EPIGENETICS AND LANGUAGE: THE MINIMALIST PROGRAM, CONNECTIONISM, AND BIOLOGY

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Abstract

Chomsky claims that linguistics should be thought of as a branch of biology. Lorenzo and Longa claim that the Minimalist Program is better than previous approaches at connecting language to biology because it relies on epigenetic processes in development, which is the current trend in biology.

Epigenetic processes alter gene expression in a heritable manner without changing DNA sequence. Recently, biologists have come to see epigenetics as extremely important to development.

We agree with Lorenzo and Longa that inclusion of epigenetic processes in linguists' theories of language development is important if linguists desire unification with biology. However, Lorenzo and Longa do not discuss processes that alter gene expression in a heritable manner without altering DNA. A close examination of their position illuminates a large gap between the Minimalist Program and epigenetics.

In contrast, there is a relatively small gap between connectionism and epigenetics. Language development in connectionist systems involves modifications of neural connections. Research shows that modification of neural connections involves processes that alter gene expression without altering DNA.

It follows that connectionism is the superior paradigm for researchers interested in unification between biology and linguistics.

1. INTRODUCTION

A key aspect of modern linguistics is the belief that language is a function of the brain. Nevertheless, linguists have never paid much attention to developments in the brain sciences, despite work reviewing the field for linguists as early as the 1960s (Lenneberg 1967). To this day, the relationship between generative linguistics and other sciences relating to the brain, such as psychology, neuroscience, and biology remains elusive.

Chomsky originally sought to connect linguistics most closely to psychology, even proposing a psycholinguistic test for his grammatical constructs (1957: 16).

In the decades that followed Chomsky has been more inclined to promote the idea that linguistics is a branch of biology (1975: 123, 1986: 27, 2000: 90). Jenkins (2000), inspired by Chomsky, goes even further, referring to generative linguistics as "biolinguistics". This sort of argument relates explanatory adequacy directly to genetic inheritance (e.g. Chomsky and Lasnik 1993; Jenkins 2000; Pinker 1994). Chomsky's proposal has generated a lot of discussion on the relation between biology and linguistics (e.g. Anderson and Lightfoot 2002; Givón 2002; Jenkins 2000; Pinker 1994, 1997; Pinker and Bloom 1990; and *many* more). Of particular interest is a recent paper by Lorenzo and Longa (2003), because it attempts to provide some unification between the most current research paradigm in linguistics, the Minimalist Program, and recent findings in biology regarding *epigenetics*.

While we are totally in sympathy with the goal of relating linguistics to epigenetics, we are not convinced by Lorenzo and Longa's arguments. From our perspective, the Minimalist Program is much farther away from an epigenetic account of language than another paradigm, connectionist linguistics. Lorenzo and Longa's attempt to link the Minimalist Program and epigenetics illustrates just how far generative linguistics is from unification with biology. In this paper we will contrast their work with connectionist work to show that epigenetics is closely related to connectionist theories, in contrast to the Minimalist Program as currently formulated.

2. BACKGROUND: EXPLANATORY ADEQUACY, BIOLOGY, AND MINIMALISM

To have explanatory adequacy a theory must "characterize the initial state of the language faculty and show how it maps experience to the state attained" (Chomsky 1995a: 386). In other words, the theory cannot just describe language — it must be a model of how a person's linguistic system came to be.

Minimalists approach this question within the Principles and Parameters framework. So, for minimalists a theory with explanatory adequacy becomes a theory which correctly identifies the principles and parameters of Universal Grammar. Many writers articulate this as a quest for what children are provided with biologically. For example, Epstein and Hornstein (1999: p. x) succinctly state: "The idea is simple. Children are biologically equipped with a set of principles of grammar". Framed in this way, the quest for explanatory adequacy becomes a quest for the biological mechanisms of language.

Despite this tendency to describe explanatory adequacy as providing an account of the biological mechanisms of language very few linguists actually attempt to link their theories to biology. Most of the work relating linguistics and biology has included very little of the "bread and butter" of generative linguistics, i.e. checking the grammar model by looking at various language data, and proposing modifications of the model as problems arise. In most linguistics texts, one can only find cursory references to biology within the introduction, without actually referring to any biological data. Instead, much of the discussion relating biology to linguistics has revolved around (1) innateness, (2) its relation to specific language impairments, (3) evolution, and (4) broader theoretical questions (Jenkins 2000; Pinker 1994, 1997; Pinker and Bloom 1990). These are important discussions, but such work does little to link actual theories from current generative linguistics with biology. Lorenzo and Longa's (2003) recent paper is unique in this respect. They attempt to show not just that the Minimalist Program fits with biological concerns, but that the specific mechanisms of Minimalist models are in agreement with recent findings in biology regarding epigenetics. Lorenzo and Longa's discussion contains several conclusions. We will concern ourselves with their assertion that language development as described by the Minimalist Program reduces genetic endowment and relies on a process called epigenesis, and the related study of epigenetics, which is increasingly influential in biology.

3. EPIGENESIS AND EPIGENETICS

Lorenzo and Longa's paper contains numerous references to epigenesis and epigenetics. They argue that these concepts are central to the Minimalist Program. If linguistics were a branch of biology this would be important, because epigenesis is unquestioned in biology, and epigenetics has received a lot of attention in recent work. In fact, epigenetics is becoming a crucial component of biologists' understanding of development. Thus, a proper discussion of explanatory adequacy in a biological framework demands inclusion of epigenesis and epigenetics. Since an exact definition of these terms is crucial to what follows, we will discuss their current usage.

3.1. Epigenesis and epigenetics: Definitions

The term "epigenesis" is relatively old (Wu and Morris 2001: 1103). Epigenesis refers to processes proposed by a theory of development that contrasts with the even older theory of preformation. The theory of preformation held that adult-like complexity already existed in the early embryo, whereas the theory of epigenesis proposed that the early embryo was undifferentiated and complexity developed over time via epigenesis (Holliday 1994: 453). Thus, epigenesis collectively refers to the processes involved in the ontogeny of a complex organism that began as an undifferentiated and relatively simple one. As biologists learned more about early development, it became clear that the theory of epigenesis was correct and the theory of preformation was incorrect. By the 20th century, epigenesis was well accepted, and in 1942 C.H. Waddington introduced the term "epigenetics", which he derived from the term "epigenesis" (Holliday 1994; Pennisi 2001: 1067; Wu and Morris 2001: 1104). Waddington (1942: 18). defined epigenetics as the study of the mechanisms that relate genotype (genetic make-up) to phenotype (physical/behavioural traits). The importance of Waddington's definition was that it provided a term that could be used to describe studies of the hugely complex interactions between an organism's genes and the multitude of factors that influence development.

The definition of epigenetics has undergone some revisions in the past two decades. An understanding of DNA came after Waddington's definition, and the excitement surrounding it led to the dominance of what can be called a gene-centrist viewpoint (Van de Vijver et al. 2002: 2). The gene-centrist position assumes that genes are the ultimate starting point of inheritance and development, and that epigenetic phenomena affect development within the framework provided by genes. However, more recent work in biology has led to a shift away from this. It has become clear in recent work that epigenetic phenomena are active in altering gene-expression, and that their effects are heritable and responsive to environmental factors (Pennisi 2001: 1064; Sutherland and Costa 2003; Van de Vijver et al. 2002: 3).

In an effort to make this clear, we provide a simplified example of an epigenetic process — control of DNA transcription via methylation. The protein-DNA complex in the nucleus of cells is called chromatin (Mukesh, Dunn and Umar 2003: 321; Suustad and Simmons 2000). Gene activity is affected by the proteins that package the DNA in chromatin (Mukesh, Dunn and Umar 2003: 322; Pennisi 2001: 1064). These effects on gene activity influence development but do not lead to a change in the DNA sequence of an organism. For instance, proteins in chromatin, called histones, are a key factor in gene expression. Environmental factors can cause chemical modifications to histones which affect gene activity (Wolffe 1998). Methylation of H3 histones creates a platform for the HP1 protein to bind to the stretch of DNA which the methylated histones surround. By allowing proteins to bind to the DNA, the histones effectively prevent transcription of the DNA stretch, thereby turning particular genes on or off (Kouzarides et al. 2001; Lachner et al. 2001).

The patterns of gene activity resulting from such epigenetic processes are, in fact, heritable, even though they do not alter the DNA (Holiday 1994; Pennisi 2001: 1064). For example, certain chromatin states are also replicated along with DNA during a particular phase of mitosis (somatic cell division) called S-phase (Bestor et al. 1994: 459).

Thus, the current definition of epigenetics is: the study of processes that affect gene expression, and are heritable, but do not affect DNA sequence (Holliday 1994: 454; Mukesh, Dunn and Umar 2003: 322; Pennisi 2001: 1064; Sutherland and Costa 2003: 51; Van de Vijver et al. 2002: 2; Wu and Morris 2000: 1104). Within the past decade biologists have come to view such epigenetic phenomena as being at the core of development (Pennisi 2001; Van de Vijver et al. 2002), even going so far as to refer to these epigenetic processes as "the 'master puppeteers' of gene expression" (Pennisi 2001: 1064).

3.2. Epigenesis and epigenetics: Relevance to linguistics

The abandonment of a gene-centrist viewpoint in biology has radically altered the "nature vs. nurture" debate between nativists and empiricists. For many years "nature" was believed to be the genetic component of behaviour, whereas "nurture" was believed to be the effects of psychological experience. The nativists and empiricists disagreed as to the importance of each factor.

Given the new findings regarding epigenetics, this dichotomy is no longer relevant. We now know that genes and experience *interact*, both requiring the other in order to fulfill their function. This radically alters how we must address "nature" and "nurture". "Nature" is still that which is encoded in the genome, but "nurture" now determines how "nature" is expressed. As the biologist Matt Ridley (2003) phrases it, this is "Nature via Nurture".

Linguistics was one of the central disciplines involved in the older "nature vs. nurture" debate. The nativism espoused by Chomsky and others led to this. Many authors suggested that explanatory adequacy could only be achieved within a nativist theory of language, while others argued that nativism was untenable. However, with the altered perspective that epigenetics has provided, we can now see that the debate was misguided. From a biological perspective we need not ask if language is "innate". Rather, we must ask, "How can experience effect our genetic expression in such a way as to produce the human capability for language as we know it?" Answering this question must involve a description of the biological processes that affect the expression of genes involved in brain development. Lorenzo and Longa attempt to show that the Minimalist Program can provide guidance.

4. The Minimalist Program and biology

The Minimalist Program is not a theory, but a research program, so it provides questions, not answers (Chomsky 1998; Epstein and Hornstein 1999; Freidin and Vergnaud 2001). The questions it provides represent a shift in the types of questions asked by some linguists (e.g. Chomsky 1995c, 1998; Martin 1999). The shift is towards a greater role for questions concerning "economy"; limiting the amount of machinery used in building syntactic derivations, and describing the relation of the Faculty of Language to other cognitive modules, often called "performance systems" (Chomsky 1995c). Lorenzo and Longa suggest that the Minimalist Program directs linguists towards theories of development that do not rely on explicit genetic endowment to the extent that previous theories had.

4.1. The Minimalist Program and biology: Reducing genetic endowment

The questions minimalists ask are guided by certain assumptions. Minimalists assume that the Faculty of Language has two interfaces with performance systems: a sensorimotor system, and a conceptual system that handles reasoning and world knowledge (Chomsky 1995c: 168; Freidin and Vergnaud 2001: 640). The Faculty of Language derives pairs of instructions to these two systems (Chomsky 1995c: 219). It is assumed that the computational component of the Faculty of Language predominantly utilizes either those items provided by the lexicon or items necessary for use by the performance systems or both (Chomsky 1995c: 225; Freidin and Vergnaud 2001: 644). Anything that is not a lexical feature and/or utilized by the performance systems is considered an "imperfection"; minimalists hope to show any such imperfections to be necessary flaws in the system (Lorenzo and Longa 2003: 647). Thus, a central strategy in minimalism is to increase the number of theoretical entities that are within the domain of the performance systems. For example, minimalist work has distinguished interpretable and uninterruptible features (Chomsky 1995). Interpretable features are considered to be rooted in the performance systems, since they are necessary for communication. In contrast, uninterruptible features are assumed to be useless to the performance systems, and thus contained in the Faculty of Language alone (Lorenzo and Longa 2003).

Lorenzo and Longa suggest that this strategy leads to a reduced genetic endowment for language. They assume that any items that are required by the performance systems do not need to be explicitly encoded in the genome, but can arise due to epigenetic processes. This assumption is based on the idea that the performance systems are the main site of variability in language, and that the Faculty of Language is unique in its reliance on explicit genetic code (Chomsky 1995). Thus, moving theoretical entities from the Faculty of Language to the performance systems reduces the extent of the genetic endowment postulated by linguists.

This argument is novel. Lorenzo and Longa are using a current generative research program to guide genetic conclusions about language, and then are arguing that these conclusions fit with the drive towards epigenetics in biology. If these conclusions do fit with epigenetics, we can presume that the Minimalist Program can indeed provide a framework for biological investigations of language. But do these conclusions about reduced genetic endowment fit with epigenetics? No, they do not. Lorenzo and Longa fall very short of linking the Minimalist Program to epigenetics.

4.2. The Minimalist Program and biology: Epigenetics?

Where does epigenetics exist in Lorenzo and Longa's arguments? At first reading it was unclear to us. Despite numerous uses of the word "epigenetic" Lorenzo and Longa (2003: 643–644, 651–655) never mention processes that alter gene expression and are heritable yet do not alter DNA sequence. They use the terms "epigenesis" and "epigenetic" in a vague manner. The definitions they do use are pulled from an introductory biology textbook (Futuyma 1998: 651). This excellent textbook only deals with epigenetics in passing. It defines *epigenesis* as "the processes that intervene during the development of an organism between gene action and the phenotypic trait", and *epigenetic* as "Developmental: pertaining especially to interactions among developmental processes above the level of primary gene action". These definitions are less specific, but related to the definitions described in Section 3.

The new direction in biology is a focus on the more specific sense of epigenetics — processes that affect gene expression in a heritable manner without altering DNA sequence. For Lorenzo and Longa's argument to have any validity, they would have to be speaking of epigenetics in this sense, but they are not; they are relying on epigenetics as vaguely defined in an introductory textbook. They fall very short of any agreement with the new direction in biological research.

One might postulate that Lorenzo and Longa still have something salvageable in their argument. The growing influence of epigenetics does suggest a departure from the gene-centrist viewpoint in biology (Van de Vijver et al. 2002), and Lorenzo and Longa do seem to be arguing that the Minimalist Program suggests a departure from a gene-centrist viewpoint in linguistics. However, suppose there is another research program in linguistics that is closer to an epigenetic account of linguistic development; should it not be seriously considered as a potentially more appropriate framework for biological inquiry into language?

5. CONNECTIONISM AND LINGUISTICS

Connectionism, like the Minimalist Program, provides certain guiding assumptions. One difference, though, is that connectionism is broader in scope; it provides a framework to describe a much wider range of phenomena than just syntax. There is a huge amount of research on language by connectionists (Ellis and Ralph 2000; Elman et al. 1996; Farrar 1998; Hinton 1981; Lamb 1966; Reich 1969, 1970a, 1970b; Reich and Richards 2004; Rumelhart and McClelland 1986; Samuelson 2002; and many more), of which linguists operating within the generative paradigm are almost completely unaware. The assumptions of connectionism revolve around the nature of knowledge and learning in the brain. Connectionists assume that the strength and morphology of connections between neurons constitute knowledge (Lamb 1998; McClelland, Rumelhart and Hinton 1986: 75). Within this framework, learning has two components to it — the development of new connections, and the modification of the strengths of existing connections (McClelland, Rumelhart and Hinton 1986: 53).

Guided by these principles, connectionists tend to focus on explaining how neural development leads to particular linguistic behaviours. Generally, a particular aspect of language behaviour is identified, e.g. role assignment, syntactic priming, lexical processing, etc., then a neural network model is put forth to explain how modifications in neural connections throughout life produce such results. For example, words learned early in life are recognized and produced more quickly than those learned later in life (Carroll and White 1973). Ellis and Ralph (2000) explore this issue and put forth several neural network models that explain this. They show that as long as early words continue to be encountered later in life, the general tendency of neural networks to rigidify with training leads to such age of acquisition effects.

It would be disingenuous not to recognize that connectionist models of this sort are at a different "level of description" than the models of generative linguists. Often, connectionists model the brain mathematically and generativists model cognition symbolically. However, these two levels of description need not be exclusive. For instance, Reich and Richards (2004) account for some peculiar effects in phonological priming using a network which can be described symbolically, allowing for a bridge between the low-level and high-level descriptions. Also, a lot of work has been done on connectionist symbol processing (see Hinton et al. 1992), so symbolic theories can usually be re-evaluated from a connectionist perspective. Thus, the treatment of language within the connectionist framework need not be exclusively low-level. Whether a connectionist researcher attempts to link the low-level aspects of their model with the high-level models of cognition linguists are familiar with is a matter of choice. As stated above, the only assumption of connectionism is that the morphology and strength of connections between neurons constitute knowledge.

5.1. Connectionism and biology

Beyond the basic assumption of the nature of knowledge, connectionism does not make any *a priori* assumptions about genetic endowment (Elman et al. 1996: 38; Rumelhart and McClelland 1986: 139). A common misperception of connectionism is that it necessarily de-emphasizes genetic mechanisms (see Jenkins 2000: 197–198). This is false. One connectionist could argue that all connections are genetically determined, while another could argue that they are determined by experience alone (Rumelhart and McClelland 1986: 140).

To be fair, the assertion that connectionists resist genetic explanations is the result of connectionist linguists using the freedom the paradigm provides to resist the sort of nativism many generativists accept (Arbib 1995: 42; Bates and Elman 1996). Connectionist linguists tend to reject the tenets of the older Government and Binding approach to language, which relied heavily on an innate component taken to be determined by genetics (Lorenzo and Longa 2003). This rejection of genetic mechanisms is not necessary for connectionists, but it is the direction many have taken (e.g. Elman et al. 1996). As we have seen, it would be questionable, given the departure in biology from a gene-centrist viewpoint, to rely heavily on mechanisms encoded in the genome. It could be argued that the Minimalist Program is still beholden to such gene-centrism, since minimalists continue to seek a Universal Grammar that determines the set of possible languages (Chomsky 1995c: 169) and the Minimalist Program is still grounded in the Principles-and-Parameters framework (Freidin and Vergnaud 2001: 640). However, if Lorenzo and Longa are correct, the Minimalist Program represents a departure from the gene-centrism associated with Government and Binding. If this is the case, the Minimalist Program is "catching up" to connectionism in terms of its agreement with biology.

Given two research paradigms, how does a linguist choose which paradigm shows the most promise for explanatory adequacy? Neurological reduction need not be the deciding factor. Unification between two sciences does not always take the form of a reduction, as in the case of unification between chemistry and physics. Indeed, according to Chomsky (1986, 1995b), theoretical entities in linguistics that have proven to be empirically useful should not be discarded for lack of reduction to other sciences. We fully agree. Explanatory adequacy could be developed symbolically if that turns out to be the most fruitful method of inquiry.

It follows that neurological reductionism is a moot point. The deciding factor will be how close each paradigm is to its stated goals. We believe that connectionism is the superior model *when unification with biology is a goal,* because it is much closer to an epigenetic account of language acquisition.

5.2. Connectionism and biology: Modifying connections

Many connectionist researchers consciously seek direction from neuroscience and biology (Arbib 1995; Elman et al. 1996; Lamb 1998; Rumelhart and McClelland et al. 1986). This is important to be aware of, because some researchers (e.g. Jenkins 2000) seem to think that connectionists are more concerned with artificial intelligence than neuroscience or biology. This is based on the fact that some connectionist simulations use machine-learning algorithms (Jenkins 2000: 87–88). Such assertions are patently false. Connectionists are greatly concerned with biology (see Arbib 1995: 45–50), and have explicitly included neurological and biological considerations since the 1980s (see Crick and Asanuma 1986). These considerations have led to considerable development towards unification between biology and connectionism.

Learning in a connectionist system involves the modification of connections between neurons. A connection between two neurons is referred to as a *synapse.* A synapse is a small space between an axon (an extension that conducts impulses away from a neuron) and a dendrite (an extension that conducts impulses towards a neuron) (Arbib 1995: 5). Chemicals known as neurotransmitters are released from the pre-synaptic area at the end of an axon and then bind to receptors at the post-synaptic site of the dendrite (p. 5). One chemical released from some axons increases the likelihood that the next neuron will fire; another chemical released from other axons decreases the likelihood that the next neuron will fire. Many factors contribute to changes in synaptic connections, including the release of neurotransmitters, the receptors on the dendrite, and the morphology of the dendrite (p. 5).

In the past two decades researchers have identified some mechanisms for inducing synaptic changes; gene expression is implicated in many of them (see Baudry 1998, for some discussion). For example, some theories of learning involve Immediate Early Genes: genes that encode transcription factors (proteins that affect DNA transcription) that alter the expression of other genes in the genome. Certain Immediate Early Genes are transcribed in response to synaptic activity (Link et al. 1995; Steward and Worley 2002); that is, they are expressed in response to experience. The expression of these genes affects the characteristics of synaptic connections (Baudry 1998: 116; Lanahan and Worley, 1998; Steward and Worley 2002: 509). Thus, the regulation of gene expression in response to environmental stimulus is a key component in synaptic modification (Arbib 1995: 46), resulting in learning in general and language development in particular.

5.3. Connectionism and biology: Epigenetics

There is a clear link between the processes described above and the sort of epigenetic processes coming to the forefront of biology. All of these processes involve environmental stimuli affecting the expression of gene activity without altering DNA sequence. We are not aware of whether any of the gene expression patterns stimulated by synaptic activity are heritable in any way, so we are hesitant to define such processes as epigenetic, given the more specific definition. Nonetheless, connectionist research is already utilizing relatively concrete descriptions of how gene expression leads to learning without altering DNA: neural activity causes transcription of the Immediate Early Genes that regulate gene expression, leading to synaptic modifications.

The Minimalist Program, on the other hand, does not have an even moderately concrete description of how gene expression leads to learning. Since the modulation of gene-expression is crucial to epigenetics, the closest the Minimalist Program comes to epigenetics is the sort of loose association Lorenzo and Longa (2003) describe. There is clearly a much smaller gap between epigenetics and connectionism than there is between epigenetics and the Minimalist Program. Thus, connectionist linguistics is much closer to an epigenetic account of linguistic development than is the Minimalist Program.

6. THE QUESTION OF "LEVELS OF DESCRIPTION"

Despite the clear advantage connectionists have over minimalists in linking their research programs to epigenetics, many readers will likely be suspicious of the argument we have presented so far. Indeed, to many generative linguists our position will appear procrustean, resting on the tired argument that theories must be neurologically reducible. The instinctive reaction these linguists have is to point out that different "levels of description" need not provide explanatory adequacy in the same way. For example, ecologists need not couch their theory in terms of chemistry; a theory of why a particular rodent population is exploding would not be expected to account for the chemical mechanisms in the brains of the rodents that lead to their reproducing. Likewise, a theory of how grammar develops need not account for the explicit neuronal, genetic, and epigenetic mechanisms of language acquisition. The "high-level" description linguists generally use will often not mesh with low level accounts of language development. Thus, a linguist's theories need not account for epigenetics to have explanatory adequacy. We could not agree more.

Linguists do not need to account for neuronal, genetic or epigenetic mechanisms. Indeed, we would be more than happy to see linguists abandon biology and focus on grammar if that is the direction they wish to take. In that case, the Minimalist Program may be their paradigm of choice.

The issue here is not that linguists *must* link their work to biology, and in turn epigenetics. The issue is that many linguists try to dress their work in the costume of biology without actually providing any real substance to their arguments. This is exactly what Lorenzo and Longa (2003) and many others, including Chomsky, Pinker, and Jenkins, have been guilty of. The reason we have gone to such pains to show how much closer connectionism is to epigenetics is because we find the argument that there is anything biological about generative linguistics absurd. We wanted to contrast Minimalism to connectionism to illustrate this. What we have attempted to engender in the reader is a critical eye for the claims from generativists such as Lorenzo and Longa that generative linguistics has anything to do with biology or epigenetics.

We hope that the reader sees in the specific case of Lorenzo and Longa that these authors failed to link minimalism to epigenetics via anything but superficial analogies, analogies which displayed a lack of understanding of current research in biology. We have done this in two ways: (1) briefly educating the reader on the actual state of epigenetics in biology as contrasted with Lorenzo and Longa's (2003) representation of it; (2) showing that non-superficial links are possible, and that connectionists are engaged in just such a research program. We hope that the reader now understands that linguists who wish to link language to biology would be foolish if they were to adopt the Minimalist Program over connectionism. We are asserting nothing more, and nothing less. If linguists are unconcerned with biology then different considerations are in order, and our arguments do not apply. Such linguists can continue to use Minimalism without fear of accusations from troublemakers like us, badgering them with reductionist arguments that they haven't linked their work to neurons, IEGs or epigenetics. It is only generative linguists in biologist's clothing whom we have targeted, and who we believe should adopt connectionism or cease in confusing their rhetoric with misguided attempts to claim a link to biology.

7. CONCLUSION

When scientists are presented with two research paradigms, there are many factors involved in their choice as to which to adopt. In our comparison of the Minimalist Program and connectionism, we have discussed one such factor, the relation to epigenetics. There are many other factors that should influence a linguist's choice, though. If connectionism were severely disadvantaged in some other area, it would be foolish to adopt it. However, this is not the case. Connectionist systems can implement the same symbolic operations linguists utilize. This can be done through development of specialized symbol processing networks (see Hinton et al. 1992) or it can be done through high-level modeling using general purpose relational network mechanisms (see Lamb 1998, Reich 1969, Reich and Richards 2004). Therefore, adopting connectionism does not leave a linguist disadvantaged in some ways; it merely provides other advantages that purely symbolic systems do not: mathematical rigour and the ability to induce regular patterns from quasi-regular input (Bates and Elman 1996).

The conclusion is clear: when the goal is unification with biology, connectionism is superior to the Minimalist Program. Chomsky (1978, 1986, 1995b) and others (e.g. Jenkins 2000) are correct in rejecting criticism of generative systems based solely on the lack of concrete unification between generative models and biology. However, it certainly is appropriate to choose one paradigm over another if one is closer to unification. Biology has recently moved away from gene-centrism and drawn more focus to epigenetics. Likewise, connectionist theories focus on processes that affect gene expression without altering DNA. We believe that unification between connectionist accounts of language acquisition and epigenetics is within reach, and may come to fruition within the next decade or two. In comparison, the closest the Minimalist Program has come to unification between its account of language acquisition and epigenetics is the rather underdeveloped arguments of Lorenzo and Longa (2003). If linguists attempt to link their theories to biology but do not adopt the connectionist paradigm, then in the near future they may find themselves unable to compete with other researchers who have, and whose theories possess *biological* explanatory adequacy. If Chomsky is correct that linguistics is a branch of biology, then connectionist linguistics is the appropriate direction for the future.

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