CHAPTER 6

Not by Bread Alone

The Role of Psychosocial Stress in Age at First Reproduction and Health Inequalities

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Chisholm and Coall's description of their work on the effects of psychosocial stress on lowering the age of menarche is a further illustration of Kuzawa's model (see Chapter 18) of how powerful in utero nongenetic effects can be in sensitizing a fetus to the conditions of postnatal risk and uncertainty. Taken together these two (and other) chapters cause us to appreciate even more that the moment of birth is not quite the developmental starting point we once took it to be, but rather, represents a kind of "been there, done that," as least insofar as what a neonate needs to do in order to successfully navigate developmentally the quality of its social and physical conditions. The authors discuss phenotypic markers of mortality risk for fetuses and infants that are initiated by maternal neuroendocrine control systems, processed in the form of mother's subjective experiences and feelings (loss, fear, risk, anxiety), and set in motion a sequence of hypothalamic–pituitary–adrenal (HPA) responses that influence fetal and postnatal development. The types of changes to which the developing child is presensitized potentially facilitate earlier maturity, including age at first intercourse. The interrelationship that in utero events have on later attachment strategies of the neonate and infant reveal many more biosocial continuities between pre- and postnatal events than could have been proposed or imagined just 15 years ago.

> The political lesson of twentieth-century Darwinian thinking is, therefore, entirely different from that of nineteenth-century Social Darwinism.... A Darwinian left, understanding the prerequisites for mutual cooperation as well as its benefits, would strive to avoid economic conditions that create outcasts.
>
> Singer, 1999, p 53

> Medicine is a social science and politics is nothing but medicine on a grand scale.
>
> Virchow, 1848/1985, p 33

Due in large part to foundational work by Nesse and Williams (1995), Stearns (1999), and Trevathan, Smith, and McKenna (1999), it is becoming accepted that evolutionary theory is useful for understanding human health and disease. In this chapter we build on these foundations by using one of the most dynamic branches of evolutionary theory—life history theory—to better understand health inequalities. We believe that life history theory leads naturally to our focus on two important questions: the determinants of age at first reproduction and the role of inequality in health. In particular, we are concerned with how and why inequality leads to early reproduction and reduces mothers' and children's capability for health and long lives.

LIFE HISTORY THEORY

Life history theory is the study of organism × environment interactions throughout and across life cycles from an evolutionary perspective. Examples of mammalian life history traits are age at first reproduction, number and size of offspring, interbirth interval, length of parental investment (e.g., nursing), and life span. Central to life history theory is the proposition that in order for organisms to have left descendants, they first had to survive, grow, and develop, and then not only produce offspring but, in the case of long-lived species, particularly mammals, rear them as well. Survival, growth and development, and producing and rearing offspring are the universal and major components of fitness and are forms of work. Doing work requires resources (e.g., energy, nutrients, security, information, time), which sooner or later are always limited. Therefore, natural selection is expected to favor organisms with mechanisms to allocate limited resources preferentially to the particular component (work) of fitness that most increased their ancestors' chances of leaving descendants under similar socioecological conditions. Because selection always favors organisms who leave more descendants (i.e., fitness is always relative), but the resources required for doing the work of leaving descendants are always limited, it is not possible to maximize all the components of fitness simultaneously, and trade-offs are inevitable. For example, if survival is the most pressing adaptive problem, resources will be allocated preferentially to this end, making them unavailable for growth and development or reproduction. Likewise, if the organism has survived to adulthood and producing offspring is its most pressing adaptive problem, the resources allocated preferentially to offspring production will not be available for rearing them (Gadgil and Bossert, 1970).

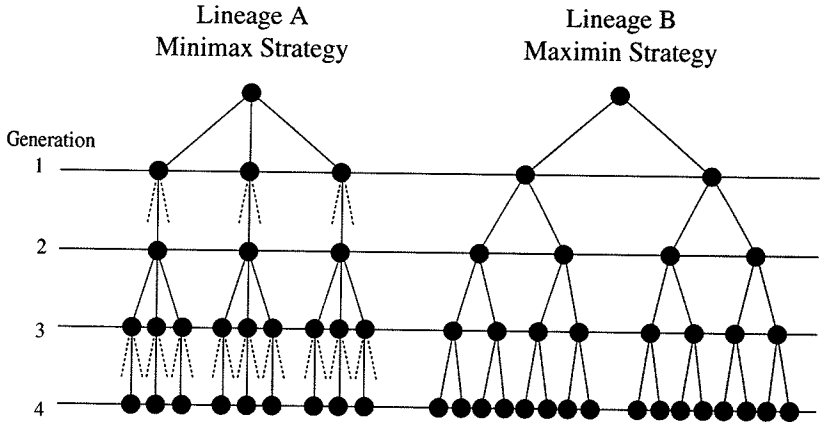
The most all-encompassing trade-off is that between current and future reproduction. Also known as the "general life history problem" (Schaffer, 1983), the current–future trade-off is a model for predicting an organism's optimal reproductive "strategy" (it need not be conscious) for leaving descendants based on the assumption that there is a trade-off between current and future reproduction. The rationale for this assumption is that beyond some threshold, increased reproduction in the short term (current reproduction) will decrease the number of its descendants in the long term (future reproduction).

This can happen because resources consumed for bearing or rearing offspring in the short term would have resulted in more descendants had they been consumed in the future and/or because current reproduction reduces parents' capability of surviving and thus bearing or rearing future offspring. One important consequence of the general life history problem is that selection is no longer always expected to favor mechanisms that simply maximize number of offspring. This is because consistently producing a small number of high-quality offspring (i.e., with a high probability of survival and reproduction) results in more descendants in the long run than having a larger number of low-quality offspring (i.e., with a low probability of survival or reproduction). And this, in turn, is because producing a small number of high-quality offspring—who are themselves likely to produce a small number of high-quality offspring, who are in turn also likely to produce a small number of high-quality offspring (and so on)—reduces the intergenerational variance in number of offspring. It's an algorithmic fact that increasing x by the multiple y through z iterations (generations) produces a larger number than increasing x through z iterations by a multiple that only averages y through z iterations. To repeat, selection is no longer expected always to favor mechanisms that maximize the production of offspring in the current generation. Instead, it is now expected that under certain circumstances selection will favor mechanisms (adaptations) that have the effect of minimizing intergenerational variance in number of offspring, thereby maximizing long-term fitness or future reproduction (Borgerhoff Mulder, 1992; Charnov, 1993; Gillespie, 1977; Harpending, Draper, & Pennington, 1990; Hill & Kaplan, 1999; Kaplan, 1994; Promislow & Harvey, 1990, 1991; Stearns, 1992).

The circumstances that matter are those of environmental risk and uncertainty, which is how evolutionary ecologists refer in the abstract to threats to an organism's capability to leave descendants (Charnov, 1993; Low, 1978; Seger & Brockmann, 1987; Stearns, 1992). In risky and uncertain environments the quantity, quality, and dependability of resources required for the work of fitness (energy, nutrients, security, time, information) are problematic, so mortality rates are high or unpredictable and the most pressing adaptive problem is to have any descendants at all. Because parents in these environments lack the resources to invest in offspring, their optimal reproductive strategy is to reproduce as early or often as possible. Maximizing offspring quantity (current reproduction) reduces their quality, but since these parents already lack the capability to have much effect on quality, this is just the cost of staying in the evolutionary game. Maximizing offspring quantity maximizes the probability that some will survive and reproduce; any is better than none. It's as if adaptations for trading offspring quality for quantity under conditions of high environmental risk and uncertainty were the phenotypic embodiment of game theory's minimax strategy of minimizing the probability of sustaining the maximum possible loss. This is the "bird in the bush worth none in the hand" or "nothing left to lose" strategy; it is the optimal strategy when the only alternative is lineage extinction or "stepping off a fitness cliff" (Ellison, 1994; Holland, 1992; Keyfitz, 1977).

In safe and predictable environments, on the other hand, the quantity, quality, and dependability of resources are at least adequate, so mortality rates are lower and steadier, survival is not such a pressing problem, and parents can afford to produce a small number of high-quality offspring who are themselves likely to survive and reproduce. Maximizing offspring quality (future reproduction) reduces their number, but since these parents have the capability to maintain or improve offspring quality, this is just the cost of investing in the future. Maximizing offspring quality maximizes the number of

descendants in future generations—or the probability of having any descendants after more generations. It's as if adaptations for trading offspring quantity for quality under conditions of low environmental risk and uncertainty were the phenotypic embodiment of game theory's maximin strategy of maximizing the probability of achieving the minimum possible (short-term, one-step-at-a-time) gain, which, as always, is just staying in the evolutionary game. This is the "bird in hand worth two in the bush" strategy; it sets the stage for a slow and steady increase in future fitness by reducing intergenerational variance in number of offspring (Figure 6-1).



	Lineage A Minimax Strategy	Lineage B Maximin Strategy
Maximum Number of Offspring per Generation	3	2
Mean Number of Offspring per Generation	2	2
Intergenerational Variance	1	0
Number of Descendents After Four Generations	9	16

FIGURE 6-1 Schematic representation of the effect of intergenerational variance in number of offspring on number of descendants. Lineage A occupies a risky and uncertain environment and consequently suffers high or unpredictable mortality (dotted lines ending without issue). The optimal strategy for members of Lineage A is to maximize quantity of offspring in each generation (current reproduction), for this minimizes the risk of lineage extinction. Lineage B occupies a safe and predictable environment so all of its offspring survive and reproduce. The optimal strategy for members of Lineage B is to maximize the quality of offspring. Thus, even though Lineage B produces only two offspring per generation (vs. three in Lineage A), their higher quality means that they are more likely to survive and reproduce. Consistently producing a small number of high-quality offspring reduces the intergenerational variance in number of offspring. Over time this results in more descendants (future reproduction) in Lineage B than in Lineage A. This consistency, however, comes at the cost of considerable parental investment, which takes resources away from producing greater numbers of offspring. (Adapted from Chisholm, 1993.)

THE DEVELOPMENT OF REPRODUCTIVE STRATEGIES

There are two main approaches in biology (Stearns, 1982; Tinbergen, 1963). The adaptationist approach is concerned with ultimate explanations of how evolution works and what selection is expected to favor. The mechanist approach is concerned with proximate explanations of how organisms work and how adaptations are realized phenotypically. In order for an organism to develop its theoretically optimal reproductive strategy (life history traits) contingent on local environmental risk and uncertainty, there must be a mechanism whereby information about environmental risk and uncertainty becomes represented in its phenotype to organize the cells, tissues, organs, etc. required to do the theoretically adaptive work proposed. This raises questions about the nature of such information, how it affects reproduction, and how it is incorporated into the phenotype. With regard to the first question, since mortality rates and patterns are determined by environmental risk and uncertainty, they are a good indicator of the local optimal reproductive strategy and information about environmental risk and uncertainty might be expected to represent or index local mortality risk. With regard to the second question, age at sexual maturity is a critical life history trait for it marks the point in the life cycle when organisms have been selected to re-allocate resources from growth to reproduction. Because of the current–future trade-off the timing of age at first reproduction can have major fitness consequences and may constitute the primary target of selection on life history traits (Charnov, 1993; Hill & Hurtado, 1996; Hill & Kaplan, 1999; Promislow & Harvey, 1990, 1991; Stearns, 1992). We might therefore expect information about mortality rates to have an impact on age at first reproduction.

Regarding the third question—how information about mortality rates is incorporated into the phenotype to affect age at first reproduction—the quantity, quality, and dependability of material resources are critical for all organisms. Organisms with inadequate or uncertain material resources (energy, nutrients, antibodies, etc.) are more likely to die. Ellison (1990) thus proposed that the energy imbalance produced by malnutrition or disease in effect provides information about mortality risk that signals metabolic, immune, and endocrine control systems to downregulate reproduction, enabling females to make unconscious "bioassays" of their own health, nutritional status, and growth rates as a means of scaling reproductive effort to the flow of material resources. It makes adaptive sense for organisms with inadequate or uncertain material resources to postpone reproduction—at least until conditions improve—but when they are adequate to reproduce early, for this enables them not only to capitalize quickly on these resources, but also to maximize the probability that their offspring will be born in time to capitalize on them as well (Cole, 1954).

However, it is also known that women with chronically inadequate or uncertain material resources in developing countries often begin childbearing in their teens and go on to have six, eight, or more pregnancies (Alan Guttmacher Institute, 1998; Bongaarts, 1980). Vitzthum (2001) proposed a resolution of this apparent paradox in terms of life history theory and the familiar physiological process of acclimatization. From the perspective of life history theory, ontogeny is the development of reproductive strategies; development itself evolved for reproduction (Bonner, 1965; West-Eberhard, 2003). Because the essential adaptive function of phenotypic plasticity is to maximize the probability of leaving descendants in the environment in which one was born—but these environments may

change before maturity—we would not expect age at first reproduction to be determined only by a woman's current energy balance but also her energy balance history. As Vitzthum put it, "a current reproductive 'decision' is dependent on both the *absolute quality* of current conditions and the *relative quality* of these conditions compared to prior conditions and predicted future conditions" (2001, p. 193; original emphasis). Thus, women who have experienced positive energy balance during development acclimatize to these good conditions, in effect "predicting" that they will continue. Should they then encounter a period of negative energy balance, their reproductive systems are downregulated because current conditions do not match those to which they have acclimatized, but which they have "predicted" will continue. Conversely, women who have acclimatized to chronic energy imbalance during development have little reason to "predict" that conditions will improve, and so to maximize their chances of reproducing at all they should reproduce early—even under their chronically marginal conditions and with potential trade-offs in reduced maternal and child health (see later). Again, any offspring, even of low quality, is better than none. (The same adaptationist logic underlies the "fetal origins of adult disease" hypothesis, i.e., that the fetus acclimatizes to conditions in utero, thereby in effect "predicting" the energy balance it will experience after birth. We'll return to this topic later as well.)

Another phenotypic marker of mortality risk, however, is the very experience of risk and uncertainty: the neuroendocrine control systems and subjective feelings associated with activation of the HPA axis by the perception of danger (the causes, correlates, and consequences, including malnutrition and disease, of high or unpredictable mortality rates). Just as malnutrition and disease have been correlated with and are thus predictors of mortality, so too, surely, have feelings of arousal, anxiety, fear, and loss (sadness and depression) been correlated with and are thus predictors of mortality—and, as LeDoux notes, for a very long time: "...amongst vertebrates, the neural system involved in detecting danger and producing defense responses is similarly organized in all species studied. This suggests that evolution long ago figured out how to organize the defense system and has continued to use this organizational blueprint" (1995, p 27; see also Crespi & Denver, 2005).

For humans especially, social relations are always a potential source of danger; the ever-present possibility of competition, aggression, and social exclusion make an adequate quantity, quality, and dependability of social–emotional resources critical. While our survival, growth, and development and ultimate reproduction are always contingent on material resources, they are also always contingent on the empathy and cooperation of others, from whom such blessings flow. This is most especially true for our children because of their extreme and prolonged helplessness—thus selection for the critical role of attachment in buffering them against risk and uncertainty (Bowlby, 1969). Attachment theory and research show that children experience all kinds of environmental risk and uncertainty subjectively as social–emotional insecurity. Their subjective experience of inadequate or uncertain material resources certainly includes hunger, pain, and lethargy, but hunger, pain, and lethargy also activate the HPA axis (McEwen, 1998a; Sapolsky, Romero, & Munck, 2000), producing subjective feelings of insecurity (fear or anxiety), thereby activating the attachment system (Ahnert et al., 2004; Desjarlais et al., 1995; Gunnar, 1998; Gunnar et al., 1996; Gunnar & Donazella, 2002; Kobak, 1999). And when parents are not sufficiently buffered against inadequate or uncertain material or social–emotional resources they are apt to feel anxious and frustrated, and are then less

capable of being consistently accepting of and sensitive and responsive to their children (Bowlby, 1973; Conger et al., 1994; McLloyd, 1998; Polan & Hofer, 1999), thereby transducing the impact of their environment on themselves to their offspring.

Human infants also face an inherently greater potential for social–emotional insecurity than other primate infants for several reasons. First, sharing is quintessentially human, while nonhuman primates rarely share. Second, alone among the great apes, human mothers deliver subsequent offspring before the preceding one is nutritionally independent, which means that only human mothers may have to decide which one is the better beneficiary of their limited resources (Kaplan et al., 2000). And alone among primates—except for cooperatively breeding monkeys like the Callitrichidae—human mothers are known occasionally to neglect, reject, or even kill their offspring (Hrdy, 2000, 2005). Finally, we are not only an extremely social species but an extremely intelligent one, with the capability to generate complex mental models of our environments and to manipulate these models so as to predict the future. When our models of the future include images of inadequate or unpredictable material resources, feelings of insecurity are likely to follow.

The distinction between material and social–emotional resources is thus far from absolute. Psychosocial stress (arousal, fear, anxiety, insecurity) consumes energy that might have been better allocated to other functions (Bjorntrop, 1991; Dallman et al., 1995; Susman & Pajer, 2004), leading potentially to faltered growth or nonorganic failure to thrive (Black et al., 1994; Chatoor et al., 1998; Drotar, 1991; Montgomery, Bartley, & Wilkinson, 1997; Rutter et al., 2004; Valenzuela, 1997) or, later, a heightened taste for "comfort foods" and thus obesity (Dallman et al., 2003). Moreover, physical pain and social–emotional pain involve much the same neurobiology (Eisenberger & Lieberman, 2004). As a starting point for disentangling their interactive effects on reproduction, Coall and Chisholm (2003) proposed a response hierarchy model in which fertility evolved to be contingent first on health and nutrition, and then, when these are adequate, on safety or security, as indexed by relative absence of, or means of coping with, the specific kind of environmental risk and uncertainty engendered by high mortality rates leading to short or unpredictable lifespans—i.e., psychosocial stress. Wingfield and Sapolsky (2003) make a similar argument. While acknowledging that reproductive suppression is a common response to acute or prolonged HPA activation, they suggest that the trade-off between survival and reproduction means that selection would favor the capability to reproduce despite such stress whenever the likely alternative was imminent death or other failure to reproduce. We might therefore expect that social–emotional or psychosocial stress would be another phenotypic marker of mortality risk and thus contribute to early reproduction. We summarize below evidence that this is the case for humans and rats (at least with positive energy balance). (For similar evidence in other species see references in Bateson et al., 2004; Kuzawa, 2005; Seger & Brockmann, 1987; Stearns, 1992; West-Eberhard, 2003; Wingfield & Sapolsky, 2003.)

PSYCHOSOCIAL STRESS REDUCES AGE AT FIRST REPRODUCTION

While age at first reproduction is influenced by a multitude of factors, we focus here on age at menarche because it is a precondition for first reproduction yet shows enormous

variation, from about 12 years in developed countries to almost 19 in some developing countries (Walker et al., 2006; Worthman, 1999); the range within countries is even greater (Parent et al., 2003). Such a broad reaction norm in such a critical life history trait suggests selection for phenotypic plasticity itself, i.e., selection for the capability for menarche at a wide range of ages, with actual age in this range determined by environmental factors. Given that early menarche is associated with numerous later health problems (see later), a better understanding of these factors might inform efforts at prevention or early intervention. We also focus on age at menarche because it is correlated with another precondition of first reproduction—age at first intercourse (Bingham, Miller, & Adams, 1990; Miller et al., 1998, 2001; Phinney et al., 1990; Sandler, Wilcox, & Horney, 1984; Smith, Udry, & Morris, 1985; Udry, 1979; Udry & Cliquet, 1982; Zabin et al., 1986). Moreover, early psychosocial stress also predicts early first intercourse and first reproduction (Boyer & Fine, 1992; Fiscella et al., 1998; Hillis et al., 2004; Miller et al., 1997; Tubman, Windle, & Windle, 1996; Turner, Runtz, & Galambos, 1999; Wyatt et al., 1999).

Insecure Attachment

More than a score of studies have reported a correlation between early psychosocial stressors and early menarche (recent work includes Bogaert, 2005; Chisholm et al., 2005; Grainger, 2004; the best recent review is Ellis, 2004). Many were inspired by Belsky, Steinberg, and Draper (1991), who first suggested that the attachment process might be an evolved mechanism for the entrainment of alternative reproductive strategies in humans, with insecure attachment histories predisposing men and women to earlier reproduction, more opportunistic and short-term sexual relations, and less consistently sensitive and responsive caretaking. They also made the important prediction that "individuals whose early family experiences are high in stress . . . should be more likely to undergo pubertal maturation earlier than children whose childhood experiences are more pacific" (1991, p 656). Chisholm (1993, 1999) offered an explicit adaptationist rationale for their mechanist model, noting that the current–future trade-off explained in principle why selection would favor the capability to adjust age at menarche contingent on attachment history. However, focusing as it does on mental constructs like Bowlby's (1969) "internal working models," attachment theory has little to say about the biological mechanisms whereby attachment organization might affect age at menarche. By analogy to Ellison's "bioassay," Chisholm (1993) thus used the term "socioassay" to refer to the psychoneuroendocrine processes whereby psychosocial stress might affect age at menarche in the Belsky et al. attachment model. Socioassays are conceived to assess the outcome of each iteration of the attachment cycle, thereby building the social capital ("connections among individuals" [Putnam, 2000, p. 19]) that the child accumulates during her attachment history. The attachment cycle is the oscillation, repeated many times a day in each of its iterations, between the infant's use of mother as secure base from which to explore and as safe haven to which to return (Chisholm, 1996; Sroufe & Waters, 1977). It is a control system for optimizing the trade-off between using mother as a secure base, which motivates play and exploration and so maximizes growth and development, and safe haven, which motivates return to mother and so maximizes survival. The social capital that the child thus accrues becomes represented phenotypically, not only subjectively, in the internal working models (beliefs and feelings) about herself and mother that she constructs from these social

relations, but also objectively, as the neuroendocrine traces of her history of HPA activation (Ahnert et al., 2004; Carter, 2005; Gunnar & Donazella, 2002; Gunnar et al., 1996, 1998; Insel & Young, 2001). If this history has been sufficiently secure (the result of sufficiently consistent, sensitive, and responsive nurturing), her internal working models of self and others will be positive and her HPA axis will have acclimatized to low and infrequent activation and rapid return to baseline levels—in effect "predicting" a secure future; if not, her internal working models will be less positive and her HPA axis will have acclimatized to higher and more frequent activation and slower return to baseline levels—in effect "predicting" an insecure future. This psychoneuroendocrine approach to attachment provides a way to explore the biological mechanisms whereby attachment history might affect age at menarche. Thus, while the human and nonhuman studies discussed below have not measured attachment history, they have measured early psychosocial stress and found that it predicts early maturation. The animal studies have also explored neuroendocrine mechanisms whereby early psychosocial stress may affect maturation.

Early Menarche in Girls Adopted from Developing Countries

Since the first observations by Adolphson and Westphal (1981) and Proos, Hofvander, and Tuvemo (1991), several additional studies have reported that girls adopted from developing into developed countries reach menarche earlier than the average for both their country of origin and their new, host country. In their review of this growing literature, Parent et al. (2003) discuss theory and evidence for several mechanisms that might account for such acceleration. They conclude that "there is no simple and single explanation" (p. 686), but also conclude that the role of genetic factors "is relatively minor and unlikely to explain the variation" (p. 680) and that despite reports that women of low birth weight due to intrauterine growth restriction have early menarche (Adair, 2001; Cooper et al., 1996; Ibanez et al., 1998, 2000; Koziel & Jankowska, 2002), there is no evidence that early menarche in the foreign adopted girls was linked to their birth weight. Likewise, while not ruling out health and nutrition, they note that early menarche has also been observed in girls migrating with their original families and with no evidence of former nutritional deprivation, which "provides further support to the role of factors other than nutrition in relation to the changing environment" (Parent et al., 2003, p. 683).

Even so, Gluckman and Hanson (2006), though citing the Parent et al. review, favor a nutritional explanation in terms of the fetal origins of adult disease hypothesis mentioned above (Barker, 1994; Bateson et al., 2004; 2004; Ellison, 2005a; Gluckman, Hanson, & Spencer, 2005; Gluckman et al., 2005; Hales & Barker, 1992). They seem to believe that these girls must have had low birth weight and then good postnatal health and nutrition, arguing that "the combination of prenatal early life deprivation with childhood nutritional excess, as seen in adopted children [who] migrated from poor to rich countries" (p. 9) is the cause of their early menarche. In their view, because of the girls' presumed intrauterine growth restriction they had low birth weight, and, as a consequence, their growth and development would have been based on the "prediction" that they would encounter similar limited resources postnatally. But having acclimatized to marginal resources prenatally and then been adopted into wealthier countries and encountering relative material abundance instead, they would have matured as early as possible in order to capitalize on their windfall (as Cole, 1954, might have predicted).

This may be so, but in light of theory and evidence discussed above we believe that the role of early psychosocial stress in foreign adopted girls' early menarche should also be considered. If human fertility evolved to be contingent first on health and nutrition, and then, when these are adequate, on safety or security, as indexed by patterns of HPA activation during development (Coall & Chisholm, 2003), the question arises whether these girls acclimatized to poor nutrition in utero and then took advantage of their "unpredicted" postnatal nutritional windfall with early menarche, or acclimatized to psychosocial stress during their early years, "predicted" an insecure future, and had early menarche as a result. One argument in favor of the latter possibility is the emerging consensus that 9 months of gestation is not enough to provide reliable information for the fetus to "predict" its resource flow in the future (Ellison, 2005b; Jones, 2005; Kuzawa, 2005; Worthman & Kuzara, 2005; see also Chapter 18). In fact, 9 months is probably a generous estimate of the amount of time the fetus has to sample its environment and base its "predictions"—as evidenced, for example, by the fact that among women pregnant during the Nazi-imposed Dutch famine winter of 1944–1945 only those exposed during their third trimester gave birth to low-birth-weight infants (Stein & Lumey, 2000; see also Chapter 7, note 1, page 437). If 9 months (still less 3) is inadequate for making a "prediction," then, in this context at least, the concept of fetal "predictions" seems questionable. As Jones (2005) argues, it is not so much that the growth-restricted fetus "predicts" a growth-restricted future, but it simply downregulates growth to conserve the resources it has, in effect sacrificing growth for continued survival, thereby "making the best of a bad start." The adaptationist rationale for this view is the logic of the current–future trade-off: For a growth-restricted fetus, maximizing the probability of its current survival is a more pressing adaptive problem than setting the stage for anything it might or might not encounter in the future. This is the essence of the minimax strategy: minimize the probability of the maximum possible loss (lineage extinction due to death). Downregulating growth in the face of starvation is not an adaptation for "predicting" the future but for survival.

Another reason for considering the role of psychosocial stress in foreign adopted girls' early menarche is that while low birth weight has been correlated with early menarche, the reverse is also true, i.e., not only do women of low birth weight seem to have early menarche, women who have early menarche also seem more likely to deliver low-birth-weight infants (Kirchengast and Hartman, 2000; Scholl et al., 1989). And, as we have seen, a score of studies report that early psychosocial stress is associated with early menarche. On the other hand, whether or not early psychosocial stress is also involved, it may be that the causal arrow points in both directions—i.e., low birth weight contributes to early menarche and early menarche contributes to low birth weight. This two-way causation might be part of the mechanism for Kuzawa's (2005; see also Chapter 18) "intergenerational phenotypic inertia" model of maternal (i.e., nongenetic) effects. Arguing that 9 months of gestation is not enough for the fetus to "predict" its lifetime resource availability, he invokes instead Ounsted and Ounsted's (1968; Ounsted, Scott, & Ounsted, 1986) hypothesis that the nutritional experience of a mother when she was a fetus affects the uterine environment she provides her daughters. (Sons, not having uteruses, are not part of the model.) Citing both human and nonhuman evidence in support, he suggests that each generation provides information to the next, and that this information accumulates over a number of generations, providing a "rolling average" of information about past environments that

each female fetus can use to "predict" its future and that the time depth of this information makes it more reliable by discounting seasonal or other short-term fluctuations in the flow of resources (Kuzawa, 2005; see also Chapter 18).

Early Stress Accelerates Maturation in Rats

The clearest evidence that early psychosocial stress also accelerates maturation in other mammals comes from long-term studies of the behavioral neuroendocrinology of rats by Meaney and colleagues (Champagne et al., 2003; Cameron et al., 2005; Meaney, 2001; Meaney & Szyf, 2005). Taking advantage of normal individual differences in maternal behavior in the rat, Meaney's group explores the development of two groups of rat pups, one reared by dams who are one standard deviation above their cohort mean in "licking and grooming" (LG) and "arched-back nursing" (ABN) and the other by dams who are one standard deviation below their cohort mean in LG and ABN. Adult offspring of low LG-ABN mothers are more fearful (increased startle responses, decreased open-field exploration, and longer latencies to eat food in a novel environment), show greater plasma adrenocorticotropic hormone and corticosterone responses to experimental stress, and reduced glucocorticoid negative feedback sensitivity. In other words, their HPA axes are altered, making them more reactive to stress. Most significantly, daughters of low LG-ABN mothers also show earlier vaginal opening—a clear marker of sexual maturation. They also show increased sexual receptivity and proceptivity and increased fecundability (80% compared to 50% in daughters of high LG-ABN mothers). Moreover, cross-fostering experiments show that all of these differences are due to maternal caretaking behavior, not genetic inheritance. The neuroendocrine mechanism entraining early sexual maturation in the daughters of low LG-ABN mothers involves the effects of HPA activity on the hypothalamic–pituitary–ovarian axis, which controls pubertal development: greater HPA activity in the daughters of the low LG-ABN mothers causes changes in oxytocin receptors (i.e., gene expression) in areas of the brain that regulate sexual behavior.

INEQUALITY CAUSES PSYCHOSOCIAL STRESS AND SHORTENED LIVES

Recapping briefly, our adaptationist argument is that under conditions of high or unpredictable mortality it will generally be adaptive for organisms to maximize current reproduction, especially by reducing age at first reproduction, for delaying only increases the risk of death without issue. Our mechanist argument is that psychosocial stress indexes or reflects mortality rates and is a proximate cause of early reproduction. We turn now to the issue we raised at the beginning of this chapter: the role of inequality in psychosocial stress and mortality.

While it has always been painfully obvious that absolute poverty is associated with ill health and shortened lives, it is now equally obvious that so too is relative poverty or inequality. The difference between absolute poverty and inequality is the difference between not having enough resources to go around and not having them go around enough. Good social relations constitute social capital (Putnam's "connections among

individuals") because they are what make resources go around. Good social relations are assets because they increase the velocity of resources (make them go around faster and farther); poor social relations are liabilities because they inhibit the flow of resources. This is the consensus explanation of the standard finding of research on the relationship between inequality and health: for each step up or down in social or economic hierarchies, there is a corresponding and equivalent step down or up in morbidity and mortality rates. It is unlikely that this ubiquitous "stair-step" pattern is due only to whatever marginal health benefits might flow from the incremental increase in material resources accompanying each upward step, because the pattern is apparent not only when the steps themselves are small, but also when it represents populations in wealthy industrial nations with universal health care. Instead, the evidence suggests that the "stair-step" pattern is largely due to the effects on health and longevity of perceived relative deprivation—the perception that one is "one up" or "one down" on another (Adler et al., 1993; Davey Smith et al., 1990, 1996a, 1996b; Farmer, 2003; Kawachi & Kennedy, 2002; Lynch et al., 2000; Marmot, 2004; Marmot et al., 1991; Marmot & Wilkinson, 1999; Marris, 1991; Sennett & Cobb, 1973; Shorris, 1997; Wilson, 1996; Wilkinson, 1996, 2001, 2005).

Being "one up" or "one down" involves what economists call "positional goods"—i.e., those we value because having them places us in a higher position than those who do not (Hirsch, 1976). Where there is no wealth in any domain, there is no inequality, but as wealth increases above the threshold required for basic survival, people commonly compete for positional goods. This generates hierarchies of power, wealth, or status, depending on the domain of competition. That humans compete for position seems undeniable; all primates have dominance hierarchies, with access to resources largely a function of position in the hierarchy (Boehm, 1999; Sapolsky, 2005). Being "one up" in a hierarchy is widely experienced as good, not only because of priority of access to material resources themselves, but also because of the subjective feeling of security entrained by a history of good access. Security is the interest on social capital. It is freedom from doubt, anxiety, or fear; it is the expectation that one is worthy of good relations with others and that others have good intentions towards oneself. The capability for our experience of social security came with the evolution of the attachment process (Chisholm, 2003). Being "one down" in a hierarchy is widely experienced as bad, not only because of uncertain access to material resources, but also because of the subjective feelings of insecurity entrained by a history of reduced or uncertain access. Inequality is a direct cause of psychosocial stress and shortened lives because overly hierarchical political and economic structures limit the flow of resources so that subordinate individuals and groups don't have enough to go around. Inequality also increases morbidity and mortality indirectly through the neuroendocrine correlates of insecurity. Insecurity results in activation of the HPA axis and release of cortisol; chronic insecurity results in chronic high levels of cortisol. Thus, for example, Flinn et al. (1996; see also Chapter 13) observed significantly higher salivary cortisol levels in children of single mothers without adequate kin support, as did Lupien et al. (2000) in low socioeconomic status (SES) children compared to high, and a significant positive correlation between children's cortisol levels and their mothers' symptoms of depression. In turn, chronic high levels of cortisol increase the risk for many disease conditions, including impaired immune function, coronary heart disease, diabetes, neuronal cell death, and anxiety and depression and consequent increased risk for self-medication with alcohol and

drugs, all of which lead to shortened lives (Brunner, 1997; Coe, 1999; McEwen, 1998a; Sapolsky, 1996).

Inequality is thus a significant cause of ill health and shortened lives. But this is a proximate explanation, describing the mechanisms whereby inequality engenders psychosocial stress and how psychosocial stress affects health and longevity. Is there an ultimate, adaptationist explanation for the association between inequality and ill health and short lives?

THE TRADE-OFF BETWEEN SURVIVAL AND REPRODUCTION

Natural selection favors the capability of organisms to leave descendants. When this capability is threatened by high or unpredictable mortality rates, selection is expected to favor mechanisms for minimizing the chance of lineage extinction by reproducing early (health and nutrition permitting). But because resources are always limited, it is not possible to maximize all of the components of fitness simultaneously, and trade-offs are inevitable. From an adaptationist perspective, therefore, the ultimate explanation of the association between inequality and ill health and short lives is this: when the only alternative is lineage extinction, natural selection favors mechanisms for reallocating resources from survival to reproduction—i.e., the capability for making the trade-off between survival and reproduction. According to this view, the numerous maternal and child health problems associated with early menarche or early reproduction are costs of reproduction. The cost of a chance at having any descendants at all (the trade-off between survival and reproduction) is one that both early-reproducing women and their children may have to pay in the form of reduced health or longevity. The costs of early menarche for women include an increased risk for reproductive cancers (Apter, 1996; Eaton et al., 1994; Kelsey, Gammon, & John, 1993; Petridou et al., 1996), obesity and obesity-related disorders (Bjorntrop, 1991; Brindley & Rolland, 1989; Colditz et al., 1987; Cordain, Eades & Eades, 2003; Kirchengast et al., 1998; Garn et al., 1986; Shangold et al., 1989; Solomon & Manson, 1997; Wamala, Wolk, & Orth-Gomer, 1997; Wellens et al., 1992), and depression, drugs, and delinquency (Angold & Worthman, 1993; Angold, Costello, & Worthman, 1998; Bratberg et al., 2005; Caspi & Moffitt, 1991; Graber et al., 1997; Heim et al., 2000; Koff & Rierdan, 1993; Magnusson, Stattin, & Allen, 1985; Ruislova, 1998; Singer et al., 2004). And in addition to the effects of mothers' poor health and shortened lives on their children, because early menarche is associated with low birth weight (Kirchengast and Hartman, 2000; Scholl et al., 1989), and low birth weight is a risk factor for the fetal origins of adult disease (see earlier), the children of early-maturing women may also pay a direct cost.

Allsworth et al. (2005) provide especially clear evidence of the potential cost of early menarche. With data from the Third National Health and Nutrition Examination Survey of 2470 U.S. women, they examined the relationship between age at menarche (early: ≤ 10 vs. late: >10) and allostatic load (the "wear and tear" an individual accumulates from chronic exposure to stress hormones [McEwen, 1998a, 2005]). After adjusting for age, "race"/ethnicity, education, household poverty, income ratio, smoking, and history of depression, women with high allostatic load scores were more than twice as likely to report early menarche as those with low scores. Allsworth et al. (2005) are the first to describe the relationship between age at menarche and allostatic load but make no attempt to explain it, noting that "[t]his association could have also been observed if an unobserved independent biologic process was associated with both age at menarche and composite allostatic load score" (p. 443). We suggest that this "unobserved process" is the mechanism for making the trade-off between survival and reproduction. When the likely alternative is lineage extinction, selection favors early reproduction. If the cost of early reproduction is reduced health and shortened lives, this is just the cost of continuing the lineage. And because such costs are paid after reproduction, they are invisible to selection anyway.

CONCLUSION: WHY INEQUALITY IS BAD FOR HEALTH

Not all health inequalities are caused by early reproduction, of course, but the logic of the trade-off between survival and reproduction is the logic of the current–future trade-off, which may apply to health inequalities in general. The trade-off between survival and reproduction is a version of the current–future trade-off: it is the sacrifice of future survival for current reproduction. But if an organism has not reached maturity, it is incapable of reproduction, and so is incapable of making this trade-off. Instead, under conditions of risk and uncertainty (causing high or unpredictable mortality), its most pressing adaptive problem is simply to survive and its only option is to sacrifice growth and development (an investment in the future) for short-term (current) survival. By continuing to live it buys time in which conditions may improve. If they do, the organism might then undergo catch-up growth, maturing as quickly as possible in order to capitalize on the improved conditions, just as mature organisms upregulate reproduction when conditions improve. If conditions don't improve, however, sacrificing growth and development endlessly to continue living defeats the ultimate adaptive function of growth and development: preparation for reproduction. Selection therefore could not favor adaptations for survival at the expense of endless failure of growth and development. Instead, selection will favor reduced chances of survival for at least some growth and development, with obvious negative implications for health and longevity. For example, fetal growth restriction does not affect all organ systems equally, but favors those most important for long-term growth and development (notably the brain) over those that are less important (like the kidneys, at the cost of long-term survival due to increased risk for kidney disease [Barker, 2004; Brenner, Garcia, & Anderson, 1988]). And Pike (2005) proposes that preterm birth itself may be due to the growth-restricted fetus sacrificing future survival for a better chance at growth and development outside a growth-restricting uterus. As Jones (2005) put it, these growth-restricted fetuses are "making the best of bad start."

In *Inequality Reexamined* (1992), Sen observes that all ethical theories agree that to have a good society there must be equality of something but disagree about precisely what it is that should be equal. This is a critical question because "the judgment and measurement of inequality is thoroughly dependent on the choice of the variable (income, wealth, happiness, etc.) in terms of which comparisons are made" (Sen, 1992, p. 2). Therefore, because inequality is the source of a great deal of pathology and many shortened lives, the answer quite literally has life and death implications. Sen's answer is "the

capability to achieve valuable functionings" (1993, p. 31). His argument is that focusing on human capabilities—what is humanly possible in terms of health, long lives, security, reason, etc.—helps us to clarify the distinction between our means and ends by taking us away from our concern with income, wealth, commodities, rights, opportunities, and so forth, and on to the ends to which they are only means. Building on Sen's work, Nussbaum (1995) conceives of our ends in terms of two thresholds: "... a threshold capability to function beneath which a life will be so impoverished that it will not be human at all; and a somewhat higher threshold, beneath which those characteristic functions are available in such a reduced way that, although we judge the form of life a human one, we will not think it a *good* human life" (1995, p. 81, original emphasis). From the perspective of life history theory, Nussbaum's two capability thresholds look like the trade-off between current and future reproduction; ultimately, inequality is bad for health because it keeps people from rising above these thresholds (Chisholm, 1999). Political planning should therefore aim at the target of minimizing the number of people who are capable only of survival (the first threshold: the minimax strategy of avoiding lineage extinction) and maximizing the number of people who are capable of a good human life (the second threshold: the maximin strategy of investing in the future).

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CHAPTER 7

Early Life Effects on Reproductive Function

Alejandra Núñez–de la Mora and Gillian R. Bentley

Here Núñez–de la Mora and Bentley demonstrate with remarkable clarity that development itself as well as development toward either positive or negative health outcomes later in life hardly begin postnatally. Rather, explanations of health must be explored beginning with the nutritional and pathogenic environment to which mothers and even grandmothers are exposed. For example, being born small for gestational age (SGA) can set in motion a chain of developmental events that, depending on the stability or lack of stability of resources, increase the risk of breast cancer later in life. The authors show how and why variations in ovarian function involving higher or lower levels of reproductive steroids differ across populations (Central Africans vs. Nepalese vs. Bostonians). They also show, based on their studies of Bangladeshi women in London, how variations in ovarian function can differ and fluctuate depending on changing nutrient and caloric availability and amount of time and energy diverted from reproductive effort to fighting disease. It is clear that developmental risks, at different times in a woman's life cycle, including the mechanisms that precipitate rapid growth and maturation, can create a cascade of responses that may be adaptive in the short term but potentially dangerous in the long run. This is a reality that altogether too many migrant women living in Western countries find out the hard way, by acquiring the same vulnerabilities to cancer, for example, that their more affluent Westerners know all too well.

INTRODUCTION

For the past two decades, innovative methods for monitoring ovarian function have encouraged detailed studies of human reproductive function among genetically, culturally, and ecologically diverse populations in field settings. Research by reproductive ecologists has established that levels of ovarian function, measured as average profiles of salivary progesterone and estradiol, differ considerably within and between individuals and populations (Ellison, Lipson, et al., 1993; Ellison, Panter-Brick, Lipson, & O'Rourke, 1993). Age and acute energetic factors, such as immune challenges, nutritional and/or energetic expenditure, whether voluntarily imposed or ecologically determined, are