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USING A LIFE HISTORY FRAMEWORK TO UNDERSTAND THE RELATIONSHIP BETWEEN NEIGHBORHOOD STRUCTURAL DETERIORATION AND ADVERSE BIRTH OUTCOMES

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Abstract
Life History Theory is a powerful framework for understanding how evolved functional adaptations to environmental conditions influence variation in significant life outcomes. Features indicating relatively high extrinsic mortality rates and unpredictability of future outcomes are associated with relatively faster life history strategies. Regulatory mechanisms that facilitated reproductive success in ancestral environments may contribute to adverse birth outcomes in modern technologically advanced populations. Adverse local environmental conditions may reduce maternal somatic investment in gestating offspring, consistent with long-term maternal interests. In this study, we demonstrated a relationship between neighborhood structural deterioration and adverse birth outcomes in Flint, Michigan, USA. We used Geographical Information Systems software to calculate the density of highly dilapidated structures, premature births, and low birth weight births in .25 mi^2 areas. Controlling for parental education and type of health coverage, the degree of structural deterioration was associated with the concentration of premature births and low birth weight births.

Keywords: Life History Theory, birth outcomes, built environment, health disparities

Introduction

We propose that Life History Theory (LHT) is a potent organizing framework for integrating "siloed" disciplinary knowledge across biological, psychological, and social-

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ecological levels. Disciplinary and methodological fragmentations impede the progress of health science (Kruger, 2008a). In this paper, we provide an initial example of how LHT can serve as the organizing conceptualization for perinatal research examining influences on adverse birth outcomes beyond traditionally assessed risk factors.

It is imperative to address the problems of adverse perinatal outcomes, including racial disparities associated with infant mortality. Adverse birth outcomes and demographic disparities persist despite decades of clinical, scientific, and legislative efforts (Hunte, Turner, Pollack, & Lewis, 2004). Preterm birth is the leading cause of health problems in infants and leads to costs of more than $26 billion annually in the USA (Center for Healthcare Research and Transformation, 2010). Even babies born “late” preterm have greater risk of clinically significant impairments after controlling for many potential prenatal and childhood confounding factors (Talge, Holzman, Wang, Lucia, Gardiner, & Breslau, 2010).

Human Pregnancy as Understood in a Life History Framework

Life History Theory (LHT) models life cycles and life history traits in an ecological context (Chisholm, 1999), integrating evolutionary, ecological, and socio-developmental perspectives (Geary, 2002). A species’ life history is its evolved trajectory of birth, growth, development, reproduction, and senescence. These aspects of the human phenotype are a product of a complex interaction between our genetic heritage, which has been shaped selection pressures across many generations, and the environmental conditions in which individuals develop. LHT illustrates how organisms must make trade-offs in the allocation of resources to these various aspects of life, and how these allocations are shaped by environmental conditions (Roff, 1992; Stearns, 1992). Energy used for one purpose cannot be used for another, and the most consequential trade-offs are those between survival and reproduction, between current and future offspring, and between size and number of offspring (Hill, 1993).

From an evolutionary perspective, offspring are crucial as they represent the continuity of a lineage and thus mothers invest greatly in a pregnancy that is highly costly physiologically. Birth outcomes such as size at birth and number of offspring reflect variations in life history. Human birth weight is between 25 and 40% heritable (Baird et al., 2001; Clausson et al., 2000; Magnus et al., 2001; Penrose, 1954), thus environmental factors determine the majority of the variation. Known individual level influences on birth weight include maternal nutritional status, weight gain, smoking status, and morbidity (Kramer, 1987). Although pregnancy is usually conceptualized as an entirely cooperative interaction between a mother and her fetus (Haig, 1993), LHT predicts that maternal somatic investment in gestating offspring will be contingent on local environmental conditions reflecting the offspring’s prospects for survival.

The differential contribution of genes into future generations drives evolution, both through the direct reproductive success of individuals and through the offspring of close relatives who share higher proportions of genes (e.g., inclusive fitness, Hamilton, 1964). Maternal reproductive success is a function of the number of offspring and the fitness of each offspring and an optimal balance between these components promotes maternal interests (Haig, 1993). Mothers are equally related to each of their children, whereas each child is more closely related to itself than to its siblings (Trivers, 1974). Mothers would maximize their inclusive fitness by investing more equally in each of their offspring, whereas offspring would maximize their inclusive fitness by skewing maternal investment in greater proportions towards themselves (Trivers, 1974). Both fetal and maternal interests are aggressively pursued by hormonal regulation (Haig, 1993). Mothers manipulate offspring size, body composition, and metabolism based on a selective investment of energy stores (Laskey & Prentice, 1997). Maternal interests are maximized if each offspring receives less investment than would be optimal for its own fitness (Trivers, 1974). Thus, human population's average birth weights are lower than the optimal perinatal survival weight (Karn & Penrose, 1952; Blurton Jones, 1978).

Mothers maximize their own fitness at the potential expense of each individual offspring (Smith & Fretwell, 1974). Thus, eventual gestational age and birth weight will be a compromise between maternal and fetal strategies. In good-quality environments, mothers have more resources to invest and offspring fitness tends towards the theoretical optimum. In adverse environments maternal and offspring's interests will have greater divergence (Wells, 2003) and investment in maternal survival will be favored at the expense of investment in offspring (Hirschfield & Tinkle, 1975). In marginal environments, reduced somatic investment will lead to low birth weight infants, reducing maternal demands and preserving resources for future offspring (Haig, 1993). In the most severe environments, maternal reproductive investment will be constricted through an inability to conceive (Frisch, 1987), miscarriage early in pregnancy (Wynn, 1987), or stillbirth (Stein, Susser, Saenger, & Marolla, 1975).

Several factors are related to the prospects of offspring survival and reproduction, including the availability of food and threats from predators. Juvenile mortality is thought to be a more powerful force on life history development than adult mortality (Promislow & Harvey, 1990). In fact, mathematical models suggest that human life history may be most strongly shaped by the survival probabilities of children ages 0 to 4 years (Jones, 2009). Anthropologists have successfully used life history models to understand reproductive outcomes in foraging populations. For example, Blurton Jones and Sibly (1978) found that the modal !Kung birth spacing interval had the most offspring surviving to age 10. Strassmann and Gillespie (2002) found that child mortality, rather than fertility, was the primary determinant of fitness in the Dogon. LHT can also provide a foundation for advancing the understanding of adverse birth outcomes in modern populations.

The Health Impact of the Built Environment

The physical deterioration of the human built environment is gaining recognition as an important influence on health (e.g., Augustin, Glass, James, & Schwartz, 2008). Since the 1920s, the ‘‘Chicago School’’ in Sociology emphasized the impact of neighborhood physical decay on mental health problems (Park & Burgess, 1925). Using systematic neighborhood observations on a standardized rating system and a telephone survey, Austin, Furr, and Spine (2002) found that housing quality affects satisfaction with the local physical environment, which predicts perceptions of neighborhood safety. This finding is consistent with "Disorder theory" (Wilson & Kelling, 1982), which proposes that physical disorder is a signal of the relative safety and social cohesion of a neighborhood.

Physical deterioration, social disorganization, and high crime rates are thought be by symptomatic of low neighborhood-level collective efficacy (Sampson & Raudenbush, 1999). Neighborhoods with high structural deterioration attract criminal behavior, because such disorder suggests that repercussions for unlawful behavior are unlikely

(Wilson & Kelling, 1982). Residents perceive lower neighborhood safety and social capital and have higher fear of crime in areas with greater concentrations of deteriorated structures (Kruger, Reischl, & Gee, 2007). Non-residents also infer lower neighborhood social quality and exhibit less trust of local adolescents in areas with greater physical disorder (O'Brien & Wilson, 2011).

Physical indicators of neighborhood decline are proposed to impact on health and mental health beyond the contribution of social factors (Wandersman & Nation, 1998). Physical neighborhood deterioration also affects mental health through its relationship to social conditions, such as social contact, social capital, and perceptions of local crime vulnerability (Kruger, Reischl, & Gee, 2007). Living in deteriorating neighborhoods may have both direct and indirect effects on the experience of stress (Gee & Payne-Sturges, 2004). An individual in a deteriorating neighborhood may directly experience the stress associated with living in a residence needing repairs, exposing the individual to extreme temperatures, damaged appliances and fixtures (e.g., lighting, plumbing), and to potentially dangerous conditions such as exposed nails or peeling paint. If an individual lives near deteriorating buildings, the indirect effects could include the strain of living in a neighborhood with declining home values, concerns with safety and crime associated with living near abandoned or damaged properties, and concerns with high resident turnover that often occurs in economically depressed neighborhoods. Baltimore residents living in neighborhoods in the highest quartile of a 20 item psychosocial hazards index had more than four times higher odds of a history of myocardial infarction and more than three times higher odds of stroke, transient ischemic attack, or intermittent claudication than residents of areas in the lowest quartile of psychosocial hazards (Augustin, Glass, James, & Schwartz, 2008).

Visible characteristics of neighborhoods, such as abandoned buildings, violent crime, and other signs of incivility, can lead to heightened states of vigilance, alarm, or threat (Ross & Mirowsky, 2001; O'Brien & Wilson, 2011). Such psychological triggers can activate a physiological stress response (McEwen, 2000; Taylor, Repetti, & Seeman, 1997), leading to dysregulation of the hypothalamic–pituitary–adrenal (HPA) axis as well as the autonomic nervous system (Skantze, Kaplan, Pettersson, Manuck, Blomqvist, Kyes, Williams, & Bondjers, 1998). Such dysregulation impacts health outcomes through deposition of abdominal fat (Moyer, Rodin, Grilo, Cummings, Larson, Rebuffe-Scrive, 1994; Jayo, Shively, Kaplan, Manuck, 1993), acute and chronic elevations in blood pressure (Kaplan, Pettersson, Manuck, Olsson, 1991), and elevated inflammatory response (Black & Garbutt, 2002).

A population based cohort study in Rotterdam, Netherlands found that women living in socioeconomically deprived neighborhoods have higher rates of adverse pregnancy outcomes, partially due to high concentrations of avoidable risk factors (Timmermans, et al., 2011). Women living in more disadvantaged neighborhoods had greater stress, less internal locus-of-control and emotional support, were more likely to smoke tobacco, drink alcohol, use hard drugs, and have an infection, inadequate prenatal care, and inadequate weight gain during pregnancy. Characteristics of the neighborhood built environment may influence birth outcomes through psychosocial and behavioral pathways. However, previous studies using limited assessments of physical environmental conditions have failed to find significant relationships between the built environment and adverse birth outcomes. For example, Schempf, Strobino, and O'Campo (2009) examined birth records and postpartum interviews from 726 women who delivered a live birth in Baltimore. Once the influence of socio-demographic characteristics and behavioral factors (tobacco smoking, other drug use, and delayed prenatal care) were accounted for, there were no residual neighborhood effects on birth weight. Neighborhood data included U.S. Census Tract level indicators of the violent crime rate, proportion Black, proportion of households in poverty, and proportion of boarded-up housing.

Hypothesis

Adverse birth outcomes may partially result from mechanisms evaluating environmental conditions and regulating investment trade-offs that facilitated reproductive success in ancestral environments. These mechanisms are a legacy from times when mortality rates were much higher; they may not promote reproductive success in modern environments and instead may lead to higher risks for infant mortality and deleterious influences on health status throughout life. Environmental conditions suggesting relatively high extrinsic mortality rates, relatively low paternal investment, and the unpredictability of future outcomes may be associated with relatively faster life history strategies. In ancestral times, reductions in somatic investment per offspring facilitated shorter inter-birth intervals and more numerous reproductions, increasing the chance that at least some offspring will survive and reproduce.

We believe that mechanisms assessing local environmental conditions and systematically regulating life history trade-offs are sensitive to neighborhood structural deterioration. As described above, conditions in the built environment are associated with perceptions of social conditions and behavioral interactions. Figueredo, et al. (2006) associate high levels of both kin and non-kin social support with slower human life histories, which would likely be associated with reduced adverse birth outcomes such as pre-maturity and low birth weight.

We predict that the proportional density of highly deteriorated neighborhood structures will predict the proportional density of premature and low birth weight births. Although adverse birth outcomes are associated with other socio-economic conditions, we may observe the predicted relationship independently from the influence of traditional socio-economic status indicators such as educational attainment. We link one of the most comprehensive assessments of the neighborhood built environment across an entire city with geographically identified birth records, newly available to the general public.

Methods

Study Site

We examined the relationship between the neighborhood built environment and birth outcomes in Flint, Michigan. Flint, the urban center of Genesee County, is an industrial city whose economy and population has expanded and declined during the 20th century with the manufacturing capacity of the city's largest employer, the General Motors Corporation (GM). In 1970, GM employed an estimated 82,000 workers at Flint area automotive plants. GM and affiliated industries employed less than 16,000 area workers in the timeframe represented by data in this study (Donnelly, 2002). As these manufacturing jobs left the area, so did a significant portion of Flint's population, declining 48% from 196,940 in 1970 to 102,434 in 2010 (U.S. Census Bureau, 2011).

Measures

Vacant and/or deteriorating structures are common in Flint, especially in areas near the former GM factories. Data on neighborhood physical conditions are from the Flint Environmental Block Assessment (EBA), conducted by researchers at the University of Michigan-Flint who assessed all of nearly 60,000 real estate parcels located within Flint in 2000. Urban Planning and Geographic Information Systems consultants from the University of Michigan's Ann Arbor campus and community advisors developed assessment tools for neighborhood structures. Trained field assessment workers rated each parcel on a scale from 0 to 25 based on the condition of the building foundation, exterior surfaces, stairs, rails, porches, roofs, gutters, downspouts, chimneys, windows, doors, and landscaping. Inter-rater reliabilities (Cronbach's alphas) for total scores were .70 for residential structures and .94 for commercial structures. Structures with scores from 5-9 were defined as being in "major disrepair" (1% of residential structures) and those scoring between 0-4 were defined as "not salvageable (0.2% of residential structures).

Analysis

We used Geographical Information Systems software (ArcGIS 9.2; Environmental Systems Research Institute) to calculate the density of residential structures that were in major disrepair or not salvageable and adverse birth outcomes. We standardized the geographic catchment area by dividing the geographic base map into equal .25 mile square areas with an overlay grid. The distance of .25 miles is a "rule of thumb" for examining effects of the built environment on individuals (Institute of Medicine Transportation Research Board, 2005) based on a Bayesian model of critical acceptable pedestrian walking distances (Seneviratne, 1985). The .25 mile heuristic is a sound operational definition for assessing the relationship between the physical condition of neighborhood residential structures and individual level social and health indicators (Kruger, 2008b; Kruger, Reischl, Gee, 2007).

We calculated kernel densities for each grid cell with ArcGIS 9.2 for the density of residential structures that were in major disrepair or not salvageable, premature (<37 weeks) and low birth weight (<2500g) singleton births for one year (See Figure 1) with the publicly available de-identified birth records provided by the Michigan Department of Public Health (MDCH). MDCH provided the geographical locations of mothers as latitude and longitude coordinates. We used the geographic grid cells as the unit of analysis. We examined the relationship between the density of deteriorated housing and birth indicators with partial correlations, controlling for maternal education, paternal education, and private insurance status - the socio-economic indicators available in public birth records (See Table 1). African Americans were overrepresented in areas with high structural deterioration and have lower birth weights than whites on average. To demonstrate that the hypothesized relationships were not an artifact of neighborhood racial composition, we replicated the analyses separately for African American and White births. We examined the relative importance of predictors of the density for adverse African American birth outcomes using forced-entry linear regressions (See Table 2).

Results

As predicted, we found that the geographic concentration of dilapidated residential structures was associated with greater concentrations of pre-mature and low birth weight births (See Table 1). Both pre-maturity and low birth weight were significantly related to the degree of structural deterioration for African American births, whereas only pre-maturity was significantly related for Whites. Structural deterioration had a stronger relationship to pre-maturity (z = 11.95) and low birth weight (z = 53.60) for African Americans than Whites (see Fisher, 1921).

The density of dilapidated structures was highly skewed and African American births were overrepresented in areas with high structural deterioration. Almost half (49%) of African American births were to mothers who resided in the top quartile for structural deterioration, compared to less than a quarter (22%) for White mothers. In fact, 20% of African American births were to mothers who resided in the top 5% for structural deterioration, compared to 6% for White mothers.

Table 1. Correlations Between Density of Structural Deterioration and Adverse Birth Outcomes by Race

Race	*Pre-maturity*	*Low birth weight*
All	.441**	.500**
African American	.354**	.336**
White	.228*	.026

Note: N = 169; units of analyses are .25 mile^2 areas; * indicates p < .01, ** indicates p < .001

As expected, several socio-economic indicators were significantly related to birth outcomes among African Americans. Average educational attainment by fathers was inversely related to prematurity, $r(164) = -.252$, $p < .001$, and low birth weight, $r(164) = -.221$, $p = .004$. Average educational attainment by mothers was inversely related to prematurity, $r(164) = -.148$, $p = .059$ (two-tailed). Higher levels of access to private insurance were associated with lower levels of prematurity, $r(164) = -.173$, $p = .027$.

Table 2. Results of Linear Regressions Predicting Adverse African American Birth Outcomes

Density of premature births					
Predictor	*B*	*SE*	*Beta*	*t*	*p*
Constant	77.06	6.61		11.65	.001
Structural deterioration	0.40	0.18	.189	2.26	.025
Fathers' education	-0.66	0.39	-.211	1.69	.092
Mother's education	0.03	0.20	.030	0.13	.895
Insurance access	-0.01	0.09	-.014	0.06	.950
Density of low birth weight births					
Predictor	*B*	*SE*	*Beta*	*t*	*p*
Constant	65.37	6.58		9.93	.001
Structural deterioration	0.52	0.17	.246	3.00	.003
Fathers' education	-0.74	0.39	-.233	1.92	.057
Mother's education	0.26	0.20	.297	1.34	.183
Insurance access	-0.01	0.09	-.187	0.86	.392

Note: N = 169; units of analyses are .25 mile^2 areas; values indicate results for two-tailed tests.

When socio-economic indicators were entered with structural deterioration into linear regressions predicting prematurity and low birth weight, only structural deterioration and fathers' educational attainment made significant unique predictions, with structural deterioration being the more powerful predictor (See Table 2). These predictors explained 10% of the variance in the concentration of premature African American births and 14% of the variance in the concentration of low birth weight African American births.

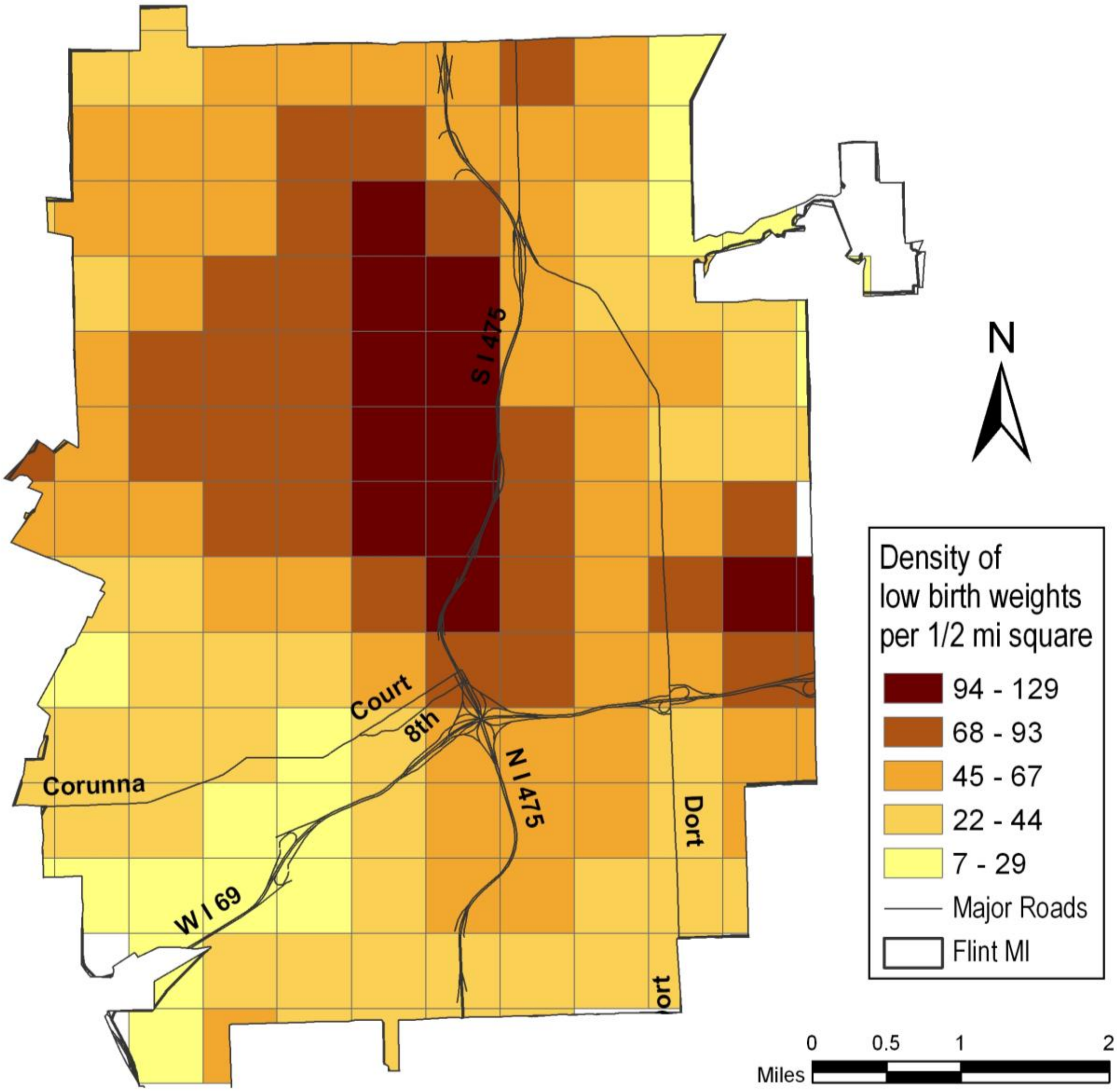

Figure 1. Density of births under 2500g controlling for parental education and insurance access.

Scatterplots (See Figures 2 and 3) suggest that the relationship of structural deterioration density to the densities of prematurity and low birth weight are non-linear. Transforming the variables into logarithmic scores increases the variances explained from 6.4% (prematurity) and 11.3% (low birth weight) to 10.1% (prematurity) and 30.0% (low birth weight). Note that there are a larger number of births on average in the points falling into the right tail of the distribution.

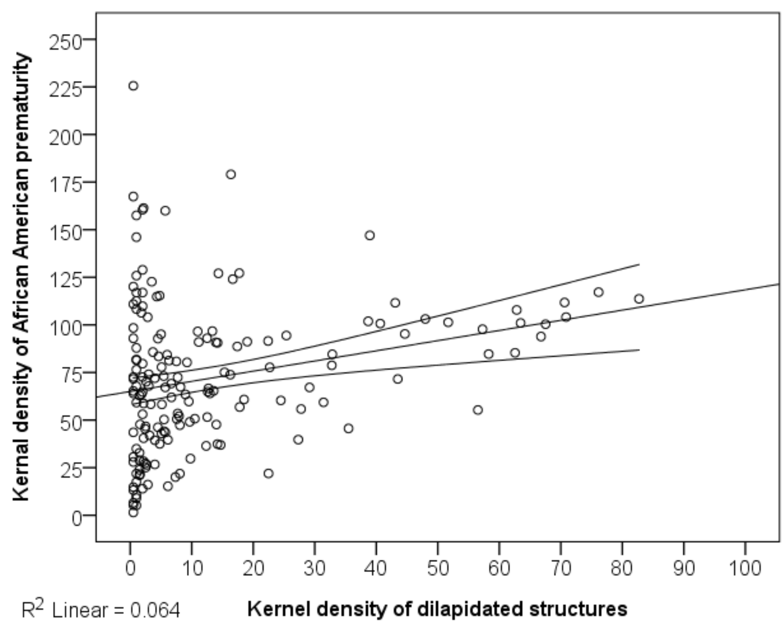

Figure 2. Density of African American prematurity by density of dilapidated structures.

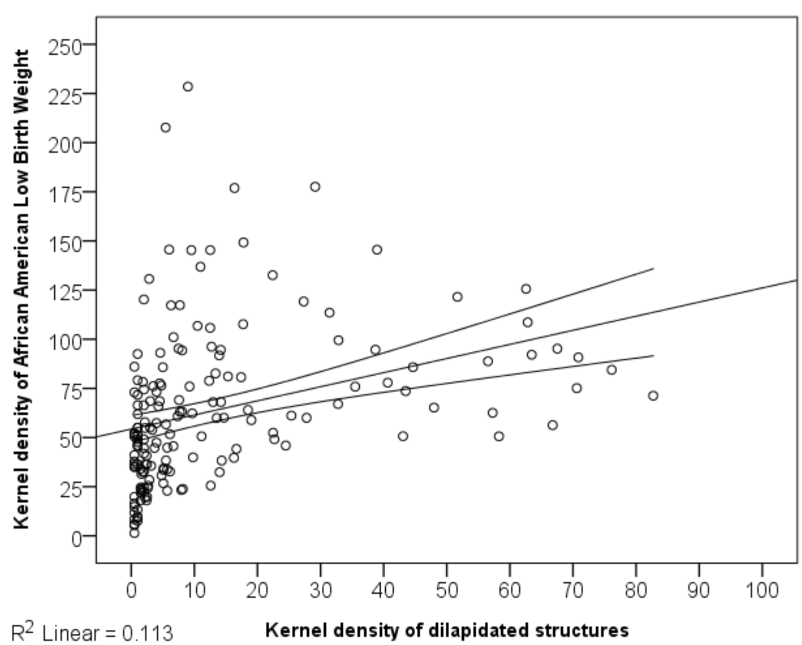

Figure 3. Density of African American low birth weight by density of dilapidated structures.

Discussion

Our findings suggest that adverse birth outcomes may partially result from mechanisms that facilitated reproductive success in ancestral environments by evaluating environmental conditions and regulating investment trade-offs. These mechanisms are a legacy from times when mortality rates throughout the lifespan were considerably higher, especially in infancy; they may not promote reproductive success in modern environments and instead may lead to adverse birth outcomes. These results also suggest the limitations of traditional interventions designed to promote healthy birth outcomes, as mechanisms regulating maternal investment contingent on environmental conditions may influence birth outcomes independently of other factors such as nutrition. Interventions promoting desirable birth outcomes may be more effective if they attend to relevant socio-ecological conditions.

Features indicating relatively high extrinsic mortality rates, relatively low paternal investment, and the unpredictability of future outcomes may be associated with relatively faster life history strategies, including shifts in investment related to the trade-off between offspring quantity and quality. Somatic investment per offspring may be reduced due to evolved mechanisms, facilitating shorter inter-birth intervals and more numerous reproductions in ancestral environments. These mechanisms are designed to increase the chance that at least some offspring will survive and reproduce.

The co-varying factors of prematurity and low birth weight are the primary cause of neonatal mortality in developed countries (MacDorman & Mathews, 2009). We demonstrate that the quality of the local built environment is related to gestational age and birth weight, controlling for individual level socio-economic status indicators. Neighborhood deterioration accounted for nearly a third of the variance in low birth weight among African Americans. Although neighborhood characteristics have previously been proposed to influence birth outcomes through psychosocial and behavioral pathways, empirical evidence of these relationships has been scarce, though previous studies utilized far less comprehensive assessments of the built environment (e.g., Schempf, Strobino, & O'Campo, 2009).

There is considerable variation in African American low birth weight and especially prematurity in areas with low structural deterioration in the built environment (see Figures 2 & 3). There are likely many different types of risk factors for adverse birth outcomes ranging across health related behaviors such as diet and tobacco smoking, access to health care services and facilities, lack of support from partners and/or kin, and socio-environmental conditions. The stress of racial discrimination may also contribute to adverse birth outcomes experienced by African American women (Carty, Kruger, Turner, Campbell, DeLoney, & Lewis, 2011).

Deterioration of the built environment is likely associated with other stressors, such as poverty, low social capital, and fear of crime (Kruger, Reischl, & Gee, 2007). Still, there is noticeable geographic variation in adverse birth outcomes across the northern end of Flint, which is more consistent demographically (see Figure 1). Neighborhood deterioration is highest in the areas close to former industrial sites, where many former factor workers lived. This raises the possibility of exposure to environmental toxins as an additional risk factor. However, living close to major industrial sites, even when active, is not always associated with adverse birth outcomes (Bhopal, Tate, Foy, Moffatt, & Phillimore, 1999).

Future studies will be necessary to examine the multiple levels of risk factors and complex causal pathways related to prematurity and low birth weight. This project incorporated a sophisticated assessment of the built environment; however the information on mothers and their infants is limited to the variables included in publically available birth records. Replications of this study in other communities with more comprehensive information will help clarify the interrelationships amongst predictive factors and demonstrate the generalizability of the phenomena.

The relationship between structural deterioration and adverse birth outcomes was stronger for African Americans than for Whites. This may be in part because the relationship between structural deterioration and adverse birth outcomes appears to be non-linear and a much greater proportion of African American births occurred in areas with the highest structural deterioration. Our model can be generalized to incorporate other socio-ecological factors that may partially underlie racial health disparities. This framework may also help explain puzzling results in previous studies. For example, in one low-income population, African American mothers had more infants born preterm, with growth restriction, and with low birth weight than did white women (Goldenberg, Cliver, Mulvihill, Hickey, Hoffman, Klerman, & Johnson, 1996). Maternal characteristics did not explain these disparities; in fact many of the risk factors for low birth weight were more common among White mothers than African American mothers (Goldenberg, et al., 1996).

Conclusion

This paper provides additional evidence for the power of evolutionary theory, and Life History Theory in particular, to promote an understanding of critical health issues in modern populations. Evolutionary theory is the most powerful explanatory system in the life sciences. Considerable advances have been made in the application of evolutionary biology to health issues in recent decades (see Nesse & Williams, 1995; Stearns & Koella, 2007; Trevathan, Smith, & McKenna, 2007). Health researchers and practitioners could benefit from an understanding of the basic principles of evolution and how humans have been shaped by natural and sexual selection, even if they are not explicitly testing evolutionary hypotheses.

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