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EDITORIAL

Invited Address: "The Times They Are A-Changin'" Gene Expression, Neuroplasticity, and Developmental Research

Ronald L. Simons · Eric T. Klopack

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Abstract For good reason, social scientists have a long history of being suspicious of biological explanations of human behavior. Importantly, however, recent paradigmatic shifts in the life sciences have largely obviated these longstanding concerns. We highlight the changes that have occurred in genetics with its movement away from genetic determinism to an emphasis on epigenetics and in neuroscience with its switch from a fixed to a neuroplastic view of the brain. We describe these new developments noting the way they recognize, indeed place a premium upon, the role of the environment. The remainder of the paper focuses upon the challenges and opportunities for social scientists, especially those involved in developmental work, proffered by these paradigmatic shifts. The evidence clearly shows that nature and nurture are inextricably interlinked. Importantly, however, it also indicates that they are connected in a manner that honors the priority that the social sciences place upon the environment. We contend that incorporating biological processes into our developmental work will sharpen our theories and enhance their significance. We argue that such biologically integrated models will provide a clearer and more comprehensive understanding of how nurture influences behavior across the life course.

Keywords Social brain · Epigenetics · Social turn in the life-sciences · Postgenomics · Placticity · Neurosociology · Life and social sciences

R. L. Simons · E. T. Klopack (✉)
Department of Sociology, University of Georgia, Athens, GA 30602, USA
e-mail: etklopack@uga.edu

R. L. Simons
e-mail: rsimons@uga.edu

Introduction

Several decades ago, Thomas Kuhn (1962) first articulated the now widely accepted idea that scientific disciplines are based on paradigms that entail assumptions regarding the nature of some class of empirical phenomena and the types of explanations required to elucidate it. According to Kuhn, normal science involves conducting research on the important questions raised by a field's paradigm and its theoretical derivatives. Although the social sciences encompass a wide variety of disciplines and subfields, they all tend to share a general paradigm sometimes labeled the standard social scientific model (e.g. Pinker 2002; Tooby and Cosmides 1992). This paradigm views human behavior as a product of socialization and culture, with biology exerting little influence. Indeed, social scientists have a long history of being suspicious of biological explanations of human behavior, and we often view ourselves as in a battle with those who would impose an unproven and socially dangerous biological determinism (Nature 2012). These fears have some basis in reality given the many examples of human abuses perpetrated in the last century based, at least in part, on flawed scientific research linking biology to various deviant behaviors (Rafter 2008). Importantly, however, recent paradigmatic shifts in the life sciences largely obviate these longstanding concerns.

In his discussion of scientific progress, Kuhn (1962) noted that research sometimes generates "anomalies" that challenge a field's existing paradigm. As these anomalies continue to accrue, a scientific revolution takes place, with the result being a new paradigm that provides a fundamentally different view of the field. This new vision rests on an alternative set of assumptions, points to new types of theories, and suggests a fresh set of problems to be investigated. Many would argue that this is what has occurred in two

branches of the life sciences: genetics with its movement away from genetic determinism to an emphasis on epigenetics and neuroscience with its movement from a fixed to a neuroplastic view of the brain. Importantly, these new paradigms recognize, indeed they place a premium upon, the role of the environment. Hence, these new developments provide a unique opportunity for rapprochement and fruitful collaboration between the life and social sciences.

We develop this argument by briefly describing the paradigmatic shifts that have taken place in genetics and neuroscience. For each of these fields, we begin by describing the old paradigm, turn to consideration of the anomalies that challenged its legitimacy, and then present the alternative, environmentally friendly paradigm that has emerged during the new millennium. The remainder of the paper focuses upon the challenges and opportunities for social scientists, especially those involved in developmental work, proffered by these paradigmatic shifts. Indeed, we will argue that coming to grips with these changes in the life sciences has the potential to foment a paradigmatic shift in the social sciences.

The Epigenetic Revolution in Genetics

The Old Gene-Centric Model

In the early 1950s, Watson and Crick (1953) discovered that genes are composed of sequences of 4 nucleotide bases and that these DNA strands represent a code for forming the body's protein molecules. Their discovery ushered in the paradigm of genetic determinism: the belief that genes control all of our traits—physical, behavioral, and emotional. Genes produce RNA which controls the production of proteins which control the functioning of cells and ultimately behavior. This idea became the dominant dogma of molecular biology, and it gave rise to much hyperbole over the decades regarding the power of genes (i.e., the gene-centric main effects model). This hyperbolic presentation was supported by behavioral genetic studies suggesting that virtually every aspect of human behavior, from disease to political ideology, was determined in large measure by a person's genes. All that was left to be done was to sequence the human genome. This would enable scientists to identify the specific genes that make people vulnerable to physical and emotional illnesses, learning difficulties, obesity, aggression, and all sorts of other undesirable traits and behaviors.

Anomalies that Challenged the Gene-Centric Model

The Human Genome Project (HGP) was launched in 1990 by the National Institutes of Health. The goal was to identify the basis of human traits, both positive and negative, and to foster development of new medical applications around the world. Based upon the assumption that genes control an organism's traits, researchers expected to find a strong correlation between the complexity of an organism and the number of genes that it possesses. With over 100,000 proteins in the human body, and with a blueprint needed to make each protein, the assumption was that the human genome consisted of at least 100,000 genes. Surprisingly, however, shortly after the turn of the century the HGP reported that humans, with over 50,000 trillion cells, have only about 23,000 genes (Venter et al. 2001; Claverie 2001), just slightly more than the barely visible roundworm. Further, recent research has revised the number of proteins utilized by the human body from 100,000 to upwards of 2 million. Clearly, the one gene-one protein assumption is incorrect (Silverman 2004). Most genes appear to be capable of producing a multitude of protein products.

Another major challenge to the gene-centric paradigm involved the "missing genes problem." Sequencing of the human genome was completed in 2002 and scientists immediately began to do Genome-Wide Association Studies (GWAS) to identify the genes associated with various diseases and disorders. Well over a decade of such research has failed to find significant associations between specific genetic variants and virtually any human traits, illnesses, or behaviors. This failure has raised serious doubts about the validity of behavioral genetics studies reporting strong heritability for most phenotypes. It appears that the high heritabilities found in these studies were due in large measure to methodological deficiencies associated with the twin study method and to a faulty conceptual model that incorrectly assumed that genes exert main effects that are independent of the effects of the environment (Burt and Simons 2014; Charney 2012)

Finally, contrary to the gene-centric model, evidence suggests that only about 2 % of the human genome codes for proteins (Carey 2012), while most of the remaining non-protein coding DNA (what used to be considered junk DNA) is involved in regulatory processes that determine which protein coding segments of a gene will be expressed and the types of proteins that will be produced (Meloni 2014; Pennisi 2012). Such findings have fostered a paradigmatic shift that places less emphasis upon inherited DNA differences between people and more importance upon identifying the epigenetic factors that control or regulate DNA expression.

The New Epigenetic Model

The new genetic paradigm views genes as a combination of DNA segments that together constitute an expressible unit. Through complex promoters and alternative splicing, the various DNA segments that comprise any particular gene

can contribute to the production of a variety of RNA sequences and proteins (Portin 1993). And what determines how a gene expresses itself? As biologist H. Frederick Nijhout (1990) has noted, a gene cannot turn itself on or off. Rather, "when a gene product is needed, a signal from its environment, not an emergent property of the gene itself, activates expression" (Nijhout 1990, p. 443). In other words, the environment controls gene expression (Powell 2005). The environment includes the external world in which the organism is located or develops, as well as its biochemical internal world of hormones, metabolism, and the like. In contrast to the old view of the deterministic gene, the new paradigm places the environment center stage. Environmental circumstances foster gene expression which, through several additional mechanisms, results in behavior.

Although most gene regulation is a response to the immediate demands of the environment, in recent years researchers have devoted much attention to a type of gene regulation that takes place over much longer intervals (Frances 2011; Carey 2012). *Epigenetics* focuses on changes in gene expression that last for months, years, or even a lifetime (Frances 2011; Carey 2012). Epigenetic regulation entails biochemical mechanisms that influence the genome to express (up regulate or down regulate) particular genes. Genes are regulated through epigenetic mechanisms such as methylation, which inhibits gene expression, and acetylation, which encourages gene expression (Frances 2011; Carey 2012). While epigenetic processes such as methylation and acetylation are responsive to developmental and physiological cues, they are also influenced by environmental conditions. Importantly for our purposes, there is rapidly accumulating evidence regarding the role of epigenetic factors in neural development. Studies have shown, for example, that epigenetic modification (e.g., methylation) of particular genes influences perception, emotion, memory, cognition, learning, and neural plasticity (Kandel 2006; Molfese 2011).

From an evolutionary perspective, epigenetic changes appear to be a fundamental process whereby a fixed genome (inherited DNA) can respond to changing environmental challenges and circumstances (Landecker and Panofsky 2013; Meaney and Szyf 2005; Meloni 2014). Epigenetic factors appear to be an important mechanism whereby life experiences become biologically embedded and provide the physiological underpinning for cognitive, emotional, and behavioral traits tailored for adaptation to environmental demands. As the editors of *Nature* recently noted:

> "It has now been proven beyond doubt that although our genes are fixed, their expression is highly dependent on what our environment throws at us. The current challenge is to work out precisely how environment affects our biological tissues and changes us." (Nature 2012, p. 143).

In short, the old gene-centric paradigm has been debunked and replaced by a new developmental model that recognizes the permeability and malleability of the genetic in response to environmental influences. This new paradigm conceptualizes and studies genes as part of a broader cellular environment that is responsive to environmental input (Meloni 2014).

The Neuroplastic Revolution in Neuroscience

The Old View of the Brain

Prior to the new century, conventional wisdom in neuroscience held that the adult mammalian brain is fixed in two respects: no new neurons are created (as neurons die there is no replacement), and the fundamental structure of an individual's brain is dictated by genes and largely immutable (Begley 2007). This fixed perspective viewed the brain as a complex machine (Doidge 2007). It consisted of a set of parts, each with a particular function. If a part was damaged or worn out, nothing could be done to replace it. An important component of the brain was its many neural pathways. Evidence suggested that it was these pathways that enabled the various bodily functions such as cognition, memory, sensory awareness, and muscle movement (Penfield and Rasmussen 1950). Importantly, these pathways were assumed to be fixed, universal, and immutable (Kandel 2006; Sanes and Donoghue 2000). Recent research has shown that, in large measure, these assumptions are incorrect (Adolphs 2010). There is strong evidence that the size and shape of the various neural pathways in our brain change depending upon what we do over the course of our lives (Davidson and McEwen 2012).

Anomalies that Challenged the Old View of the Brain

First of all, research has established that the assumption that no new neurons are produced following birth is incorrect. Evidence suggests that neurogenesis—the manufacture of new neurons within the brain—takes place well into old age, particularly in areas such as the hippocampus (Cameron and Gould 1996; Kempermann 2011). Second, the assumption that when a particular part of the brain is injured or worn out it cannot be replaced is contradicted by studies showing that individuals often regain a function following brain injury (e.g., stroke) because another portion of the brain is appropriated as a substitute for the injured area (Taub et al. 2006). In such cases, the brain

recruits nearby healthy neurons to perform the function of the damaged ones. Such findings are clearly contrary to the assumption that the brain is a prewired machine where each part serves a particular function. Finally, and this is the finding most relevant for social scientists, there is now strong evidence that environmental influences can change the network of neuropathways within a person's brain (Davidson and McEwen 2012).

Several studies have reported evidence of such neuroplasticity among children. MRI and fMRI studies have indicated, for example, that exposure to harsh and unpredictable childhood conditions (e.g., parental neglect) is associated with greater volume and reactivity of the amygdala, a portion of the brain that is responsible for vigilance and emotional responsiveness to threat (e.g., Mehta et al. 2009), and alteration of the prefrontal cortex, the area responsible for executive control (Hanson et al. 2010; Wilson et al. 2011). Other studies have reported that among adopted children, those adopted later have larger amygdala volume than those adopted earlier (Tottenham et al. 2010), and that children continuously exposed to maternal depression show larger amygdala volume than those without such exposure (Lupien et al. 2011). Importantly, the amygdala and prefrontal cortex, as well as their interconnection, are implicated in emotional regulation (e.g., Wager et al. 2008), impulsivity (e.g., Kim and Lee 2011; Raine 2002), reactive aggression (Crowe and Blair 2008), and internalizing problems (Tottenham et al. 2010).

Moreover, in addition to these findings regarding childhood, there is also strong evidence that neuroplasticity continues throughout adulthood (Bloss et al. 2010; Davidson and McEwen 2012). A recent study by Mackey et al. (2013), for example, revealed that young adults enrolled in a Law School Admissions Test (LSAT) course showed strengthening in networks of the brain implicated in high-level reasoning. Such work challenges the view that intelligence is a set of innate, immutable abilities. Other studies have reported the growth of areas in the brain associated with context and space among taxicab drivers (Maguire et al. 2006) and of areas associated with finger movements in virtuoso violinists (Elbert et al. 1995). Indeed, simply repeatedly imagining oneself playing a simple five-note sequence on the piano has been shown to increase the space in the motor cortex devoted to the fingers (Pascual-Leone et al. 2005).

Further, while hundreds of studies have shown that cognitive behavior therapy (CBT) can effectively change the thought processes and behaviors of adults with various types of psychopathology (Hofmann et al. 2012), there is strong evidence to suggest that these cognitive and behavioral changes are associated with neurological changes when assessed with MRI and fMRI (Kandel 2006; Jokić-Begić 2010; Schwartz and Begley 2002; Goldapple et al. 2004). Similarly, experiments have shown both mindfulness and compassion-focused meditation to be effective in reducing anxiety, depression, and anger while enhancing emotion regulation, empathy, and psychological well-being (e.g., Eberth and Sedlmeier 2012; Hofmann et al. 2011). These changes have been linked to changes in gene expression (e.g., Kaliman et al. 2014; Sharma et al. 2008) and in brain function and structure (Hofmann et al. 2011; Hölzel et al. 2011).

Thus there is a wealth of data indicating that the old view of the brain is incorrect. The brain appears to adapt to everyday circumstances and challenges. This plasticity is most apparent in childhood, but continues to a lesser degree throughout life.

The Neuroplasticity Paradigm

The core feature of the newly emergent neuroplastic paradigm is the recognition that repeated experiences, activities, and thoughts alter gene expression and, in turn, the wiring or structure of our brain (Adolphs 2010; Davidson and McEwen 2012). This process involves growth in cortical (brain) space devoted to processes and functions that are used more frequently and a corresponding decrease in cortical space devoted to rarely performed processes. This is a result of the competitive process constantly at work in the brain whereby frequently used networks are strengthened while those that are rarely utilized are gradually lost (Merzenich 2001). As a consequence, the thickness, space, and extensiveness of the various pathways that comprise a particular person's brain are determined by the demands of his or her everyday environment. Thus, "the very structure of our brain—the relative size of different regions, the strength of connections between one area and another—reflects the lives we have led" (Begley 2007, p. 8–9).

Implications for the Social Sciences

Although the social sciences have tended to see nature and nurture as two competing explanations for human behavior, the recent paradigmatic changes in the life sciences just described indicate that this is a false dichotomy. Indeed these new plasticity paradigms identify various avenues whereby environment influences, including social factors, become biologically embedded. Through processes like epigenetically induced changes in gene expression, biological systems such as the sympathetic nervous system (SNS) and hypothalamic–pituitary–adrenal (HPA) axis are calibrated and the brain sculpted in a manner that prepares the individual to function and survive given existing environmental conditions. These biological systems, in turn, influence the way that an individual responds to

subsequent situations and events. Importantly, however, new environments and experiences can change gene expression and alter biological systems. In other words, systems can be *re*calibrated and the brain can be *re*sculpted to facilitate adaptation to subsequent changes in the environment.

This new plastic view of human biology vindicates social scientific claims regarding the importance of the social environment in explaining human health and behavior and provides a basis for rapprochement between the social and life sciences. As the editors of *Nature* recently noted:

> Now is a perfect time for reconciliation of the two cultures…Sociologists have been studying human environments for decades…Biologists are now in a position to benefit from their insights, although they will need to learn the language of sociology. And sociologists stand to benefit from the understanding that biology will bring to their own, vindicated, empirical research. (2012, p. 143)

Both camps stand to benefit from entente and increased collaboration. It is an opportunity for the life sciences to better identify the manner in which the environment influences biological processes and an occasion for the social sciences to enhance the comprehensiveness and precision of their theories by making them more biologically integrated.

Collaboration between the life and social sciences is already well underway in the area of medical research. For the past few years, the National Institutes of Health have promoted interdisciplinary work on issues related to physical and mental illness. As a consequence, interdisciplinary teams consisting of physicians, geneticists, psychologists, and sociologists are examining issues such as the manner in which stress across the life course influences gene expression, inflammation, metabolic dysregulation, biological aging, and health. Such work is rooted in a new biopsychosocial perspective that emphasizes the interpenetration of environmental, psychological, and biological processes. Using this paradigm, old disciplinary boundaries blur and begin to lose their meaning. There is, of course, a division of labor among the team members; indeed, that is the purpose of bringing together such a mix of scientists. At the same time, however, the team members must learn something about the corpus of knowledge associated with each other's fields. The psychologist and sociologist must learn the basics of genetics and human biology, and the physician and geneticist must master rudimentary information regarding human development, families, and communities.

Social scientists are absolutely essential to such teams. Medical researchers, for example, are very interested in how environmental conditions influence biological processes such as gene expression and health, but they have only a crude understanding of how the environment should be conceptualized and measured. Thus, past medical research regarding the impact of stress on biomarkers of health has been largely limited to an examination of the consequences of SES. A comprehensive understanding of how various childhood and adult experiences, including social relationships, influence biology and health requires team members with training in the social sciences.

Participation on such a research team is both exciting and challenging. The biologically oriented scientists on our team are surprised at the theoretical and statistical complexity associated with investigating seemingly simple environmental effects such as the manner in which romantic partners influence each other's health, whereas the psychologists and sociologists on the team find it fascinating to venture into the world of gene regulation and biomarkers of health. The end result is group discussions where all of the parties are pushed to go beyond their comfort zone and to think about problems in more nuanced and comprehensive ways.

Although such interdisciplinary work will likely increase dramatically in the coming years, it is also the case that the social sciences are interested in much more than helping the life sciences identify and assess environmental factors that might influence health (Rose 2013). The various social scientific disciplines have their own topics and concerns. Importantly, there are many instances where the new biology might be utilized to elaborate and fine tune extant theoretical explanations (Landecker and Panofsky 2013). Much of social scientific research involves building models of the manner in which social experiences influence the way individuals think and act. These models might be expanded to include epigenetic and neurological changes as well as other potentially mediating and moderating biological processes.

There is strong evidence indicating, for example, that childhood adversity fosters an insecure, distrusting attachment schema (Bowlby 1973; Mickelson et al. 1997). Further, past research has shown that the neuropeptide oxytocin shapes the neural circuitry of trust, empathy, and intimacy in human beings (Baumgartner et al. 2008). This suggests that that the oxytocin system may serve as a critical biological mechanism linking adversity to attachment style. Consistent with this idea, studies have linked childhood mistreatment to lower levels of oxytocin (Heim et al. 2009; Wismer Fries et al. 2005), and a recent study revealed that methylation (down regulation) of the oxytocin receptor gene mediates the effect of adult stress on changes in attachment style (Simons and Lei 2014). This pattern of results suggests that calibration of the oxytocin system serves to mediate the impact of childhood adversity

on attachment style but that recalibration of this system can take place in adulthood. Such findings not only identify the biological underpinnings for distrusting attitudes and behaviors, they also make the theoretical argument linking adversity to attachment style more complete, precise, and compelling.

In our view, this line of research provides an exemplar for how the new biology might be used to expand our understanding of the link between a wide variety of social experiences and human cognition and behavior. For instance, findings from our project indicate that factors such as exposure to discrimination (Burt et al. 2012; Simons et al. 2006), family adversity (Simons et al. 2011), neighborhood violence (Stewart and Simons 2010), and incarceration (Mears et al. 2013) are associated with increases in anger, distrust, and aggression. In the coming months, we hope to obtain better insight into these relations by identifying epigenetic changes that are associated with these cognitive, emotional, and behavioral changes. Our goal is to identify how environmental events shape biological processes that serve as the underpinning for cognitive and behavioral tendencies. The fact that attitudes and behaviors become biologically embedded explains why they are often so difficult to change, especially during adulthood. However, the new plastic view of genes and the brain suggests that some degree of change can and does take place throughout life. Hopefully, in the coming years, social science research will make important contributions to our understanding of the degree of plasticity associated with various periods of the life course.

Conclusion

For a variety of reasons, the social sciences have a long history of opposition to biological explanations of human behavior. In recent years, however, the life sciences have moved away from the biological determinism that the social sciences found so objectionable. The new paradigms in genetics and neuroscience recognize the importance of the environment in regulating gene function and sculpting the brain. Given this new perspective, the old nature versus nurture argument no longer has any meaning; rather, the new view is nature and nurture. We have argued that this rapprochement between the life and social sciences presents opportunities for enhancing the power and comprehensiveness of our theories by making them more biologically integrated. Although we have emphasized paradigmatic changes regarding the environmental and biological plasticity, it is certainly the case that the social sciences can benefit from other developments in the life sciences as well. The discovery of mirror neurons, for example, aids our theorizing about concepts such as theory of mind and taking the role of the other (Franks 2013), and findings suggesting an innate concern with fairness and reciprocity provide us with a clearer understanding of human nature (Pfaff 2007; Pinker 2002).

The bottom line is that a multitude of discoveries and theoretical developments in the life sciences require a paradigmatic revolution in the social sciences. The standard social science model is no longer tenable. The evidence clearly shows that both nature and nurture are necessary to explain human behavior. This new reality should not be seen as in any way challenging the legitimacy or the raison d'etre of the social scientific enterprise. The evidence not only suggests that the two fields are inextricably interlinked, but, importantly, it indicates that they are connected in a manner that honors the priority that the social sciences place upon the environment. Accepting this fact and incorporating biological processes into our work will sharpen our theories and enhance their significance. On the other hand, waging war with a superannuated biological determinism is like tilting at windmills. It makes us look foolish and irrelevant.

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Ronald L. Simons is a distinguished research professor in the Department of Sociology and a fellow in the Institute for Behavior Research at the University of Georgia. His research has examined the developmental roots of externalizing/internalizing problems as well as the extent to which adult transitions involving romantic relationships, employment, and incarceration influence desistance/remission. Recently, his research program has expanded to include tests of various biosocial models of mental and physical health. His work has appeared in journals such as the *American Sociological Review*, *Criminology*, *Developmental Psychology*, and *Social Problems*.

Eric T. Klopack is a doctoral student in the Department of Sociology at the University of Georgia. His major research interests include biosocial and neurosocial perspectives on deviance and antisocial behavior.