



PAPER

Environmental stimulation, parental nurturance and cognitive development in humans

Martha J. Farah,¹ Laura Betancourt,¹ David M. Shera,²
Jessica H. Savage,¹ Joan M. Giannetta,³ Nancy L. Brodsky,³
Elsa K. Malmud³ and Hallam Hurt³

1. Department of Psychology and Center for Cognitive Neuroscience, University of Pennsylvania, USA

2. Division of Biostatistics and Epidemiology, Department of Pediatrics, Children's Hospital of Philadelphia and University of Pennsylvania; Department of Epidemiology and Biostatistics, University of Pennsylvania, USA

3. Division of Neonatology, Department of Pediatrics, University of Pennsylvania and Children's Hospital of Philadelphia, USA

Abstract

The effects of environmental stimulation and parental nurturance on brain development have been studied extensively in animals. Much less is known about the relations between childhood experience and cognitive development in humans. Using a longitudinally collected data set with ecologically valid in-home measures of childhood experience and later in-laboratory behavioral measures of cognitive ability, we were able to test hypotheses concerning the effects of environmental stimulation and parental nurturance. A double dissociation was found: On the one hand, there was a selective relation between parental nurturance and memory development, consistent with the animal literature on maternal buffering of stress hormone effects on hippocampal development. On the other hand, there was a selective relation between environmental stimulation and language development. The relevance of these findings to socioeconomic gradients in cognitive ability is discussed.

Introduction

Animal studies have provided decisive evidence that variation in early life experience influences subsequent brain and cognitive function, and these studies also suggest specific mechanisms by which experience shapes the brain. However, the generalizability of these research findings to the development of normal healthy humans has yet to be assessed. In this article we address the relation between childhood experience and cognitive development in humans, with particular attention to three questions.

The first question concerns the similarity between the effects of experience on animal and human development. Although it is not possible to experimentally vary the nature of children's early home lives in order to replicate the animal studies, it is possible to measure naturally occurring variation in the same general dimensions of experience that have been manipulated in animal studies. These measurements provide a basis for testing hypotheses suggested by the animal research. The second question concerns the specificity of the relations between childhood experience and cognitive outcome. Is the effect of childhood experience on later cognitive attainment relatively global and undifferentiated, with generally

better early environments associated with generally better cognitive function? Alternatively, are differences in specific aspects of childhood experience associated with differences in the development of specific cognitive systems? This question is related to the first, insofar as the animal literature suggests a degree of specificity in the relationships between early experience and later cognitive function. Finally, the third question concerns possible explanations for the disparities in cognitive attainment across different levels of socioeconomic status.

Rosenzweig (Rosenzweig, 1966; Rosenzweig, Bennett, Hebert & Morimoto, 1978) and Greenough (Greenough, 1975; Greenough, Black & Wallace, 1987) carried out some of the earliest systematic investigations of the effects of environment on brain development in rodents. From this and subsequent research we know that experience plays a causal role in animal brain development, and we know some of the specific aspects of experience that are influential. The variety and complexity of the cage environment influences many different aspects of brain structure, including the number of neurons, glial cells, myelination, blood supply, dendrites and synapses. Brain function, measured in terms of neurotransmitter and growth factor activity, adult neurogenesis, single cell electrophysiology and whole animal behavior, is also

Address for correspondence: Martha J. Farah, Department of Psychology and Center for Cognitive Neuroscience, University of Pennsylvania, 3720 Walnut Street, Philadelphia, PA 19104, USA; e-mail: mfarah@psych.upenn.edu

affected. These changes in structure and function have been observed across a wide range of cortical and subcortical brain areas (see van Praag, Kempermann & Gage, 2000, for a review).

The characteristics of the environment responsible for stimulating positive brain changes include a variety of toys, changed on a regular basis, which provide stimulation, novelty and opportunity for perceptual, cognitive and motor activity, as well as social interaction. Attempts to isolate a single critical factor in this set of environment factors have failed. For example, the effects of allowing visual access to the complex environment without the opportunity for physical exploration (Ferchmin & Bennett, 1975), physical activity in a standard laboratory cage (Bernstein, 1973; Rosenzweig *et al.*, 1978) or social interaction in a standard laboratory cage (Rosenzweig *et al.*, 1978) are either substantially reduced or null.

Whereas perceptual, motoric and social stimulation seem to function as a complex whole in stimulating brain development, there is one aspect of early experience that may operate at least somewhat independently as an influence on brain development, namely stress. The stress of prolonged maternal separation (i.e. hours per day) on young animals has been shown to exert lasting negative effects on brain development, particularly hippocampal development. In contrast, the effect of a brief handling (minutes per day), which also separates the animal from its mother, appears beneficial. Both prolonged maternal separation and brief handling affect later life stress regulation ability and memory ability as a result of their impact on hippocampal development. The salutary effect of brief separations appears to result from the intensified nurturing behavior that follows the separation. The more a mother rat licks her pup following a brief stressor, the better regulated the pup's later response to stressors and the better its learning ability (Liu, Diorio, Day, Francis & Meaney, 2000).

The majority of research on experience and the brain has been conducted with rodents, but similar effects of environmental stimulation and stress have also been observed in nonhuman primates (Kozorovitskiy, Gross, Kopil, Battaglia, McBreen, Stranahan & Gould, 2005; Parker, Buckmaster, Sundlass, Schatzberg & Lyons, 2006). Experimental studies of the effects of childhood experience in humans do not exist. The closest type of study can be found in the literature on intervention effects, in which one or more aspects of childhood experience is manipulated for some delimited period of time. Although substantial and socially important effects have been found in many of these studies (e.g. Barnett & Hustedt, 2005; Campbell, Pungello, Miller-Johnson, Burchinal & Ramey, 2001), none published to date has been designed to reveal effects of specific aspects of experience on specific neurocognitive systems. In addition, many interventions manipulate experience along different dimensions from the ways in which normal childhood experiences differ, and may best be thought of as superimposing new and potentially helpful

experiences rather than remodeling the existing context of the child's life. Given the virtual impossibility of randomly assigning children to different, experimentally controlled childhoods, most studies of the effects of childhood experience are correlational.

There are two main types of correlational study relevant to the effects of childhood experience on human development. The first type involves children who have experienced trauma or abuse and compares them with children who have not suffered in this way. Studies of extreme adverse experience address certain important questions about the etiology of psychopathology and resilience (Teicher, Andersen, Polcari, Anderson, Navalta & Kim, 2003) but are not directly relevant to the relation between variation in normal childhood experience and variation in normal brain development.

The second type of human study addresses normal development more directly, by assessing the relationship between overall quality of early life experience and later intellectual attainment. Such studies have demonstrated that more cognitive stimulation and less socioeconomic adversity are associated with better outcomes on many broadband cognitive outcome measures such as IQ and school achievement (e.g. Bradley, Conyn, Burchinal, McAdoo & Coll, 2001; Evans, 2004). However, these findings do not allow us to answer the questions posed earlier concerning the specificity of effects or their relationship to the mechanisms demonstrated in animal research.

The present study is a first investigation of how normal variation in childhood experience is related to specific differences in cognitive functions associated with distinct neurocognitive systems. Specifically, we attempted to identify the human counterparts of the two types of early life experience studied in animals, environmental enrichment and stress-buffering maternal behaviors, and to analyze their relationships to later cognitive function.

The neurocognitive systems of *a priori* interest were the language and memory systems. We chose these systems for two reasons. First, they are among the systems that reliably correlate with SES in various studies. In our own previous work assessing the neurocognitive profile of SES-related abilities in kindergarten, first grade and middle school children, the largest SES effects have invariably been in language abilities (Farah, Shera, Savage, Betancourt, Giannetta, Brodsky, Malmud & Hurt, 2006; Noble, Norman & Farah, 2005; Noble, McCandliss & Farah, 2007). Long-term memory also correlated strongly with SES in the two studies that assessed it following a delay (Farah *et al.*, 2006; Noble *et al.*, 2007). Research that was focused on these specific systems, as opposed to the overall profile, also shows pronounced SES effects (for reviews see Hermann & Guadagno, 1997; Whitehurst, 1997). These systems show the most pronounced SES disparities, along with executive functions. In our previous studies we found cognitive control and working memory to be particularly dependent upon SES. This is consistent with other studies in which executive

function alone has been assessed in children of low SES (e.g. Blair, 2002; Lipina, Martelli, Vuelta & Colombo, 2005; Mezzacappa, 2004).

In our previous studies and in the present one, language and memory were assessed behaviorally using tasks (a) that are face valid for language and memory processing and (b) for which published imaging and patient data indicate an uncontroversial localization to left perisylvian and medial temporal regions, respectively. Each system was assessed with two different tasks and a composite score for each neurocognitive system was created by averaging the within-sample *z*-scores for each pair of tasks.

SES is correlated with many aspects of childhood experience. Higher SES is associated with greater environmental stimulation in the form of toys, books, trips, conversation, and less childhood stress, including less stress on the family as a whole and more supportive parenting practices (e.g. Bradley *et al.*, 2001). If these correlates of SES are in part responsible for the differences in neurocognitive outcome between low and middle SES children, then they would be expected to vary systematically with outcome even within a level of SES. Using the longitudinally collected data on the home lives of the subjects of the present study, who were of low SES, we were able to test this hypothesis.

Children's home experience was evaluated at ages 4 and 8 years using the Home Observation for Measurement of the Environment (HOME) Inventory, a 1-hour structured interview and observational checklist that includes subscales measuring specific aspects of the child's home life (Caldwell & Bradley, 1984). Composites for Environmental Stimulation were created by averaging the *z*-scores subscales that emphasize the availability of cognitively stimulating toys and activities. For Parental Nurturance, the corresponding subscales emphasized the warmth and availability of parental care. Specific subscales with examples of items are listed in the Methods section.

Methods

Study participants

One hundred and ten African American middle school-aged children (mean age 11.8 yr, *SD* = 1 yr), of whom 59% were female, participated in the study. They had been recruited at birth for a study of the effects of gestational cocaine exposure (for full details see Hurt, Brodsky, Betancourt, Braitman, Malmud & Giannetta, 1995a; Hurt, Brodsky, Braitman & Giannetta, 1995b). Maternal use of cocaine as well as amphetamines, opiates, barbiturates, benzodiazepines, marijuana, alcohol and tobacco was ascertained by interview and medical record review at time of birth and, for all but the last three, maternal and infant urine specimens. Use of drugs other than tobacco, alcohol, marijuana and cocaine was an exclusionary criterion. The children were born at

a single inner-city hospital, of mothers receiving public assistance, at or near term, with a mean gestational age of 38.4 weeks (*SD* = 2.2), a mean 5-minute Apgar score of 8.8 (*SD* = .6), normal cranial ultrasound and no asphyxiation. Mothers were native English speakers free of major psychiatric illness. None of the children had Fetal Alcohol Syndrome or any chromosomal disorder known to be associated with developmental delay. Since enrollment, the children have been evaluated semi-annually for measurements of growth, development, language, and cognitive and social-emotional outcomes (Hurt, Brodsky, Betancourt, Braitman, Belsky & Giannetta, 1996; Hurt *et al.*, 1995a; Hurt, Brodsky, Roth, Malmud & Giannetta, 2005; Hurt, Giannetta, Brodsky, Malmud & Pelham, 2001; Hurt, Malmud, Betancourt, Braitman, Brodsky & Giannetta, 1997; Hurt, Malmud, Betancourt, Brodsky & Giannetta, 1997; Hurt, Malmud, Betancourt, Brodsky & Giannetta, 2001; Hurt, Malmud, Braitman, Betancourt, Brodsky & Giannetta, 1998; Hurt, Malmud, Brodsky & Giannetta, 2001). Assent was obtained from all participating children and informed consent was obtained from their parents or guardians. The project was conducted in accordance with the principles expressed in the Declaration of Helsinki and was approved by the Institutional Review Boards of the University of Pennsylvania and Children's Hospital of Philadelphia.

Measures

Environmental stimulation, parental nurturance and other potential influences on neurocognitive development

Children's home environments were evaluated at age 4 years (4.1 ± 0.2) and 8 years (8.4 ± 0.5) using the Home Observation for Measurement of the Environment (HOME) Inventory (Bradley, 1994; Caldwell & Bradley, 1984). The HOME is a 1-hour structured interview and observational checklist that includes subscales measuring specific aspects of the child's home life. Two composites, measuring environmental stimulation and parental nurturance, were created by averaging the *z*-scores of the relevant subscales listed here.

The *Environmental Stimulation* composite incorporated those subscales that seemed most analogous to the experiential factors that vary with environmental enrichment in animal studies. For 4-year-olds, these subscales (with two sample items from each) included: Learning stimulation ('child has toys which teach color', 'at least 10 books are visible in the apartment'), language stimulation ('child has toys that help teach the names of animals', 'mother uses correct grammar and pronunciation'), academic stimulation ('child is encouraged to learn colors', 'child is encouraged to learn to read a few words'), modeling ('some delay of food gratification is expected', 'parent introduces visitor to child'), and variety of experience ('child has real or toy musical

instrument', 'child's art work is displayed some place in house'). For 8-year-olds, the relevant subscales were: Growth fostering materials and experiences ('child has free access to at least ten appropriate books', 'house has at least two pictures of other type of art work on the walls'), provision for active stimulation ('family has a television, and it is used judiciously, not left on continuously', 'family member has taken child, or arranged for child to go to a scientific, historical or art museum within the past year'), family participation in developmentally stimulating experiences ('Family visits or receives visits from relatives or friends at least once every other week', 'family member has taken child, or arranged for child to go, on a trip of more than 50 miles from his home').

The *Parental Nurturance* composite incorporated those subscales that measured the warmth and availability of parental care. For 4-year-olds, these subscales (with two sample items from each) included: Warmth and affection ('parent holds child close 10–15 minutes per day', 'parent converses with child at least twice during visit') and acceptance ('parent does not scold or derogate child more than once', 'parent neither slaps nor spansks child during visit'). For 8-year-olds, the subscales used were: Emotional and verbal responsivity ('Child has been praised at least twice during past week for doing something', 'parent responds to child's questions during interview'), encouragement of maturity ('family requires child to carry out certain self-care routines', 'parents set limits for child and generally enforce them'), emotional climate ('parent has not lost temper with child more than once during previous week', 'parent uses some term of endearment or some diminutive for child's name when talking about child at least twice during visit') and paternal involvement ('Father [or father substitute] regularly engages in outdoor recreation with child', 'Child eats at least one meal per day, on most days, with mother and father [or mother and father figure]').

Two other variables with the potential to account for differences in neurocognitive development included in our analyses were prenatal substance exposure and maternal intelligence. *Prenatal Substance Exposure* was coded for analysis on an integer scale of 0–4, with 1 point for each of the following substances: tobacco, alcohol, marijuana and cocaine. Use of other substances was an exclusionary criterion. Fifty-six percent of the children in this sample had gestational exposure to cigarettes, 70% to alcohol, 21% to marijuana and 46% were exposed to cocaine.

Maternal Intelligence was measured by the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) when the child was 6 years old. Maternal intelligence could influence child neurocognitive outcome by genetic mechanisms or by its effect on the environment and experiences provided by the mother for the child. Mean Full Scale IQ score was 83 ($SD = 9$), typical for this demographic (Kaufman, McLean & Reynolds, 1988; Lange, Chelune, Taylor, Woodward & Heaton, 2006).

Cognitive ability

Children's neurocognitive functioning was evaluated using a battery of neurocognitive tasks, each designed to tax a specific neurocognitive system defined by functional and anatomical criteria. Seven neurocognitive systems were assessed, although the focus of the present study was the two systems previously found to be most strongly associated with SES (Farah *et al.*, 2006; Noble *et al.*, 2007) and only these tasks are described here. They are the language system and the memory system. Each system was assessed with two different tasks and a composite score for each neurocognitive system was created by averaging the *z*-scores for each pair of tasks.

The *Language* system was assessed by a pair of tasks that tap two main and distinct components of language ability, lexical semantics and syntax. We assessed these with well-known and age-appropriate instruments.

Peabody Picture Vocabulary Test (PPVT). This is a standardized vocabulary test for children between the ages of 2.5 and 18. On each trial, the child hears a word and must select the corresponding picture from among four choices. Similar word–picture matching tasks used in functional neuroimaging studies also implicate fronto-temporal cortex (Thompson-Schill, D'Esposito, Aguirre & Farah, 1997).

Test for Reception of Grammar (TROG). In this sentence–picture matching task designed by Bishop (1983), the child hears a sentence and must choose the picture, from a set of four, which depicts the sentence. Its lexical-semantic demands are negligible, as the vocabulary is simple and a pre-test ensures that subjects know the meanings of the small set of words that occur in the test. The syntactic abilities tested here localize to left perisylvian frontal and temporal cortex (Just, Carpenter, Keller, Eddy & Thulborn, 1996).

The *Memory* system was assessed by two incidental learning tasks. Most standard memory tests are sensitive to both medial temporal and prefrontal function, because performance is influenced by the subject's ability to organize the material to be learned and apply mnemonic strategies. We used incidental learning tests, in which the subject does not know that a memory test is coming when the to-be-remembered stimuli are presented, in order to obtain a relatively pure measure of learning ability.

Incidental word learning. In the word learning task, the child views pairs of pictures, presented one pair on a page, and must point to the one named aloud by the experimenter. During the 'test' phase, the child listens to a list of words and must decide which items were viewed earlier. Patients with medial temporal damage do poorly on incidental word learning (Mayes, Meudell & Neary, 1978).

Incidental face learning. This task is analogous to the task with words, except that the learning set stimuli are photographs of faces and the exposure to the initial set takes place while participants judge the faces to be older

or younger than 30 years. Medial temporal damage also impairs incidental learning of visual materials, including faces (Mayes, Meudell & Neary, 1980).

Data analysis

To reduce the effect of outlier data points, values of cognitive task performance and the two childhood experience composites were Winsorized (Chen, Welsh & Chan, 2001), that is, the two most extreme values at each end of the distribution of all children's scores were replaced with the third most extreme value at each end. Fifteen children were missing either the age 4 or age 8 HOME visit, and their *Environmental Stimulation* and *Parental Nurturance* composites were therefore based on only one visit and were weighted accordingly in the regression analyses.

Data were analyzed using stepwise regression. This involves building a model of the association between multiple potential causal factors and an outcome. In backward stepwise regression, all of the factors are initially used to model the outcome, and then the least useful factor is iteratively eliminated until further elimination significantly reduces the fit of the model to the outcome data. In forward stepwise regression, the model is built up one factor at a time until further additions fail to significantly increase the fit of the model.

Initially, backwards stepwise regressions were performed with each cognitive system composite as the dependent variable and *Environmental Stimulation*, *Parental Nurturance*, *prenatal substance exposure*, and *maternal intelligence*, along with the child's gender and age at time of neuro-cognitive testing, as independent variables. Removal level for all backward selection was set at 0.10. The same data were then analyzed using forward stepwise regression, with entry level criterion set at 0.05. This was expected to result in similar models but with possibly fewer variables because of the more stringent inclusion criterion.

Results

The results reveal a double dissociation between two different aspects of childhood experience and their effects on the development of two different cognitive systems. As can be seen in Table 1, the largest effect on the Language composite was the Environmental Stimulation composite, with more stimulation associated with better language ability. This was a moderately large effect; after adjusting for age, each standard deviation of difference in Environmental Stimulation was associated with over two-thirds of a standard deviation (.704, to be exact) of difference in language ability. In addition, children's age at time of testing was positively associated with their language ability. None of the other child, maternal or home variables predicted language ability. Specifically, after adjusting for age and Environmental Stimulation, the Parental Nurturance composite, maternal intelligence, prenatal substance exposure and, surprisingly, gender failed to predict significant variance in the Language composite. An identical pattern of results was obtained by forward (model|variable) regression. Figure 1 illustrates the relationship between the composite measures for environmental stimulation and language.

As shown in Table 2, the largest effect on the Memory composite was the Parental Nurturance composite, with more nurturance associated with better memory ability in both backward and forward selection analyses. This was a small-to-medium effect; after adjusting for age and prenatal substance exposure, each standard deviation of difference in Parental Nurturance was associated with about a third of a standard deviation of difference in memory ability (.325 and .340). Two other variables remained in the model obtained by backward selection, but were not included after forward selection. As for language, children's age at time of testing showed a weak positive association with memory ability in the backward selection analysis. In addition, backwards selection identified a weak negative association between prenatal

Table 1 Final models for stepwise regression of environmental stimulation composite, parental nurturance composite, prenatal substance exposure, maternal intelligence, gender and age on language composite score. (a) backward (model|variable) selection; (b) forward (model|variable) selection. Results indicate that the largest and most significant factor accounting for variance in language ability measured at middle school age is the amount of environmental stimulation experienced earlier in childhood. Age at time of testing was also a significant factor for language ability. Other variables, including earlier childhood parental nurturance, were not predictive

Dependent variable and analysis	Language composite Backward selection			Language composite Forward selection		
	<i>B</i>	<i>t</i>	<i>p</i>	<i>B</i>	<i>t</i>	<i>p</i>
Intercept	-3.239	-2.810	0.006	-3.239	-2.810	0.006
Age at language testing	0.268	2.747	0.007	0.268	2.747	0.007
Gender	-	-	-	-	-	-
Maternal IQ	-	-	-	-	-	-
Prenatal substance exposure	-	-	-	-	-	-
Parental nurturance	-	-	-	-	-	-
Environmental stimulation	0.704	4.305	0.000	0.704	4.305	0.000

Table 2 Final models for stepwise regression of environmental stimulation composite, parental nurturance composite, prenatal substance exposure, maternal intelligence, gender and age on Memory composite score. (a) backward (modellvariable) selection; (b) forward (modellvariable) selection. Results indicate that the largest and most significant factor accounting for variance in memory ability measured at middle school age is the amount of parental nurturance experienced earlier in childhood. Age at time of testing and prenatal polysubstance exposure were also found to be more weakly predictive in the backwards selection analysis, but did not enter the model in the forward selection analysis. Other variables, including earlier childhood environmental stimulation, were not predictive

Dependent variable and analysis	Memory composite Backward selection			Memory composite Forward selection		
	<i>B</i>	<i>t</i>	<i>p</i>	<i>B</i>	<i>t</i>	<i>p</i>
Intercept	-1.586	-2.130	0.036	-0.031	-0.486	0.628
Age at memory testing	0.144	2.252	0.027	–	–	–
Gender	–	–	–	–	–	–
Maternal IQ	–	–	–	–	–	–
Prenatal substance exposure	-0.098	-2.202	0.031	–	–	–
Parental nurturance	0.325	2.838	0.006	0.340	2.927	0.004
Environmental stimulation	–	–	–	–	–	–

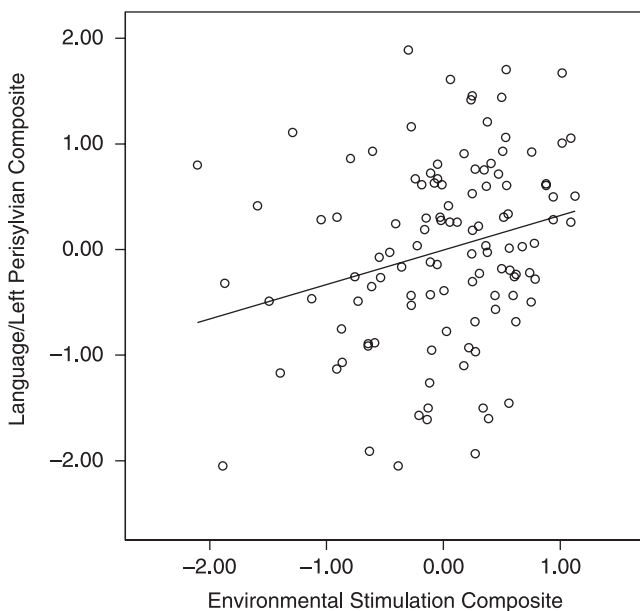


Figure 1 Scatter plot of winsorized Environmental Stimulation and Language Composite scores.

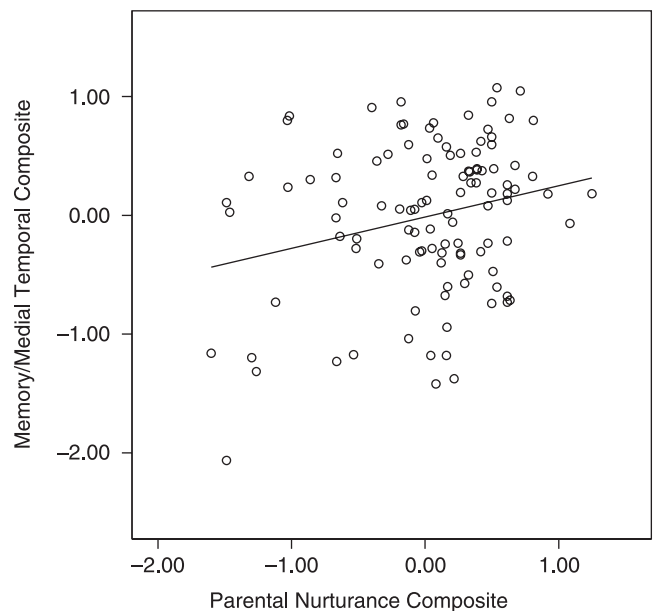


Figure 2 Scatter plot of winsorized Parental Nurturance and Memory Composite scores.

substance exposure and memory ability. None of the other variables accounted for significant variance in the Memory composite. Figure 2 illustrates the relationship between the composite measures for parental nurturance and memory.

Discussion

Common sense tells us that childhood experience affects cognitive development. Yet common sense does not tell us which psychological or brain functions will be affected by experience, or which specific aspects of childhood experience will exert an effect. The research reported here was an attempt to address these issues

empirically with a unique longitudinally collected data set including ecologically valid in-home measures of early childhood experience and later laboratory measures of cognitive function. The effects found were strikingly selective and, in addition to their statistical significance, were substantial in size.

This research was motivated by the desire to understand the causal influence of childhood experience on later neurocognitive function. However, without having experimentally manipulated our participants' childhoods – clearly an impossibility – we cannot be certain of the direction of causality. This is particularly true of the association between environmental stimulation and language ability. Perhaps children who are more verbal succeed in soliciting more books, educational toys and trips to the zoo from

their caregivers. Perhaps parents who are more verbal are also more likely to give their children books, toys and trips as well as transmitting their genes for verbal ability. Multiple mechanisms, acting alone or in combination, may underlie the observed association.

Analogous explanations of the association between parental nurturance and memory ability are logically possible as well, but much less plausible. There is no obvious reason why children with better memory would elicit more nurturing behavior from their parents, or why memory and parenting would have a common genetic basis. In addition, a causal effect of parental nurturance on memory ability has been demonstrated in animals, strengthening the interpretation that our participants' memory ability was influenced by their earlier life experience.

The children in our study sample were African Americans of low socioeconomic status, which distinguishes them from a nationally representative sample of American children, or children worldwide. We cannot be certain whether the results obtained with this sample would generalize to children of differing nationality, ethnicity or socioeconomic background. This is an empirical issue that we are beginning to pursue with a socioeconomically more diverse sample. Whatever the outcome, low SES is not in itself abnormal or atypical. Over 17% of American children live below the poverty line according to the 2004 census.

SES is associated with many different types of life outcome, including physical health, mental health and cognitive ability. Typical life experiences differ across the socioeconomic spectrum, and some of these differences appear to play a causal role in life outcomes. For example, stressful events are more common in the lives of lower SES individuals (Dohrenwend, 1973), and this disparity has been linked to health disparities (Anderson & Armstead, 1995). When measured standard deviation for standard deviation, the relationship between SES and cognitive ability is stronger than that between SES and physical health or mental health (Duncan, Yeung, Brooks-Gunn & Smirth, 1998). Furthermore, the impact of poverty on children's cognitive development represents a plausible mechanism for the intergenerational transmission of poverty. Overcoming the many environmental, social, economic and political obstacles that impede upward socioeconomic mobility is a challenge in itself, and is all the more daunting for those with lowered cognitive resources. We therefore have a strong social as well as scientific incentive to understand the complex relations among SES, life experience and cognitive development.

How do the results of this study bear on the questions posed earlier? First, they suggest that the same general dimensions of early life experience identified as important in animal studies of brain development are also important for humans. In particular, the relation between the composites measuring parental nurturance and later memory ability, which have no common-sense

connection, is consistent with studies of experience and brain development in animals. The present findings thus provide an important bridge between the study of neuro-cognitive development in animals and humans. Second, variation in the childhood experience of healthy humans bears a systematic relationship to cognitive development, and this relationship is more selective and specific than simply better environments predicting better development. Memory development is predicted by parental nurturance but not environmental stimulation, whereas language development is predicted by environmental stimulation, but not parental nurturance. Finally, these effects represent a possible mechanism by which socio-economic status is associated with intellectual attainment.

Acknowledgements

The authors appreciate the helpful comments of Adele Diamond and Bruce McEwen on an earlier version of this paper. The research reported here was supported by NIH grants R21-DA01586, R01-HD043078, R01-HD055689, R01-DA14129 and R01-DA18913.

References

- Anderson, N.B., & Armstead, C.A. (1995). Toward understanding the association of socioeconomic status and health: a new challenge for the biopsychosocial approach. *Psychosomatic Medicine*, **57** (3), 213–225.
- Barnett, W.S., & Hustedt, J.T. (2005). Head Start's lasting benefits. *Infants and Young Children*, **18**, 16–24.
- Bernstein, L. (1973). A study of some enriching variables in a free-environment for rats. *Journal of Psychosomatic Research*, **17** (2), 85–88.
- Bishop, D.V.M. (1983). *The Test for Reception of Grammar*. Age and Cognitive Performance Research Centre, University of Manchester.
- Blair, C. (2002). School readiness: integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist*, **57**, 111–127.
- Bradley, R.H. (1994). The HOME Inventory: review and reflections. In H.W. Reese (Ed.), *Advances in child development and behavior* (Vol. 25, pp. 241–288). San Diego, CA: Academic Press.
- Bradley, R.H., Convyn, R.F., Burchinal, M., McAdoo, H.P., & Coll, C.G. (2001). The home environments of children in the United States part II: relations with behavioral development through age thirteen. *Child Development*, **72** (6), 1868–1886.
- Caldwell, B.M., & Bradley, R.H. (1984). *Home Observation for Measurement of the Environment (HOME)*. Little Rock, AR: University of Arkansas at Little Rock.
- Campbell, F.A., Pungello, E.P., Miller-Johnson, S., Burchinal, M., & Ramey, C.T. (2001). The development of cognitive and academic abilities: growth curves from an early childhood educational experiment. *Developmental Psychology*, **37**, 231–242.
- Chen, L.-A., Welsh, A.H., & Chan, W. (2001). Estimators for the linear regression model based on Winsorized observations. *Statistica Sinica*, **11**, 147–172.

- Dohrenwend, B.P. (1973). Social status and stressful life events. *Journal of Personality and Social Psychology*, **28**, 225–235.
- Duncan, G.J., Yeung, W.J., Brooks-Gunn, J., & Smirth, J.R. (1998). How much does childhood poverty affect the life chances of children? *American Sociological Review*, **63**, 406–423.
- Evans, G.W. (2004). The environment of childhood poverty. *American Psychologist*, **59**, 77–92.
- Farah, M.J., Shera, D.M., Savage, J.H., Betancourt, L., Giannetta, J.M., Brodsky, N.L., Malmud, E.K., & Hurt, H. (2006). Childhood poverty: specific associations with neurocognitive development. *Brain Research*, **1110** (1), 166–174.
- Ferchmin, P.A., & Bennett, E.L. (1975). Direct contact with enriched environment is required to alter cerebral weights in rats. *Journal of Comparative and Physiological Psychology*, **88** (1), 360–367.
- Greenough, W.T. (1975). Experiential modification of the developing brain. *American Scientist*, **63** (1), 37–46.
- Greenough, W.T., Black, J.E., & Wallace, C.S. (1987). Experience and brain development. *Child Development*, **58** (3), 539–559.
- Hermann, D., & Guadagno, M.A. (1997). Memory performance and socioeconomic status. *Applied Cognitive Psychology*, **11**, 113–120.
- Hurt, H., Brodsky, N.L., Betancourt, L., Braitman, L.E., Belsky, J., & Giannetta, J. (1996). Play behavior in toddlers with *in utero* cocaine exposure: a prospective, masked, controlled study. *Journal of Developmental and Behavioral Pediatrics*, **17** (6), 373–379.
- Hurt, H., Brodsky, N.L., Betancourt, L., Braitman, L.E., Malmud, E., & Giannetta, J. (1995a). Cocaine-exposed children: follow-up through 30 months. *Journal of Developmental and Behavioral Pediatrics*, **16** (1), 29–35.
- Hurt, H., Brodsky, N.L., Braitman, L.E., & Giannetta, J. (1995b). Natal status of infants of cocaine users and control subjects: a prospective comparison. *Journal of Perinatology*, **15** (4), 297–304.
- Hurt, H., Brodsky, N.L., Roth, H., Malmud, E., & Giannetta, J.M. (2005). School performance of children with gestational cocaine exposure. *Neurotoxicology and Teratology*, **27** (2), 203–211.
- Hurt, H., Giannetta, J., Brodsky, N.L., Malmud, E., & Pelham, T. (2001). Are there neurologic correlates of *in utero* cocaine exposure at age 6 years? *Journal of Pediatrics*, **138** (6), 911–913.
- Hurt, H., Malmud, E., Betancourt, L., Braitman, L.E., Brodsky, N.L., & Giannetta, J. (1997). Children with *in utero* cocaine exposure do not differ from control subjects on intelligence testing. *Archives of Pediatrics and Adolescent Medicine*, **151**, 1237–1241.
- Hurt, H., Malmud, E., Betancourt, L., Brodsky, N.L., & Giannetta, J. (1997). A prospective evaluation of early language development in children with *in utero* cocaine exposure and in control subjects. *Journal of Pediatrics*, **130**, 310–312.
- Hurt, H., Malmud, E., Betancourt, L., Brodsky, N.L., & Giannetta, J.M. (2001). A prospective comparison of developmental outcome of children with *in utero* cocaine exposure and controls using the Battelle Developmental Inventory. *Developmental and Behavioral Pediatrics*, **22** (1), 27–34.
- Hurt, H., Malmud, E., Braitman, L.E., Betancourt, L.M., Brodsky, N.L., & Giannetta, J.M. (1998). Inner-city achievers: who are they? *Archives of Pediatrics and Adolescent Medicine*, **152**, 993–997.
- Hurt, H., Malmud, E., Brodsky, N.L., & Giannetta, J. (2001). Exposure to violence: psychological and academic correlates in child witnesses. *Archives of Pediatrics and Adolescent Medicine*, **155** (12), 1351–1356.
- Just, M.A., Carpenter, P.A., Keller, T.A., Eddy, W.F., & Thulborn, K.R. (1996). Brain activation modulated by sentence comprehension. *Science*, **274**, 114–116.
- Kaufman, A.S., McLean, J.E., & Reynolds, C.R. (1988). Sex, race, residence, region, and education differences on the 11 WAIS-R subtests. *Journal of Clinical Psychology*, **44** (2), 231–248.
- Kozorovitskiy, Y., Gross, C.G., Kopil, C., Battaglia, L., McBreen, M., Stranahan, A.M., & Gould, E. (2005). Experience induces structural and biochemical changes in the adult primate brain. *Proceedings of the National Academy of Sciences of the United States of America*, **102** (48), 17478–17482.
- Lange, R.T., Chelune, G.J., Taylor, M.J., Woodward, T.S., & Heaton, R.K. (2006). Development of demographic norms for four new WAIS-III/WMS-III indexes. *Psychological Assessment*, **18** (2), 174–181.
- Lipina, S., Martelli, M.I., Vuelta, B., & Colombo, J.A. (2005). Performance of the A-not-B task of Argentinean infants from unsatisfied and satisfied basic needs homes. *Interamerican Journal of Psychology*, **39**, 49–60.
- Liu, D., Diorio, J., Day, J.C., Francis, D.D., & Meaney, M.J. (2000). Maternal care, hippocampal synaptogenesis and cognitive development in rats. *Nature Neuroscience*, **3** (8), 799–806.
- Mayes, A.R., Meudell, P.R., & Neary, D. (1978). Must amnesia be caused by either encoding or retrieval disorders? In M.M. Grueneberg, E. Morris, & R.N. Sykes (Eds.), *Practical aspects of memory*. London: Academic Press.
- Mayes, A.R., Meudell, P.R., & Neary, D. (1980). Do amnesiacs adopt inefficient encoding strategies with faces and random shapes? *Neuropsychologia*, **18**, 527–541.
- Mezzacappa, E. (2004). Alerting, orienting, and executive attention: developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child Development*, **75**, 1373–1386.
- Noble, K.G., McCandliss, B.D., & Farah, M.J. (2007). Socioeconomic gradients predict individual differences in neurocognitive abilities. *Developmental Science*, **10**, 464–480.
- Noble, K.G., Norman, M.F., & Farah, M.J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science*, **8**, 74–87.
- Parker, K.J., Buckmaster, C.L., Sundlass, K., Schatzberg, A.F., & Lyons, D.M. (2006). Maternal mediation, stress inoculation, and the development of neuroendocrine stress resistance in primates. *Proceedings of the National Academy of Sciences of the United States of America*, **103** (8), 3000–3005.
- Rosenzweig, M.R. (1966). Environmental complexity, cerebral change, and behavior. *American Psychology*, **21** (4), 321–332.
- Rosenzweig, M.R., Bennett, E.L., Hebert, M., & Morimoto, H. (1978). Social grouping cannot account for cerebral effects of enriched environments. *Brain Research*, **153** (3), 563–576.
- Tang, A.C., Akers, K.G., Reeb, B.C., Romeo, R.D., & McEwen, B.S. (2006). Programming social, cognitive, and neuroendocrine development by early exposure to novelty. *Proceedings of the National Academy of Sciences of the United States of America*, **103** (42), 15716–15721.

- Teicher, M.H., Andersen, S.L., Polcari, A., Anderson, C.M., Navalta, C.P., & Kim D.M. (2003). The neurobiological consequences of early stress and childhood maltreatment. *Neuroscience and Biobehavioral Reviews*, **27** (1–2), 33–44.
- Thompson-Schill, S.L., D'Esposito, M., Aguirre, G.K., & Farah, M.J. (1997). The role of the left prefrontal cortex in semantic retrieval: a reconsideration. *Proceedings of the National Academy of Sciences*, **94**, 14792–14797.
- van Praag, H., Kempermann, G., & Gage, F.H. (2000). Neural consequences of environmental enrichment. *Nature Reviews Neuroscience*, **1** (3), 191–198.
- Wechsler, D. (1981). *Wechsler Adult Intelligence Scale Manual*. San Antonio, TX: The Psychological Corporation.
- Whitehurst, G.J. (1997). Language processes in context: language learning in children reared in poverty. In L.B. Adamson & M.A. Ronski (Eds.), *Research on communication and language disorders: Contribution to theories of language development* (pp. 233–266). Baltimore, MD: Brookes.

Received: 9 May 2007

Accepted: 18 October 2007