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Environmental Neuroscience and Environmental Psychology

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Introduction

The external environment can have a profound impact on our brains and behavior. Yet, even with such a profound impact, it is often easy to ignore just how much the environment can affect us. This is exacerbated by the fact that humans have been able to manipulate their environment so effectively to ease daily life. Even so, the environment shapes our brains and behaviors tremendously. This article will review the literature on how the environment (examined from different levels of analysis) can affect our brains and behaviors. The article draws on research across disciplines (e.g., biopsychology in nonhuman animals) and with different technologies (e.g., genomics and fMRI) to uncover just how powerfully the environment can affect our brains and behaviors. There are four main sections to this article. The first deals with the in utero environment and how it can affect the brain. The second focuses on the maternal environment and other changes in the environment during development that can affect the brain and behavior. The third section discusses epigenetic factors and how environmental factors can affect an organism's gene expression, which will influence neural, psychological, and behavioral development. Lastly, impacts of the social and physical environment on brain and behavior are discussed. Importantly, it is not possible to review all the extant literature on how the environment can affect brain and behavior. These studies were selected on the basis of the authors' research interests and knowledge base. Any omissions are not a sign of lack of interest, but rather the limitations in summarizing a large body of knowledge. In all, the selected set of studies shows the profound impact that the environment can have on brain and behavior.

General Overviews

As mentioned in the introduction, there is a tendency for humans to ignore the powerful effects that the environment can have on our brains and behavior. Bargh and Chartrand 1999 posits that some of this neglect is due to the fact that so much of human behavior is guided by unconscious processing that helps us regulate our behavior in our environment. Another source of this neglect may be due to our tendency to ignore situational/environmental factors and their impact on behavior. Research by Edward Jones and Victor Harris (Jones and Harris 1967) uncovered a now well-known social-psychological phenomenon, the fundamental attribution error, which describes how individuals tend to ignore the impact of situational/environmental factors when evaluating other people's behavior. Another contributing factor to this neglect is the level of difficulty in studying the environment, given the incredible amount of available information contained in the external environment. Even with this difficulty, a related field has developed, which has been termed "population neuroscience" (Paus 2013). As Tomáš Paus explains, the goal of population neuroscience is to understand how the brain is shaped by internal effects such as genes and from external factors such as the social and physical environment. Falk, et al. 2013 concludes that a critical element of population neuroscience is to examine data sets with large numbers of participants to have the power to uncover these relationships, a point that has more recently been made by other researchers. This certainly makes the study of the environment's impact difficult but should not dissuade researchers from pursuing this line of inquiry. In addition to these large population studies, there have been a number of theories that posited just how the environment can have an impact on our behavior. One such theory, known as attention restoration theory (ART), was introduced by research in Kaplan 1995 and Kaplan and Berman 2010, which posits that interacting with natural environments can have a salubrious effect on psychological processing, by resting top-down attentional mechanisms via activating bottom-up attentional mechanisms. More specifics regarding this and other theories will be presented in subsequent sections of this article.

Bargh, J. A., and T. L. Chartrand. 1999. The unbearable automaticity of being. *American Psychologist* 54.7: 462–479.

This article presents just how much of our self-regulated behavior is driven by unconscious processing.

Falk, E. B., L. W. Hyde, C. Mitchell, et al. 2013. What is a representative brain? Neuroscience meets population science. *Proceedings of the National Academy of Sciences of the United States of America* 110.44: 17615–17622.

This article encourages neuroscience researchers to increase the sample size of their studies and the representativeness of their samples, and it further encourages population researchers to begin thinking of neural mechanisms involved in said phenomena.

Jones, E. E., and V. A. Harris. 1967. The attribution of attitudes. *Journal of Experimental Social Psychology* 3.1: 1–24.

This article is one of the first to show the fundamental attribution error.

Kaplan, S. 1995. The restorative benefits of nature: Toward an integrative framework. In *Special issue: Green psychology*. *Journal of Environmental Psychology* 15.3: 169–182.

This is the first article to present the ART for why interacting with nature may be restorative to psychological processing.

Kaplan, S., and M. G. Berman. 2010. Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science* 5.1: 43–57.

This paper presents evidence as to the common resource between executive functioning and self-regulation being the ability to direct attention. Direct attention can be restored via interactions with natural environments.

Paus, T. 2013. *Population Neuroscience*. Heidelberg, Germany: Springer.

This book presents a comprehensive view of the field of population neuroscience. It also shows the connections to environmental neuroscience.

In Utero Environment

Incredibly, the in utero environment in which humans develop can have a profound impact on their bodies and brains. This may not be too surprising when we consider the research in Weinstock 2001, which shows not only adverse effects of teratogens (e.g., alcohol), but how more-subtle factors such as mother's stress can also affect how human's brains develop. One factor that has been known to affect the brains of developing fetuses is maternal smoking. Toro, et al. 2008 demonstrates that prenatal smoking can lead to lower cortical thickness in the orbital frontal cortex. In addition, Lotfipour, et al. 2009 discusses that this thinning also predicts drug use in exposed adolescents. Another interesting and simultaneously concerning finding is that exposure to environmental toxins when a woman is pregnant may have direct effects not just on the developing fetus, but also on the reproductive cells of the fetus. Perera and Herbstman 2011 argue that transgenerational effects may occur because of direct exposures rather than only germline transmission. Due to the profound impact the in utero environment has over human development, which can transcend generations, practitioners and clinicians should focus on prevention tactics to inform pregnant or possibly pregnant patients. Specifically, these tactics entail communicating the dangers of smoking and alcohol use as well as communicating the need to reduce maternal stress levels if at all possible.

Lotfipour, S., E. Ferguson, G. Leonard, et al. 2009. Orbitofrontal cortex and drug use during adolescence: Role of prenatal

exposure to maternal smoking and BDNF genotype. *Archives of General Psychiatry* 66.11: 1244–1252.

This study found that thinning of the orbital frontal cortex associated with prenatal exposure to cigarette smoking predicted drug abuse in adolescence.

Perera, F., and J. Herbstman. 2011. Prenatal environmental exposures, epigenetics, and disease. In *Special issue: Prenatal programming and toxicity II (PPTOX II): Role of environmental stressors in the developmental origins of disease*. *Reproductive Toxicology* 31.3: 363–373.

This article reviews the literature on how prenatal exposure to toxins can have epigenetic consequences in childhood, over life, and even transgenerationally.

Toro, R., G. Leonard, J. V. Lerner, et al. 2008. Prenatal exposure to maternal cigarette smoking and the adolescent cerebral cortex. *Neuropsychopharmacology* 33.5: 1019–1027.

This study examined how prenatal exposure to cigarette smoking leads to thinning of the cerebral cortex.

Weinstock, M. 2001. Alterations induced by gestational stress in brain morphology and behaviour of the offspring. *Progress in Neurobiology* 65.5: 427–451.

This review article examines the literature on humans and animals and how prenatal stress affects brain and behavior.

Developmental Environment

Research suggests that the effect of the environment on brain and behavior may be most pronounced during an organism's development. Different facets of the developmental environment are discussed in the following subsections. Due to the brain's malleability throughout development, an organism's experiences and interactions with the environment directly affect overall plasticity for vision and audition. This is especially true when examining the organism's physical environment. Neural development has a direct relationship with maternal nurturing and positively stimulating environments. This is evident within several areas of cognition, such as problem solving, emotional recognition, and general affect. The final subsections cover well-documented research on maternal care—specifically, the effect of maternal deprivation on cognitive and behavioral development both in nonhumans and humans.

Experience-Dependent Plasticity

Experience-dependent plasticity is the effect of neural changes based on an organism's experiences and interactions with the environment that optimize the organism's navigation of that environment. Typically, the effect of experience-dependent plasticity is most pronounced during development, when the brain is most malleable. Classic demonstrations of experience-dependent plasticity came from studies by David Hubel and Torsten Wiesel (Hubel and Wiesel 1962, Hubel and Wiesel 1968), who studied the effect of environmental factors on the development of visual cortex in cats and nonhuman primates. In related work, the authors of Blakemore and Cooper 1970 reared kittens in environments that contained only vertical bars of light. After exposure to such environments, neurons in the kittens' visual cortex became tuned to respond only to light that was oriented vertically. Such demonstrations show that the kittens' visual cortex optimized to navigate these artificial environments, but these kittens would be essentially blind if forced to navigate a typically occurring environment. Other examples of experience-dependent plasticity come from research in Lomber, et al. 2010, which shows how auditory cortex was recruited for visual tasks, which improved visual processing in deaf individuals. Gougoux, et al. 2005 finds that blind individuals' occipital cortex reorganizes to aid in other senses such as audition. This plasticity also may not need to occur early in life; research in Maguire, et al. 2000 shows that taxi drivers in London develop larger gray-matter volume in certain areas of the hippocampus and that this change correlates with the amount of time of being a taxi driver.

Blakemore, C., and G. F. Cooper. 1970. Development of brain depends on the visual environment. *Nature* 228.5270: 477–478.

Classic study showing that when kittens are reared in environments that contain only vertical bars of light, neurons in their occipital cortex develop to respond only to light that is oriented vertically.

Gougoux, F., R. J. Zatorre, M. Lassonde, P. Voss, and F. Lepore. 2005. A functional neuroimaging study of sound localization: Visual cortex activity predicts performance in early-blind individuals. *PLoS Biology* 3.2: e27.

This study found that the occipital cortex in blind individuals reorganizes to aid in other senses such as audition.

Hubel, D. H., and T. N. Wiesel. 1962. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *Journal of Physiology* 160.1: 106–154.

This study examined how cortical receptive fields are built and how researchers can use binocular synergy as a means of uncovering significant information about a receptive field.

Hubel, D. H., and T. N. Wiesel. 1968. Receptive fields and functional architecture of monkey striate cortex. *Journal of Physiology* 195.1: 215–243.

Seminal studies examining the organization of visual cortex in monkey striate cortex and the effect of experience-dependent plasticity.

Lomber, S. G., M. A. Meredith, and A. Kral. 2010. Cross-modal plasticity in specific auditory cortices underlies visual compensations in the deaf. *Nature Neuroscience* 13.11: 1421–1427.

This study exemplified experience-dependent plasticity in deaf individuals where auditory cortex aids in vision to improve visual processing.

Maguire, E. A., D. G. Gadian, I. S. Johnsrude, et al. 2000. Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences of the United States of America* 97.8: 4398–4403.

This experiment showed that taxi drivers in London developed larger gray-matter volume in certain areas of the hippocampus.

Enriched Physical Environment

Some early work by Donald Hebb (Hebb 1947) showed that rats raised as pets achieved better problem-solving performance compared to rats raised in regular cages. Later work in Rosenzweig, et al. 1962 and Bennett, et al. 1965 found neural changes in rats raised in enriched cages that contained toys, wheels, ladders, etc., compared to rats raised in normal cages. Specifically, rats raised in enriched cages had increased gray-matter volume, and these increases were due to increased numbers of synapses and glia cells. All this work suggests that a richer environment during development can lead to improved problem solving, which appears to be driven by increased cerebral cortex volume.

Bennett, E. L., M. R. Rosenzweig, D. Krech, and M. C. Diamond. 1965. Evidence for increased glia cells in rat cortex resulting from environmental complexity and training. *Federation Proceedings* 24.2P1: 327–335.

This experiment compared rats raised in isolation with those raised in a complex environment (i.e., daily handling, maze training) and found significant increases in synapse and glia cell quantities throughout the cortex for rats raised in complex environments.

Diamond, M. C., D. Krech, and M. R. Rosenzweig. 1964. The effects of an enriched environment on the histology of the rat cerebral cortex. *Journal of Comparative Neurology* 123.1: 111–119.

This study examined macroscopic physical changes in the brain as a consequence of altering the organisms' experiences via an enriched environment.

Hebb, D. O. 1947. The effects of early experience on problem solving at maturity. *American Psychologist* 2:306–307.

This paper proposed a novel experimental concept called "enriched environments"; that is, that performance could be improved by being reared in a more complex and nurturing environment. This concept was anecdotally supported by behavioral performance differences between rats kept at a laboratory and rats kept as pets.

Rosenzweig, M. R., D. Krech, E. L. Bennett, and M. C. Diamond. 1962. Effects of environmental complexity and training on brain chemistry and anatomy: A replication and extension. *Journal of Comparative and Physiological Psychology* 55.4: 429–437.

This experiment compared rats raised in isolation with those raised in a complex environment (i.e., daily handling, maze training) and found significant weight and cholinesterase activity differences throughout the cortex and subcortical structures from being raised in a more complex environment.

Attachment Theory

Attachment theory attempts to describe changes in behavior as a function of long-term interpersonal relationships between humans and was developed by John Bowlby (Bowlby 1973) and Mary Ainsworth (Ainsworth and Bell 1970). Much of the theorizing behind attachment theory was due to the growing interest in the link between maternal loss or deprivation and later personality development. This link represents a body of research looking at developmental correlations between psychological disorders and lack of maternal support or lack of environmental control. One such study was conducted by Bruce Chorpita and David Barlow (Chorpita and Barlow 1998), who found that growing up in environments that lacked control or, rather, perceived locus of control gave rise to the development of vulnerabilities for anxiety in adolescence. Sroufe, et al. 1999 constructively criticizes attachment theory's early causal explanation of psychopathology. Instead of viewing early experiences as causing pathologies in a linear way, varying patterns of attachment style may play a dynamic role in pathological development, depending on how the environment shapes tendencies and expectations. Furthermore, these patterns of attachment may play a role in developmental processes via their impact on basic neurophysiological and affective regulation. Patricia Crittenden (Crittenden 1992) examined attachment theory by exploring coping strategies in response to adverse home environments and parental-care type (e.g., neglectful, abused, or adequate) for different cohorts of children. Crittenden found differences in strategies employed by abused, neglected, and adequately raised groups of children when engaged in free play. Attachment theory can also be applied outside child development. One such study examined how parental support significantly predicted collegiate grade point average after controlling for family conflict and achievement orientation (Cutrona, et al. 1994). It is important to note that with such a wide breadth of research on the effect of home environments on developing children, practitioners and teachers helping children raised in adverse environments should be wary not to perform streamlined therapy. Research on attachment theory can be particularly helpful in developing specific therapies on a case-by-case basis for a patient, by analyzing how that individual reacts to the particular stressors in the environment after undergoing experiences of being raised in a less supportive home environment.

Ainsworth, M. D. S., and S. M. Bell. 1970. Attachment, exploration, and separation: Illustrated by the behavior of one-year-olds in a strange situation. *Child Development* 41.1: 49–67.

This experiment examined the relationship between mother and offspring attachment and attachment behavior. The presence of a mother increased exploratory behavior while the absence of a mother increased attachment behaviors such as crying and frantic search.

Bowlby, J. 1973. The nature of the child's tie to his mother. In *Attachment and loss*. Vol. 1. By J. Bowlby, 175–198. New York: Basic Books.

This review, originally published in 1958 (*International Journal of Psycho-analysis* 39:350–373), thoroughly examines four psychoanalytic theories of attachment behaviors between a mother and her offspring.

Chorpita, B. F., and D. H. Barlow. 1998. The development of anxiety: The role of control in the early environment. *Psychological Bulletin* 124.1: 3–21.

This study postulated that a lack of environmental control in early development could lead to vulnerabilities for anxiety.

Crittenden, P. M. 1992. Children's strategies for coping with adverse home environments: An interpretation using attachment theory. *Child Abuse & Neglect* 16.3: 329–343.

This study examined children in different attachment groups with varying levels of parental-type care under free-play conditions and recorded behavioral differences.

Cutrona, C. E., V. Cole, N. Colangelo, S. G. Assouline, and D. W. Russell. 1994. Perceived parental social support and academic achievement: An attachment theory perspective. *Journal of Personality and Social Psychology* 66.2: 369–378.

This experiment controlled for any confounding variables to examine how the perception of social support and academic achievement can influence a college student's grade point average.

Sroufe, L. A., E. A. Carlson, A. K. Levy, and B. Egeland. 1999. Implications of attachment theory for developmental psychopathology. *Development and Psychopathology* 11.1: 1–13.

The authors argue that the prediction of future psychopathologies by early developmental attachment strategies should be restructured to display an appreciation for how the strategies frame the way the individual engages the environment.

Maternal Environments: Nonhuman

The influence of maternal care or, more specifically, of maternal deprivation has been well documented both among nonhuman and human populations. There is clear evidence within the literature on rats that the quality and quantity of maternal care received by offspring has a substantial influence on adult behavior. In an experimental paradigm called artificial rearing (AR), rat pups are removed from their mother (and litter mates) immediately after birth and are raised by the experimenter in isolation. As adults, animals that are artificially reared display a number of altered behaviors, including altered maternal behavior (Gonzalez, et al. 2001), increased sensitivity to amphetamine (Lovic, et al. 2006), increased impulsive action (Lovic, et al. 2011), and deficits in attentional set shifting (Lovic and Fleming 2004). Moreover, Francis, et al. 2002 reports that replacement of the maternal stimulation remediates these effects, and that environmental enrichment can counteract some of the adverse effects of maternal separation. These experimental data clearly demonstrate the impact of early-life maternal deprivation on adult behavior and also suggest ways that some of these early-life effects

can be reversed through enriching and supportive environments.

Francis, D. D., J. Diorio, P. M. Plotsky, and M. J. Meaney. 2002. Environmental enrichment reverses the effects of maternal separation on stress reactivity. *Journal of Neuroscience* 22.18: 7840–7843.

This study showed that environmental enrichment can counteract the effects of maternal separation.

Gonzalez, A., V. Lovic, G. R. Ward, P. E. Wainwright, and A. S. Fleming. 2001. Intergenerational effects of complete maternal deprivation and replacement stimulation on maternal behavior and emotionality in female rats. *Developmental Psychobiology* 38.1: 11–32.

This study examined the effects of early rearing experiences on the development of maternal behavior in female rats and found differences across behavioral, endocrine, and neurochemical mechanisms.

Lovic, V., and A. S. Fleming. 2004. Artificially-reared female rats show reduced prepulse inhibition and deficits in the attentional set shifting task—reversal of effects with maternal-like licking stimulation. *Behavioural Brain Research* 148.1–2: 209–219.

Using an artificial rearing paradigm, this study demonstrates that rats reared in isolation display cognitive deficits including reduced pre-pulse inhibition and deficits in an attentional set-shifting task. Moreover, replacement maternal stimulation remediated these effects.

Lovic, V., A. S. Fleming, and P. J. Fletcher. 2006. Early life tactile stimulation changes adult rat responsiveness to amphetamine. *Pharmacology Biochemistry and Behavior* 84.3: 497–503.

This study found that rats reared artificially displayed an enhanced response to amphetamine, but not to methylphenidate once having reached adulthood.

Lovic, V., D. Keen, P. J. Fletcher, and A. S. Fleming. 2011. Early-life maternal separation and social isolation produce an increase in impulsive action but not impulsive choice. *Behavioral Neuroscience* 125.4: 481–491.

This study showed that rats reared artificially display increased impulsivity; however, these effects were largely remediated through replacement maternal-like stimulation.

Maternal Environment: Human

Among the literature on human behavior, there is also evidence that early-life adversity influences adult behavior and growth. The most dramatic example of this is found in literature tracking the development of a group of Romanian orphans who endured extremely impoverished early-life experiences before being adopted. Children who were born into these environments display a variety of physical and cognitive delays, including reduced height and weight as compared to noninstitutionalized peers (Le Mare and Audet 2006), increased risk for psychiatric disease (Zeanah, et al. 2009), deficits in cognitive and social functioning (Kaler and Freeman 1994), lower cortical gray-matter volume (Sheridan, et al. 2012), and structural (Eluvathingal, et al. 2006) and metabolic (Chugani, et al. 2001) aberrations in the brain. Fortunately, as scientists continue to study these children as they are adopted into families, many of these delays show signs of remediation. For example, as opposed to children who remained in the institutional setting, Johnson, et al. 2010 finds that children receiving high-quality foster care at an early age are able to catch up to normal levels of height and weight. Concurrently, Windsor, et al. 2013 shows that children in foster care by age two display an advantage in language development compared to their institutionalized counterparts, and placement in foster care by one year of age boosted children to near-normal language abilities.

Chugani, H. T., M. E. Behen, O. Muzik, C. Juhász, F. Nagy, and D. C. Chugani. 2001. Local brain functional activity following early deprivation: A study of postinstitutionalized Romanian orphans. *NeuroImage* 14.6: 1290–1301.

This study demonstrates metabolic changes in the brains of children raised in Romanian orphanages.

Eluvathingal, T. J., H. T. Chugani, M. E. Behen, et al. 2006. Abnormal brain connectivity in children after early severe socioemotional deprivation: A diffusion tensor imaging study. *Pediatrics* 117.6: 2093–2100.

This study demonstrates structural aberrations in the brains of children who experienced socioemotional deprivation; more specifically, changes in the left uncinate fasciulus.

Johnson, D. E., D. Guthrie, A. T. Smyke, et al. 2010. Growth and associations between auxology, caregiving environment, and cognition in socially deprived Romanian children randomized to foster vs ongoing institutional care. *Archives of Pediatrics & Adolescent Medicine* 164.6: 507–516.

As opposed to those children who remained in the institutional setting, children receiving high-quality foster care at an early age were able to catch up to normal levels of height and weight.

Kaler, S. R., and B. J. Freeman. 1994. Analysis of environmental deprivation: Cognitive and social development in Romanian orphans. *Journal of Child Psychology and Psychiatry* 35.4: 769–781.

This study documented deficits in cognitive and social functioning among children raised in Romanian orphanages.

Le Mare, L., and K. Audet. 2006. A longitudinal study of the physical growth and health of postinstitutionalized Romanian adoptees. *Paediatrics & Child Health* 11.2: 85–91.

This study compared deficits in height and weight among children in institutional settings with their noninstitutionalized peers.

Sheridan, M. A., N. A. Fox, C. H. Zeanah, K. A. McLaughlin, and C. A. Nelson III. 2012. Variation in neural development as a result of exposure to institutionalization early in childhood. *Proceedings of the National Academy of Sciences of the United States of America* 109.32: 12927–12932.

Compared to children raised exclusively in home environments, children with a history of institutionalization (but who had been adopted) had lower cortical gray-matter volume, though white-matter volume did not differ between these groups. Children who remained in institutionalized care did have lower white-matter volume.

Windsor, J., A. Moraru, C. A. Nelson III, N. A. Fox, and C. H. Zeanah. 2013. Effect of foster care on language learning at eight years: Findings from the Bucharest Early Intervention Project. *Journal of Child Language* 40.3: 605–627.

Children who were removed from an institutional setting and placed in foster care by age two displayed an advantage in language development compared to their still-institutionalized counterparts; placement by one year of age boosted children to near-normal language abilities.

Zeanah, C. H., H. L. Egger, A. T. Smyke, et al. 2009. Institutional rearing and psychiatric disorders in Romanian preschool children. *American Journal of Psychiatry* 166.7: 777–785.

This study showed that children raised in institutional settings are at increased risk for psychiatric disease.

Epigenetics

Epigenetics is the field of research that collectively examines how genetic transcription factors can be altered by environmental factors to influence brain and behavior, including the risk for mental illness. Belsky, et al. 2009, an influential paper, challenges the classic diathesis-stress model. Rather than proposing that people are vulnerable to developing psychopathology based on genetic vulnerabilities, Jay Belsky and colleagues argue that genes thought to be vulnerability genes, particularly 5-HTTLPR (thought to increase vulnerability to depression), may be more appropriately conceptualized as plasticity genes that affect one positively or negatively depending on the type of environmental exposure. For example, carriers of the 5-HTTLPR short allele show increases in depression when exposed to negative environments, but they show reductions in depression when exposed to positive environments (Eley, et al. 2004). Therefore, the short-allele carriers are not more vulnerable to depression; rather, they are more affected by the environment, either positively or negatively. Within the literature on rats, Liu, et al. 2000 examines the relationship between maternal care and hippocampal development, finding that offspring of mothers that showed higher levels of pup licking and grooming resulted in increased expression of N-methyl-D-aspartate (NMDA) receptors, which enhanced spatial learning and memory. In related work, the authors of Francis, et al. 1999 performed a series of cross-fostering studies that found a causal relationship between maternal behavior and stress reactivity in offspring. They found that it was more important that the foster mother was a high licker and groomer than if their maternal mother was a high licker and groomer. Having a foster mother that was a high licker and groomer affected gene expression that was related to stress reactivity, even if the rat pup had a maternal mother who was low on licking and grooming. These results all point to the complex relationship between genes and environment in determining behavior.

Belsky, J., C. Jonassaint, M. Pluess, M. Stanton, B. Brummett, and R. Williams. 2009. Vulnerability genes or plasticity genes? *Molecular Psychiatry* 14.8: 746–754.

This experiment examined groups of clinically depressed individuals with variants in the 5-HTTLPR gene and mediating effects from the environment.

Eley, T. C., K. Sugden, A. Corsico, et al. 2004. Gene-environment interaction analysis of serotonin system markers with adolescent depression. *Molecular Psychiatry* 9.10: 908–915.

This study found that depending on the type of 5-HTTLPR allele, a person may be more or less susceptible to environmental factors, either positively or negatively depending on the type of environment.

Francis, D., J. Diorio, D. Liu, and M. J. Meaney. 1999. Nongenomic transmission across generations of maternal behavior and stress responses in the rat. *Science* 286.5442: 1155–1158.

This experiment examined cross-fostered rats that received grooming and high licking either from their maternal or foster mothers, and the authors discuss the importance of maternal behavior for offspring stress response.

Liu, D., J. Diorio, J. C. Day, D. D. Francis, and M. J. Meaney. 2000. Maternal care, hippocampal synaptogenesis and cognitive development in rats. *Nature Neuroscience* 3.8: 799–806.

This experiment found hippocampal synapse changes were dependent on maternal care in developing pups.

Physical and Social Environment

The following sections discuss the importance of social interaction and engaging in natural environments toward improving one's

physical health and psychological functioning. Specifically, research is cited on how loneliness or lack of social interaction can adversely affect health. Research is also presented showing the negative impacts of stress in urban environments on psychological health, and the impacts of low socioeconomic status (SES) on health and other factors. Research has also focused on how perceived disorder of the environment, as posited by the broken-windows theory, can have adverse consequences on behavior. The section closes with research on how interacting with natural environments can be beneficial psychologically, and how environmental interventions can be used to promote health both in clinical and nonclinical populations.

Social Isolation

Humans are a social species and require social interactions to maintain positive physical and mental health. Research has shown that loneliness, or the lack of social interactions, is related to poor health. John Cacioppo and colleagues have looked at the impact of loneliness on health and have found that loneliness predicts morbidity and mortality (Luo, et al. 2012), increased blood pressure (Hawkley, et al. 2010), and reduced physical activity (Hawkley, et al. 2009). In addition to the adverse health effects of social isolation, there is an extensive literature showing that social interactions promote improved physical health and psychological functioning. Kiecolt-Glaser and Newton 2001 reviews the literature on the quality of marital relationships and their effects on male and female physical and mental health. Quality of social interactions has also been found to be important to health outcomes in older adults, as shown by research in Seeman 2000, which shows that positive social interactions promote health and that negative social interactions can result in depression and depressed immune function.

Hawkley, L. C., R. A. Thisted, and J. T. Cacioppo. 2009. Loneliness predicts reduced physical activity: Cross-sectional & longitudinal analyses. *Health Psychology* 28.3: 354–363.

This study found that loneliness in middle- to older-aged adults is a risk factor for physical inactivity and increases the likelihood that physical activity will be discontinued over time.

Hawkley, L. C., R. A. Thisted, C. M. Masi, and J. T. Cacioppo. 2010. Loneliness predicts increased blood pressure: 5-year cross-lagged analyses in middle-aged and older adults. *Psychology and Aging* 25.1: 132–141.

This study examined the impact of loneliness on blood pressure across a five-year time period and found that loneliness can predict an increase in blood pressure.

Kiecolt-Glaser, J. K., and T. L. Newton. 2001. Marriage and health: His and hers. *Psychological Bulletin* 127.4: 472–503.

This review article examines the impact of the quality of a marriage on male and female health.

Luo, Y., L. C. Hawkley, L. J. Waite, and J. T. Cacioppo. 2012. Loneliness, health, and mortality in old age: A national longitudinal study. In *Special issue: Migration, "illegality," and health: Mapping embodied vulnerability and debating health-related deservingness*. *Social Science & Medicine* 74.6: 907–914.

This study found that feelings of loneliness increased mortality rates during a six-year period.

Seeman, T. E. 2000. Health promoting effects of friends and family on health outcomes in older adults. *American Journal of Health Promotion* 14.6: 362–370.

This research article examines the quality of social interactions in older adults and their subsequent effects on health.

Social Stress in Urban Environments

Sustained exposure to stressful social environments can also lead to adverse consequences. For example, Lederbogen, et al. 2011 shows that individuals who have been raised in a primarily urban environment exhibit greater neural activation in stress-related brain areas (i.e., amygdala) when presented with a social stressor. In fact, researchers have found that the incidence of psychopathology is greater in urban environments (van Os, et al. 2003; van Os, et al. 2010). Mitchell and Popham 2008 argues that while there may be many complex factors at play, it is certainly possible that the social stressors that are affiliated with living in urban environments could contribute to poorer health; furthermore, stress may be reduced via access to green space and increased with lack of green space. This suggests that one way to remediate the adverse effects of stressful urban environments is the incorporation of natural green spaces in cities. This will be discussed in greater detail in the Natural Environments and Attention section.

Lederbogen, F., P. Kirsch, L. Haddad, et al. 2011. City living and urban upbringing affect neural social stress processing in humans. *Nature* 474.7352: 498–501.

This study examined how growing up in more-rural versus more-urban environments affects the brain's response to social stress.

Mitchell, R., and F. Popham. 2008. Effect of exposure to natural environment on health inequalities: An observational population study. *The Lancet* 372.9650: 1655–1660.

Large-scale population-based study showing that exposure to natural environments may remediate health inequalities due to differing income levels.

van Os, J., M. Hanssen, M. Bak, R. V. Bijl, and W. Vollebergh. 2003. Do urbanicity and familial liability coparticipate in causing psychosis? *American Journal of Psychiatry* 160.3: 477–482.

This study provided evidence that there is a gene-environment interaction, which may predict incidence of psychosis in humans exposed to urban environments.

van Os, J., G. Kenis, and B. P. F. Rutten. 2010. The environment and schizophrenia. *Nature* 468.7321: 203–212.

This perspective piece examines how psychiatric disorders can be caused by gene-environment interactions, and more specifically how urban environmental factors may increase the incidence of psychopathology, such as schizophrenia.

Socioeconomic Status and Stress

Socioeconomic status (SES) strongly influences an individual's experiences from childhood into adulthood. Growing up in a family with lower SES is associated with impaired cognitive and emotional development as well as deficits in psychological well-being. Hackman, et al. 2010 reviews the literature comparing children and adolescents from higher SES backgrounds to children and adolescents from lower SES backgrounds, finding that the lower-SES group showed greater rates of depression, anxiety, and attention problems, all of which increase with the duration of impoverishment. Among the researchers' findings, chronic stress related to living in dangerous neighborhoods and low social rank within low-SES families mediated impairments in attentional control and working memory, which affected overall child development. In related work, an exploration of social hierarchy in nonhuman primates was conducted by the authors of Sapolsky 2005, who examined how perceived dominance rank, a categorical social ranking found within most social species, influences the extent to which an individual sustains physical and psychological stressors. Although humans are not hierarchical in a linear sense (i.e., humans can belong to multiple hierarchies), these findings support an increasing body of evidence that subjective or perceived SES in humans can be as predictive of health (both psychological and physical) as objective SES (Adler, et al. 2000). Another related study, Capron and Duyme 1989, examines the independent effects of being born to high- or low-SES parents and the effect of being adopted by high- or low-SES parents, in a cross-fostering study in humans. The researchers' findings indicate that children born to parents with high SES score higher on an IQ test than children born to parents with low SES, independent of the SES level of their adoptive parents. In addition, children adopted by high-SES parents score higher than children adopted by low-SES

parents; however, there is no evidence for an interaction between these two factors. These findings provide a unique opportunity for understanding how environmental factors can lead to individual differences. With this understanding, public policies should be constructed to alleviate SES-related disparities to promote healthier neural development.

Adler, N. E., E. S. Epel, G. Castellazzo, and J. R. Ickovics. 2000. Relationship of subjective and objective social status with psychological and physiological functioning: Preliminary data in healthy, white women. *Health Psychology* 19.6: 586–592.

This study examined how perceived socioeconomic status relates to objective socioeconomic status, finding that the two are significantly similar.

Capron, C., and M. Duyme. 1989. Assessment of effects of socio-economic status on IQ in a full cross-fostering study. *Nature* 340.6234: 552–554.

This experiment found that children born to high-SES parents had higher IQ scores than children born to low-SES parents and that children adopted by high-SES parents had higher IQ scores than children adopted by low-SES parents, but these factors were independent from one another.

Hackman, D. A., M. J. Farah, and M. J. Meaney. 2010. Socioeconomic status and the brain: Mechanistic insights from human and animal research. *Nature Reviews Neuroscience* 11.9: 651–659.

This review discusses the ecology of socioeconomic status, and how, in addition to parenting quality and in utero environments, several other factors (e.g., nutrition, drug exposure, stress, toxin exposure) can influence neural development.

Sapolsky, R. M. 2005. The influence of social hierarchy on primate health. *Science* 308.5722: 648–652.

This study examined the effect that dominance rankings in nonhuman primates have on how the organism experiences psychological and physiological stressors, while relating findings to human populations and perceived SES.

Broken-Windows Theory

The “broken-windows theory,” which was proposed by social scientists George L. Kelling and James Q. Wilson (Kelling and Wilson 1982), posited the following basic premise: if the physical environment is clean or orderly, then people will behave in more-orderly ways. While there has been some controversy surrounding this theory, there have been some clever demonstrations that seem to support it. In a very interesting study performed in the Netherlands, researchers examined how likely pedestrians were to steal a five-euro bill attached to a package in a public mailbox. This study, in Keizer, et al. 2008, showed that if the mailbox had graffiti on it, passersby were twice as likely to steal the money than if the mailbox had no graffiti on it. In another study, performed in Lowell, Massachusetts, the author of Johnson 2009 found that cleaning up the physical environment was more effective at reducing crime than putting more police on the street. Additionally, researchers have found that a modest amount of natural setting around public housing projects is related to reductions in crime rates and reports of aggressive behavior (Kuo and Sullivan 2001a, Kuo and Sullivan 2001b). More recently, Vohs, et al. 2013 finds a more nuanced effect whereby orderly environments move people to act in more-conventional ways and to act healthier and also more generously, whereas disorderly environments encourage individuals to act in more-unconventional ways and may increase creativity. All these results point to the fact that the physical environment, and how ordered or disordered it is, can nudge people into different behavioral states.

Johnson, C. Y. 2009. Breakthrough on “broken windows.” *Boston Globe*, 8 February.

This article discusses how disorderly conditions can breed bad behavior and how crime can be linked to “broken windows” in the

environment.

Keizer, K., S. Lindenberg, and L. Steg. 2008. The spreading of disorder. *Science* 322.5908: 1681–1685.

This study rigorously tested the broken-windows theory through a series of well-controlled and ecologically validated experiments.

Kelling, G. L., and J. Q. Wilson. 1982. Broken windows. *The Atlantic*, 1 March.

This seminal article outlines how the organization of the physical environment can influence our behavior.

Kuo, F. E., and W. C. Sullivan. 2001a. Aggression and violence in the inner city: Effects of environment via mental fatigue. *Environment and Behavior* 33.4: 543–571.

This experiment tested the hypothesis that contact with nature may mitigate mental fatigue and reduce aggressiveness and violence; Kuo and Sullivan's results showed that the relationship between nearby nature and aggression was fully mediated through attentional improvements.

Kuo, F. E., and W. C. Sullivan. 2001b. Environment and crime in the inner city: Does vegetation reduce crime? *Environment and Behavior* 33.3: 343–367.

This article shows the positive impact of nearby nature on reducing aggression, mental fatigue, and crime in a Chicago public housing project.

Vohs, K. D., J. P. Redden, and R. Rahinel. 2013. Physical order produces healthy choices, generosity, and conventionality, whereas disorder produces creativity. *Psychological Science* 24.9: 0.

This study examined how the order and disorder of the environment can push people into being more generous/conventional versus being more creative/unconventional.

Natural Environments and Attention

Research and theory have suggested that interacting with natural environments, such as a city park, can have salubrious effects on psychological functioning. One of the primary theories to suggest why interacting with nature may be beneficial is attention restoration theory (ART) (Kaplan 1995, Kaplan and Berman 2010). The basic premise of ART is that attention comes in two forms. One form is directed attention (i.e., top-down attention), where the individual person controls his or her attentional focus. It is thought that this sort of attention is susceptible to fatigue, and therefore one can direct his or her attention only for so long before mental fatigue sets in. The second form is involuntary attention (i.e., bottom-up attention), where attention is captured automatically by interesting stimulation in the environment. It is thought that this sort of attention is not as susceptible to fatigue. Therefore, the idea behind ART is to interact with environments rich with interesting stimulation to activate involuntary attention, while simultaneously not placing demands on directed attention (Berman, et al. 2008; Kaplan 1995; Kaplan and Berman 2010). Most natural environments typically contain this duality. In addition, ART makes the distinction between how involuntary attention needs to be captured. Soft fascination implies a soft attentional capture from environmental stimulation such as the attentional capture that would be instantiated by a waterfall or painting. Harsh fascination implies a stronger attentional capture that is all consuming and would be instantiated by loud noises, bright lights, etc. Therefore, ART also makes the distinction between soft and harsh fascination, with the former leading to a restorative capture of involuntary attention (Kaplan 1995, Kaplan and Berman 2010). Natural environments tend to meet these criteria, but other built environments may also meet these same criteria (e.g., walking through a museum). Evidence in support of ART comes from a number of experimentally controlled studies that find that walking through natural environments leads to improvements in objective measures of

memory and attention (Berman, et al. 2008; Berman, et al. 2012). Mood also tends to improve after interacting with nature but does not correlate with the memory benefits, suggesting independent mechanisms (Berman, et al. 2008; Berman, et al. 2012). More-recent work in this area, such as in Berman, et al. 2014, has focused on the low-level visual features of nature that may produce these benefits to inform the design of newly built environments.

Berman, M. G., M. C. Hout, O. Kardan, et al. 2014. The perception of naturalness correlates with low-level visual features of environmental scenes. *PLoS ONE* 9.12: e114572.

This study examined the low-level visual features that predict perceptions of naturalness and how those salient features could be manipulated to examine their restorative power.

Berman, M. G., J. Jonides, and S. Kaplan. 2008. The cognitive benefits of interacting with nature. *Psychological Science* 19.12: 1207–1212.

This article reports the results of two experiments that measured both attention and memory after exposure to nature via walks or visual images; the results validated the ART theory.

Berman, M. G., E. Kross, K. M. Krpan, et al. 2012. Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders* 140.3: 300–305.

This study showed that interacting with nature can be salubrious for individuals diagnosed with major depressive disorder.

Kaplan, S. 1995. The restorative benefits of nature: Toward an integrative framework. In *Special issue: Green psychology*. *Journal of Environmental Psychology* 15.3: 169–182.

This is the first article to present ART, and and it argues why interacting with nature may be restorative to psychological processing.

Kaplan, S., and M. G. Berman. 2010. Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science* 5.1: 43–57.

This paper presents evidence as to the common resource between executive functioning and self-regulation being the ability to direct attention and how that resource can be restored via interactions with nature.

Environmental Interventions and Other Theories

There is a growing body of evidence that interacting with natural environments can promote communal well-being as well as increase psychological and physical health. Across Europe and the United States, recreational or work-related activities on agricultural grounds are serving as a rehabilitative source for drug abusers, people with learning disabilities, and even the elderly. Hassink and van Dijk 2006 posits that social farming, or “green care farming” services can bolster self-esteem, social skills, responsibility, and physical health while improving the social community. Zhang, et al. 2014 extends past research by demonstrating how the perception of nature as “beautiful” can give rise to unique prosocial benefits. The researchers provide evidence that positive emotions and tendencies to perceive nature as beautiful both mediate and moderate the association between beauty and prosociality. Concerning nature’s benefits on overall health, research in Cimprich and Ronis 2003 found positive effects of interacting with nature for breast cancer patients. A related and seminal study, Ulrich 1984, shows that patients recovering from gallbladder surgery recovered faster and used fewer analgesics if they had a view of a modest amount of nature from their hospital room, compared to patients who had a view of a wall. There are other theories that posit why interacting with nature is restorative. One such theory, known as the biophilia hypothesis, claims that interacting with nature is restorative because of human beings’ innate love of nature and an innate desire to be in natural

environments (Kellert and Wilson 1993, Wilson 1984). Other theories claim that interacting with nature is beneficial because it increases one's feelings of connectedness (Mayer, et al. 2009), reduces stress levels (Laumann, et al. 2003; Ulrich, et al. 1991), or improves mood (van den Berg, et al. 2007). While there may be many differing mechanisms that lead to psychological improvements, there is little argument that interacting with these environments can improve psychological functioning, and perhaps clinicians can include exposure to a natural environment as a means of rehabilitation. Further research into environmental interventions will ultimately give rise to design guidelines for the construction of urban parks and other built environments to promote health. One hopes that this body of research will offer a realistic framework to develop policy to ensure that natural spaces proliferate, particularly in urban settings.

Cimprich, B., and D. L. Ronis. 2003. An environmental intervention to restore attention in women with newly diagnosed breast cancer. *Cancer Nursing* 26.4: 284–292.

This study examined how a natural-environment intervention can be beneficial for women newly diagnosed with breast cancer, compared to control condition where women could select different activities to perform.

Hassink, J., and M. van Dijk, eds. 2006. *Farming for health: Green-care farming across Europe and the United States of America*. Wageningen UR Frontis 13. Dordrecht, The Netherlands: Springer.

This looks at the benefits of social farming both as a societal aid for communities and as an individual rehabilitative aid for various physical and psychological ailments.

Kellert, S. R., and E. O. Wilson, eds. 1993. *The biophilia hypothesis*. Washington, DC: Island.

This book explains the idea that there exists an innate tendency to appreciate life and lifelike processes, which may give rise to the physiological and psychopathological benefits of nature viewing.

Laumann, K., T. Gärling, and K. M. Stormark. 2003. Selective attention and heart rate responses to natural and urban environments. In *Special issue: Restorative environments*. *Journal of Environmental Psychology* 23.2: 125–134.

This experiment measured cardiac interbeat interval and voluntary attention capacity while manipulating video content exposure (i.e., subjects viewed either nature or urban videos); results indicate that the nature video reduced autonomic arousal and engendered less spatially selective attention.

Mayer, F. S., C. M. Frantz, E. Bruehlman-Senecal, and K. Dolliver. 2009. Why is nature beneficial? The role of connectedness to nature. *Environment and Behavior* 41.5: 607–643.

This study examined how participants' feelings of connectedness to nature led to psychological benefits after an interaction with nature.

Ulrich, R. S. 1984. View through a window may influence recovery from surgery. *Science* 224.4647: 420–421.

Seminal study showing that people recovering from surgery had better recoveries if they had views of nature from their hospital rooms, compared to views of built objects.

Ulrich, R. S., R. F. Simons, B. D. Losito, E. Fiorito, M. A. Miles, and M. Zelson. 1991. Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology* 11.3: 201–230.

This experiment measured physiological changes in subjects who viewed a stressful video followed either by urban or natural videos, finding that subjects' rates of physiological recovery were faster when exposed to natural videos rather than urban ones.

van den Berg, A. E., T. Hartig, and H. Staats. 2007. Preference for nature in urbanized societies: Stress, restoration, and the pursuit of sustainability. *Journal of Social Issues* 63.1: 79–96.

This article discusses the challenges of urbanicity and compares four key research issues when designing urban societies that would conform to environmental preferences.

Wilson, E. O. 1984. *Biophilia*. Cambridge, MA: Harvard Univ. Press.

This book provides further evidence of the suggestion in the biophilia hypothesis for an instinctive bond between human beings and other living systems.

Zhang, J. W., P. K. Piff, R. Iyer, S. Koleva, and D. Keltner. 2014. An occasion for unselfing: Beautiful nature leads to prosociality. *Journal of Environmental Psychology* 37:61–72.

This experiment used a series of independent variables to examine how perceiving nature as beautiful gives rise to prosociality. This study showed how the organization of the environment influences conventional and unconventional behavior, finding both pros and cons to orderly and disorderly environments.

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