007), a precursor to Neuroemergentism, does discuss how the child is constrained by a focus on processing of the world via the senses and their corresponding motor responses. It is ironic that in its current iteration, Neuroemergentism, a natural extension of the sensorimotor hypothesis, might have lost a bit of the embodied flavor of earlier work. Isbilen et al. (2018) point out that we should make sure to not forget about the role of physical and sensory constraints on the processing of language in general. D'Souza and D'Souza (2018) extend this to consider cognitive and language development more specifically. Still in its infancy, Neuroemergentist approaches to language will have to better articulate these sets of constraints in a clear and testable manner.

3. Bilingualism and Cognition

The relationship between Bilingualism and Cognition is one that has become contentious in recent years. In their commentary, Marian and Hayakawa consider bilingualism and its effects on cognitive control as well as the role of language development. Some have suggested that young adults may not show such strong effects as older adults and children (Bialystok, Martin, & Viswanathan, 2005). Marian and Hayakawa note how complex the landscape is with regard to the differences and similarities between monolinguals and bilinguals. They also suggest that we should investigate the ways in which experience in a domain such as language can alter performance in another domain such as visual perception. A Neuroemergentist approach to this question would take into account an individual's language experience and how it would interact with other types of cognitive processing. However, there is one point where we think this could be taken further by considering development and the non-linear interactive process emphasized within Neuroemergentism. For example, some have suggested that infants may have a form of synesthesia in which information from one sense actually influences the other senses much more so than in children or adults (Maurer, Mondloch, Robertson, & Sagiv, 2005, pp. 193–213). Early in development what we would consider visual perception and language are much more intimately linked in a way that would seem unrecognizable to our adult experiences. This is similar to the point that D'Souza and D'Souza (2018) make about the impact of short arms on object processing. In a similar vein, older adults may begin to compensate for changes that occur in sensory acuity and fluid intelligence. Thus, the type of effects that bilingual experience might have on cognitive control would differ depending on the age at which a language is learned as well as on the age of participants.

Kovelman and Marks (2018) bring up a similar point with regard to the effects of language on cognition. Of particular note is their discussion of results from child bilinguals who read in more than one language. For example, they note that reading in English by children who speak another language is colored by the nature of the other language. Take the case of children in Singapore who tend to make alphabetic errors in spelling whereas those in China make semantic errors. This has to do with the fact that the native language is biasing either a semantic or phonological based approach to learning to read in the second language. In a similar vein, Kovelman and Marks (2018) discuss findings of enhanced phonological awareness in Spanish-English bilinguals relative to both English monolinguals as well as Chinese-English bilinguals. This is due in part to the transparency of the sound-to-print mapping in Spanish. Other researchers have suggested similar beneficial transfer effects that depend on language typology. For example, work with children in Spanish-English dual-immersion programs finds benefit for both Spanish and English native speakers with regard to derivational morphology (i.e. -able, -ment, -city) in English (Kuo, Ramirez, de Marin, Kim, & Unal-Gezer, 2017). That is, learning that *elastic* and *elastico* can become *elasticity* and *elasticidad* leads children to start to notice this much more than English speaking children

in English-only schooling. This shows the ways in which one language can add to the other.

While there has been considerable discussion of the effects of exposure to language, researchers have also begun to consider the role of individual differences. [Sulpizio and Abutalebi \(2018\)](#) provide an interesting perspective on the importance of individual differences in multilingualism. One way in which this has been explored is with respect to the sulcal anatomy of the anterior cingulate cortex (ACC). The brain anatomy in this area is set at a very early age, within 10–15 weeks gestation, leaving it immune to a great extent from the effects of the prenatal and postnatal environment. Results with both children and adults, monolinguals and bilinguals, and across different ages, report differences in efficiency on inhibitory control tasks depending on the presence of either a symmetrical or leftward asymmetry in the neuroanatomy of this region. These effects are not due to environmental effects but rather due to inherent differences in an individual. The importance of individual differences is also a topic that has been studied in our laboratory via the effects of a polymorphism of the DRD2 gene, a characteristic that is either present or absent in the individual before birth, on the brain activity observed in a group of bilingual adults ([Vaughn et al., 2016](#)). Taken together these results suggest that how the brain handles two languages depends on the particular skills that an individual brings to the table.

The importance of individual differences is probably a fundamental question that needs to be addressed in considering the discussion of what, if any, the effect of bilingual experience might be on the presence or absence of a bilingual advantage. Neuroemergentism would naturally ask a more dynamic question in this respect. That is, whether bilingualism leads to an advantage, an advantage leads to bilingualism, or small sets of skills interact with an individual's natural tendencies leading to a group that differentiates itself across time in a highly dynamic manner. This thinking is one that has been articulated in the expertise literature very nicely ([Hambrick, Burgoyne, Macnamara, & Ullén, 2018](#)). Our laboratory along with others feel that work should continue to actively pursue this topic by considering not only the effect of bilingualism on cognitive control but also the effect of cognitive control on bilingualism ([Hernandez, Greene, Vaughn, Francis, & Grigorenko, 2015](#); [Hernandez & Li, 2007](#); [P.; Li & Grant, 2015](#); [Ping; Li, Legault, & Litcofsky, 2014](#); [Vaughn, Greene, Ramos Nuñez, & Hernandez, 2015](#)).

Finally, we would like to draw attention to a somewhat less central but important point brought up by Marian and Hayakawa. In their comments, they discuss language attrition and its importance within a bilingual context. They discuss examples of what appears to be complete loss in some individuals who experience extreme foreign language immersion in childhood. In other cases, there is a loss of sensitivity to the phonological contrasts in a native language. This is an important and fascinating topic not just because of its relevance to bilingualism but also because of what it tells us about plasticity in the child and adult language systems. Marian and Hayakawa suggest that by studying language attrition “we may gain a better understanding of mechanisms driving the development and loss of expertise more generally.”

We agree with this point wholeheartedly but would like to draw attention to one minor but critical part of the language attrition literature: the use of the word attrition. The use of this word implies that something is lost. We think a better term would be language absorption, which gives a sense of what happens in childhood. Our memories are always changing and never remain the same. Language is similar in that sense. Rather than a language being lost, which is what attrition implies, we would argue that it is absorbed which fits in with the notion of being repurposed. For an adult, absorption may be too simple a term and perhaps we could consider language reconfiguration. In short, languages are absorbed, repurposed, and reconfigured for a different use. This view can be seen in the earlier discussed commentary by [Kovelman and Marks \(2018\)](#) which highlights how one language affects the other. Thus, a child who is exposed to Spanish at home but learns in English at a young age may show a reduction in Spanish knowledge over time. However, the tendency toward greater phonological awareness brought on by learning a transparent language at a young age endures into adulthood. Earlier we also noted how gains in one language can be made from exposure to another language, as is the case of learning derivational morphology knowledge in English after exposure to these terms in Spanish.

Of course, the relationship between two languages is complex. The fluidity of this process is consistent with Hernandez's view ([Hernandez, 2013](#)) of two languages as being like two species in one ecosystem both cooperating and competing for resources at any given time. Transfer across languages occurs at multiple levels and as such the term attrition should be replaced with absorption or reconfiguration. Marian and Hayakawa as well as [Kovelman and Marks \(2018\)](#) make this point very nicely. Our only suggestion is that they join us in the quest, spurred in part by the Neuroemergentist framework, to find new terminology to discuss the types of changes observed in bilingualism and second language learning.

4. Neural models of cognition

[Smith \(2018\)](#) and [Stocco \(2018\)](#) continue in the trend of complimentary responses to our Neuroemergentist discussion. [Smith \(2018\)](#) brings up a fascinating point by looking at whether Emergentism presupposes a non-modular system. In his response, he provides a modular cognitive framework in which systems can intermingle and as such is not subject to the strict modular framework as conceptualized by [Fodor \(1983\)](#) or Chomsky ([Chomsky, 1966, 1975](#)). One important point [Smith \(2018\)](#) brings up is whether Emergentism exists at the behavioral, neural or at both levels. What might appear Emergentist at the level of behavior, for example, the influence of prosody and phonology on grammatical processing, does not necessarily mean that the brain systems for each of these processes are also reorganizing.

In contrast to Smith's theoretical approach which is grounded to some extent on philosophy and experimental science, an approach that is shared by almost all the other commentators, [Stocco \(2018\)](#) is the only one to embrace a truly neurocomputational approach. He begins by noting that computations at the neural level often time show Emergentist properties. For example, the very notion of network dynamics involves the interactions between populations of relatively simple neurons that form neighborhoods and eventually lead to large-scale networks that traverse brain areas. Hence, the neurocomputations underlying cognition have Emergentist properties as complex cognition arises from relatively simple building blocks.

Although not explicitly noted in his discussion, Stocco (2018) moves beyond a modular/interactive dichotomy by suggesting a more complex subsymbolic view of language involving memory and reward-based learning, a view that is very resonant with Neuroemergentism. Stocco (2018) proposes that a crucial aspect of language development could be thought of as consisting of reward-based learning and memory. In his proposal, syntax involves the basal ganglia which has been associated with reward-based learning whereas the learning of semantics relies to a greater extent on memory, which is driven by the hippocampus. In this sense, Stocco's view resembles the Declarative/Procedural model of Ullman and colleagues (Ullman, 2001, 2006). The use of a reward-based learning approach is particularly interesting in light of the fact that it has been associated with neurotransmitters such as dopamine as well as with particular influences on the frontostriatal tract (Westbrook & Frank, 2018).

Stocco's discussion of these two neurobiologically based systems not only contributes to the evaluation of models of cognition but also makes the case for the underlying importance of a neurocomputational approach. His extension of Neuroemergentism involves interactions at both the brain and behavior level which in some ways provides a counterpoint to Smith's view. Following this train of thought further makes it difficult to reconcile a modular view with a more interactive connectionist approach. Specifically, at which point does a module exist? How does it come into existence? What are the underlying components that lead to the formation of these modules? These are questions with which we grappled in our discussion of Neuronal Recycling, Neural Reuse and Neuroconstructivism. Each of these theories consider brain areas. Stocco's consideration of the hippocampus and its relationship to vocabulary also follows along these lines. However, the introduction of reward-based learning is interesting in that it is not a system dedicated to language itself. Stocco (2018) notes that this approach leaves out other aspects, including sensory and motor aspects of language. Considering reward-based learning leads to significant questions about how cognition is built, thereby showing how neurocomputational models of cognition can change the questions one might be asking. We are also left with the question of how either of these models handles development. Perhaps as Smith (2018) argues there are leaky modules at the outset, something akin to the thalamic and cortical face recognition systems that were reviewed in our paper.

Identifying what underlying systems exist at birth and how they transform across development remains a significant challenge regardless of our theoretical approach. Considering opposite theoretical viewpoints clearly leads to all kinds of new questions. Smith (2018) and Stocco's responses show us that a deeper conversation from two approaches that on the surface appear diametrically opposed is likely to sharpen our view of language, cognition and development to a great extent.

5. Conclusion

Neurocomputational Emergentism seeks to consider change within a developmental framework and consider that small simple things can become something very different. In this particular articulation of this newer framework we sought to bring to light how this might apply to bilingualism. We also offered the work by Morton and Johnson as an example of how neural and behavioral descriptions of face perception show the intricacies of dynamic interactions across time that reveal something fundamental about cognition in general. While Neuroemergentism is in its infancy as pointed out by many of the commentators, it also brings us great excitement to consider all the ramifications of this approach going forward. What we hope is to extend the work of pioneers in Emergentism, Dynamical Systems, and Neurocognitive Development to the neural and computational level in order to derive a model that can more accurately capture the dynamic nature of language and cognitive development.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.jneuroling.2018.06.001>.

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