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Nature, Nurture or Interacting Developmental Systems? Endophenotypes for learning systems bridge genes, language and development

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In the foregoing article, Lee and Tomblin (in press) present an innovative picture of language. Their exploratory study integrates the genetics and structural neuroscience of the procedural learning system to help understand an important and widespread developmental communication disorder, Specific Language Impairment. This study is necessarily exploratory, highly technical, and seemingly focused on language disorders. However, it plants a flag for a new approach to thinking about language. In their sophisticated approach to the biology of language development, there are clear bridges to the well-worn issue of nature and nurture in language development. Yet, a closer look at their results and their approaches points the field to something richer, more sophisticated, and ultimately more insightful.

Perhaps the oldest issue in the language sciences is the question of nature and nurture (Chomsky, 1958; Skinner, 1957). To what extent are uniquely human abilities like language the product of our so-called “endowment”, or to what extent are they acquired from our rich and complex developmental experience? The argument for a heavy contribution from a human endowment is well worn and seems compelling: humans are the only species with something as sophisticated as language; there appear to be certain universals in the way that language is structured (Pinker & Bloom, 1990); and despite the sophistication of language most children seem to acquire it with little direct instruction (Bowerman, 1988; Marcus, 1993).

However, the case for an endowment may be circumstantial, as these widespread assumptions are under continuous debate. Research suggests animals may possess many of the requisite capacities for language (e.g., Gentner, Fenn, Margoliash, & Nusbaum, 2006; Griebel & Oller, 2012; Wasserman, Brooks, & McMurray, 2015); the case for language universals may rely on fairly selective sampling of languages (Evans & Levinson, 2009); and there are clever ways of overcoming the problem of lack of negative evidence (e.g., Elman, 1990; A. S. Hsu & Chater, 2010).

Getting beyond this circumstantial case would seem to require a more direct investigation of the biology – such as that of Lee and Tomblin (in press). But in light of these broader

questions of nature/nurture it is helpful to consider the intellectual and historical underpinnings of this kind of work. Behavioral genetics—twin studies—would seem to offer a more direct answer to the question of nature and nurture. The deceptive simplicity of twin studies appears to offer a clear delineation of the amount of variability due to genetics and environment. It is important to note that the emphasis of twin studies is necessarily on variation among individuals in language, not on the innate underpinnings of a universal ability. As such, researchers must identify phenotypes that vary across individuals, and have often focused on estimating heritability for clinical conditions like specific language impairment (SLI).

While this would seem to make for a narrower window onto these issues, SLI is clinically defined as poorer than normal language in the absence of any obvious cause (neurological disorder, hearing impairment, etc.). With such a loose definition, a number of researchers have argued that SLI may in fact be the low end of a continuous scale (Leonard, 1987, 1991; Tomblin & Christiansen, 2009; Tomblin & Zhang, 1999), meaning that an SLI diagnosis may be more properly seen as a proxy for functional language ability writ large. Thus, in this light, genetic studies of SLI, may offer real insight into the heritability of language more generally.

Indeed, a large number of studies suggest a moderate heritability to many domains of language (Bishop & Hayiou-Thomas, 2008; Dale et al., 1998; Kovas et al., 2005; Tomblin & Buckwalter, 1998) (see Stromswold, 2001, for a review). However, behavioral genetics have also been criticized on a number of grounds (Davis, Phelps, & Bracha, 1995; Joseph, 2002; Kan, Ploeger, Raijmakers, Dolan, & Van Der Maas, 2010; Richardson & Norgate, 2005): monozygotic and fraternal twins may not have identical developmental environments, they assume an additive model making it difficult to account for dynamic interactions among factors, and twin studies have a hard time dealing with alternative routes to heritability like epigenetic or prenatal factors.

This would seem to drive the need for studies that more directly link genes and gene variants to language outcomes. However, as Lee and Tomblin (in press) discuss, these studies have also been inconclusive. For example, for even the best known gene linked to language, FOXP2 (Lai, Fisher, Hurst, Vargha-Khadem, & Monaco, 2001), only relatively rare variants have been linked to variation in language (Meaburn, Dale, Craig, & Plomin, 2002; Newbury et al., 2002). The bottom line though is that there is a sizeable set of candidate genes, but none exert large effects that are clearly independent of environmental factors. This sets up a sort of missing heritability problem (for an interesting discussion of this problem, see Chaufan & Joseph, 2013).

The fundamental issue with this entire line of thinking however, is the assumption that there is a *unique* contribution of genes (or anything “innate”) to language. That is simply not how genes work (Fox Keller, 2009; Johnston & Edwards, 2002). This is not to criticize geneticists or those that do this kind of work – that work is often pitched carefully and biologically realistically. However, when extrapolating from genetics to these broader issues of nature and nurture, often the subtlety is lost.

So if genes do not make a unique contribution to language, what do they do? Genes contain information for creating proteins, which help build cells, and so forth. But genes don't "act" alone – they are expressed in response to the cellular environment, which in turn is shaped by brain activity and that is in part a product of the organism's environment. There is no single path between genes and language (Figure 1). There do not appear to be any proteins or brain structures that are unique to language; just as there do not appear to be any learning events that are solely about language. The path from genes to language is more complex than this.

In light of this, mounting work in developmental psychobiology eschews the utility of a clear nature/nurture divide in favor of *developmental systems* (Gottlieb, 2007; Johnston & Edwards, 2002; Oyama, 2000; Spencer et al., 2009), the notion that development is the product of ongoing bidirectional interactions between genes, proteins, cells, brain structures, behavior and the environment. Under this view, development is not simply the additive result of genes and environment, but rather, can only be described in terms of ongoing interactions between multiple levels of the system. This helps (but does not fully) explain the difficulty in linking genes to high level outcomes like language. Genes don't code for language, they code for proteins, and between genes and distal outcomes like language, there are a lot of levels of analyses and developmental pathways.

This systems view is built on pioneering embryology, genetics and psychobiology, work which for the most part has not addressed the complexities of human language. This work suggests that 1) genes typically do not produce organismal form or behavior directly, but rather respond in cascades to proteins created by regulatory genes that themselves respond to environmental stimuli both internal and external; 2) development of both organismal form and behavioral capabilities occurs through dynamically varying cycles of interaction among genes, and environmental events (Lickliter & Honeycutt, 2003); 3) the role of environment and experience is not always rational or obvious (Gottlieb, 1997) – language development, for example, is not solely the product of language input; and 4) there are multiple avenues of inheritance beyond genetic mechanisms including culture, learning, prenatal environment and epi-genetic factors (e.g., Francis, Diorio, Liu, & Meaney, 1999; Francis, Szegda, Campbell, Martin, & Insel, 2003; Weaver, 2007). Together they promote a view in which genes cannot be simply equated to traits, but rather participate in a rich developmental process by which traits and behaviors emerge developmentally, but these behaviors in turn can affect gene expression and participate in multiple routes to inheritance.

This developmental systems view is not commonly applied to high level human phenomena like language (though see, Christiansen & Chater, 2008; Elman et al., 1996; McMurray, in press; Samuelson & McMurray, in press; Tomblin & Christiansen, 2009). However, while this view makes it apparent that we will not make headway by trying to isolate genetic influences on language, it also underscores the fact that neither can we cannot ignore the role of genes. So what is the role of genes in such a system?

While genes do not "cause" development, they contain rich information that development can use. In particular, genes contain information about proteins, proteins which may be needed to implement changes in cellular structure resulting from learning and experience. In

this way, then, gene variants may be more closely linked to upstream processes such as learning systems in the brain.

Lee and Tomblin (in press) take this logic by emphasizing endophenotypes, that is, measureable phenotypes that may be closer to gene action; in a sense moving down a level or two in Figure 1 from language to its neural and cognitive underpinnings. They use these endophenotypes to understand the development of SLI (and by proxy, general language abilities). Building on the now important finding that procedural learning systems (centered in the striatal system) may be important for learning language (Hedenius et al., 2011; Tomblin, Mainela-Arnold, & Zhang, 2007; Ullman & Pierpont, 2005) (though see, H. J. Hsu & Bishop, 2014), Lee and Tomblin simultaneously link genes associated with procedural learning to structural brain imaging of basal ganglion system, performance on several procedural learning tasks, and to language diagnoses.

One might take a standard nature/nurture view to argue that this shows the ultimate importance of genes for a learning system necessary for language; that is, genes → learning systems → language. Under this view, this work appears document the innate nature of these learning systems. However, from a systems perspective, development itself is the focus. The point of learning systems is to acquire information for the environment, and these genes likely play a role in how, when, and in what manner this information is stored. That is, they must respond to the state of the organism, not direct its development. Here, genes contain the information needed for implementing learning, and of course, learning is intricately dependent on rich input from the environment. From this perspective, this genetic work becomes a way to highlight which learning systems may be involved in harnessing this information to drive particular aspects of language development.

Of course, Lee and Tomblin's (in press) exploratory study is not that ambitious nor can it be that precisely targeted. However, it illustrates the promise of combining advances in human neuroscience and genetics with careful measurements of cognitive processing and ultimate real-world outcomes like SLI. This study points to the simultaneous contribution of genes, learning systems, and environment as contributors to language outcomes, and by doing this it starts to unpack language as a developmental system.

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Figure 1.

Language as part of a developmental system in which levels of the system like genes engage in bidirectional interactions with adjacent levels, such that genes are used to create proteins that can be involved in neural processes like learning, but gene expression is simultaneously modulated by the cellular environment. Similarly, language is a product of regularities environment, but this is shaped at the higher level by cultural forces (the structure of the language, regularities of the social environment), and these regularities must be acquired by neural mechanisms which are shaped by the biology of the organism.