

Neurodevelopmental Effects of Early Deprivation in Postinstitutionalized Children

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The neurodevelopmental sequelae of early deprivation were examined by testing ($N = 132$) 8- and 9-year-old children who had endured prolonged versus brief institutionalized rearing or rearing in the natal family. Behavioral tasks included measures that permit inferences about underlying neural circuitry. Children raised in institutionalized settings showed neuropsychological deficits on tests of visual memory and attention, as well as visually mediated learning and inhibitory control. Yet, these children performed at developmentally appropriate levels on similar tests where auditory processing was also involved and on tests assessing executive processes such as rule acquisition and planning. These findings suggest that specific aspects of brain-behavioral circuitry may be particularly vulnerable to postnatal experience.

Over the past decade, increased attention has been devoted to the development of children who have spent some or all of their lives in institutional care (Johnson, 2001). The increase in adoption of institutionalized children has heightened concerns about long-term effects of early deprivation. While the deprivation experienced by children in institutional settings is often impossible to accurately quantify, the environments many of these children endure fall below the quality needed to sustain normal physical and behavioral development. As evidence, institutionalized infants and toddlers lose about 1 month of linear growth for every 2–3 months in institutional care (Johnson, 2001), with behavioral

development exhibiting similar dramatic delays (Gunnar, 2001). When institutionalized children are placed in families, marked improvements in physical, social, and cognitive functioning are typically observed, yet many of the children maintain persistent behavioral problems (Ames, 1997; Hodges & Tizard, 1989; Rutter, 1998; Verhulst, Althaus, & Versluis-denBieman, 1990, 1992). The developmental difficulties experienced by many of these children raise questions about the effects of early deprivation including factors such as failure to provide adequate nutrition, medical care, stimulation, and the lack of consistent and supportive caregiving relationships. Although early research emphasized the significance of maternal deprivation, Rutter (1981) rightly noted that many other types of stimulation needed for normal development are also deficient in these environments.

The critical questions that emerge from the plight of these children concern which aspects of inadequate stimulation result in cascading developmental effects, which developmental processes are most affected by inadequate early care, and specification

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about how the transfer to more normative caregiving can foster growth and recovery following institutionalization. Institutionalized children have experienced highly species atypical deprivation; in many countries the institutional conditions are quite poor: Children may be confined to cots, fed gruel through propped up bottles, lack toys or stimulation, and receive very little linguistic stimulation and/or one-to-one interaction with caregivers (Nelson, 2007; Rutter, 1998). Even in institutions where basic physical needs were met, lack of individualized care and attention remain prominent. At adoption, children generally move into middle- to upper-middle-class families, who are generally highly stable and well educated (Hellerstedt et al., 2008). In short, adoption marks a dramatic termination of deprivation, allowing an examination of the impact of early deprivation and neglect on subsequent development. Adoption into a supportive home can provide a profound natural intervention in the life of a child exposed to significant early adversity (van IJzendoorn, Juffer, & Poelhuis, 2005). As a result, internationally adopted children provide a natural experiment on the impact of different degrees and duration of care on subsequent biobehavioral development. Despite occasional significant adjustment problems of the children, there are very few adoption disruptions for families who adopt internationally (e.g., Brumble, 2007). Furthermore, all studies of children adopted or fostered from institutions have shown that, varying with duration of institutionalization, once out of the institution children begin to show remarkable rebounds in physical and cognitive development (Kreppner et al., 2007; Maclean, 2003). Both the capacity of children to rebound after early institutional care and limitations on recovery imposed by longer periods of institutionalization were recently demonstrated experimentally in a study involving random assignment to high-quality foster care for children who began their lives in Romanian institutions (Nelson et al., 2007). Studying postinstitutionalized (PI) children several years after adoption allows examination of long-term impacts of early experience on children's development.

The present study is specifically motivated by the convergence of behavioral studies of PI children and experimental studies of deprivation on the nonhuman primates (see review by Sanchez & Pollak, 2009). In terms of domains where children do not appear to catch up in the immediate years following adoption, Beckett et al. (2007) reported that children adopted after a prolonged period of institutional care from Romania had significantly

lower scholastic attainment scores than those adopted early (before 6 months) either within the United Kingdom or from Romania. A separate research team also concluded that although adopted children showed age-expected development in some domains, adoptions after 12 months of age were associated with problems in school achievement (van IJzendoorn & Juffer, 2006). Another recent report indicated that children residing within Romanian orphanages had poorly developed language abilities (Windsor et al., 2007). One recent study focused specifically on language and cognitive outcomes at 6 and 11 years of age with a large sample of institutionally reared Romanian children adopted into UK families. This study noted few negative effects of deprivation if institutionalization ended before the age of 6 months. Even for the children over 18 months, the presence of even very minimal language skills (the child's ability to imitate speech sounds) at the time of arrival was a strong positive prognostic factor for school-aged cognitive outcomes. Importantly, variations in adoptive parent characteristics were unrelated to differences in the adopted children's cognitive outcomes (Croft et al., 2007). Studies of institutionally reared children yield consistent evidence that early deprivation can have long-term consequences for cognitive functioning and school readiness. Yet, most extant research has employed gross measures of functioning such as checklists, questionnaires, school records, and global developmental quotient (DQ) and intelligence quotient (IQ) tests. While such global measures provide some suggestion of which neural systems may have been affected, they are not specific enough to test hypotheses about the development of neural systems. Our goal was to more directly examine brain-behavior processes in systems believed to underlie children's scholastic performance, such as aspects of attention, inhibitory control, working memory, and learning.

These domains are of interest not only because of the persistent difficulties observed in previously neglected children but because nonhuman primate studies suggest that the prefrontal cortex (PFC) and its associated systems are particularly relevant to understanding cognitive functions and may be especially vulnerable to early experience (e.g., Sanchez, Ladd, & Plotsky, 2001). The PFC develops over a protracted period, well into adolescence (Huttenlocker, 1990; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). While the timing of development in different regions has not been fully determined, there is evidence that neuronal

organization in the dorsolateral prefrontal cortex (DL PFC; Brodman areas 9 and 10) changes dramatically until 5–7 years of age (Blinkov & Glezer, 1968) and slows thereafter. A similar protracted period has been observed for the neurotransmitter systems mediating prefrontal activity. Bourgeois (2000) has plotted the overproduction and pruning of synapses in the rhesus monkey against that of the human, taking into consideration differences in age compression (i.e., the rate at which each species develops), and has reported remarkable similarity across species. Collectively, these data, coupled with the postmortem data, point to a protracted period of PFC development. Presumably, this may allow experience-dependent fine-tuning of attention, learning, emotion, and memory systems (e.g., Black, Jones, Nelson, & Greenough, 1998).

Although it is critical to understand whether and how postnatal deprivation and neglect influence brain development in human children, the human neuroscience evidence is sparse. Two studies conducted by Chugani and colleagues reported that PI children from Romania showed significantly decreased metabolism bilaterally in the orbital frontal gyrus, the infralimbic PFC, the medial temporal structures (amygdala and head of hippocampus), the lateral temporal cortex, and the brain stem as compared to normal adults and children with chronic epilepsy. Diffusion tensor imaging also suggested that the PI children had reduced white matter tracts between the anterior temporal and frontal lobes (Chugani et al., 2001; Eluvathingal et al., 2006). These brain imaging findings are consistent with recent work from the Bucharest Early Intervention Project (BEIP; see Zeanah et al., 2003). For example, this group has reported that children reared in institutions show dramatic reductions in brain activity as revealed by the electroencephalogram and the event-related potential (ERP; see Marshall et al., 2004; Parker, Nelson, & the BEIP Core Group, 2005a, 2005b). Importantly, children placed in high-quality foster care before the age of 2 years show improvement in their electroencephalogram (Marshall, Reeb, Fox, Nelson, & Zeanah, 2008); ERP amplitude also improves with placement in foster care, although it is not time- or sensitive-period dependent (Moulson, Fox, Zeanah, & Nelson, 2009).

The present study sought to determine which domains of cognitive development may be particularly affected by institutional neglect and deprivation using children adopted internationally from orphanages or other institutions. These PI children were (a) adopted over age 12 months, (b) spent at least 75% of their lives prior to adoption in institu-

tional care, and (c) resided in their adoptive families for a minimum of 3 years at the time of testing. We compared these children to two different groups. Our first comparison group consisted of children who were adopted before 8 months predominantly from foster care overseas, having little or no institutional care history. This group helps to control for prenatal factors and heritable factors associated with a child becoming orphaned or abandoned. Our second comparison group consists of nonadopted (NA) children who were reared in their families of origin. As noted by Rutter, Dunn, Plomin, and Simonoff (1997), even when using “normed” neuropsychological evaluations, and especially when using nonstandardized tests, it is critical to include NA children who have grown up in families of similar economic and educational histories to the families of adopted children. Furthermore, for domains that yielded differences between the PI children and both other groups, we examined whether duration of institutional care correlated with the children’s performance. Thus, the strategy employed here is to identify as “institutional deprivation effects” those cognitive functions for which the PI group differs from the two comparison groups and, further, whether the duration of institutional care is associated with the outcome within the PI group. Here, we focus on basic cognitive and learning processes that might underlie school-based learning problems.

Method

Participants

The participants were 132 children ages 8 years 0 months to 9 years 11 months. Three groups were examined (see Table 1 for details). A PI group whose selection criteria were adopted at 12 months of age or older (range = 12–78 months, $M = 23.4$ months, $SD = 12.9$) having spent at least 75% of their preadoption lives in institutional care. Over 50% of this group had no experience other than institutional care prior to adoption ($M = 22.1$ months in institutional care, $SD = 12.4$). Children in the PI group were adopted from Asia ($n = 19$), Latin America ($n = 1$), Russia and Eastern Europe ($n = 27$), and Africa ($n = 1$). An early adopted predominantly from foster care (EA) group whose selection criteria were adoption at 8 months or earlier (range = 2–8 months, $M = 5.2$ months, $SD = 1.7$ months) having spent 2 months or less in institutional care. Nearly 83% of this group had spent all of their preadoption lives in foster care overseas.

Table 1
Sample Characteristics

	Postinstitutionalized (N = 48)	Early adopted (N = 40)	Control (N = 44)
Sex (% female)	50	47	55
Age	8 years 4 months (0.5 months)	8 years 4 months (0.5 months)	8 years 5 months (0.5 months)
IQ ^a	105.9 (15.8)	113.7 (16.5)	124.7 (15.7)
Years of parent education	16.3 (2.2)	16.8 (1.6)	16.4 (2.0)
Median family income	75–110K	75–110K	50–75K

^aEstimated based on Vocabulary and Block Design subtests of the WISC Wechsler Intelligence Scale for Children, 3rd ed. (C–III), or the Leiter International Performance Scale, Revised (Leiter–R) for participants who scored below the normal range on the WISC–III.

Those with institutional experience had been adopted before 3 months of age. Children in the EA group were adopted from Asia (67%) and Latin America (33%). The EA group permitted comparison with children who had experienced loss of birth families and adoption into another culture. Finally, the third group was children born and raised in their birth families in the United States (NA). The children were recruited and tested at two sites, the University of Wisconsin ($n = 58$) and the University of Minnesota ($n = 74$). As shown in Table 1, there were no differences between the three groups in terms of the numbers of boys versus girls, child's age, or parent education. As expected, children in the PI group had lower IQ scores than those children in the two (EA and NA) comparison groups, $F(2, 131) = 16.13$, $p < .001$. On average, adoptive parents had higher family incomes than those from control families, $F(2, 131) = 3.99$, $p = .02$.

Recruitment and Screening

The internationally adopted children were drawn from the Minnesota and the Wisconsin International Adoption Project Registries—registries of families created through international adoption that expressed interest in being contacted about research participation. The NA children were recruited in Wisconsin through fliers and advertisements and in Minnesota from the Institute of Child Development Participant Pool, a registry of children whose parents indicated interest in being contacted about research opportunities in response to a mailing soon after their children were born.

Within 6 months of the present study, the children were all screened to determine if they met the study's group assignment (described earlier) and exclusion criteria. Criteria for group assignment were determined through phone interview and parent questionnaire. Children then participated in an extensive developmental profile, parts of which

determined exclusion criteria. Children were excluded if their IQs were below the normal range (< 78), parents reported congenital abnormalities (e.g., Down syndrome or cerebral palsy), and failure on the fetal alcohol syndrome (FAS) screener. We screened for IQ using the Vocabulary and Block Design subtests of the Wechsler Intelligence Scale for Children, 3rd ed. (WISC–III; Wechsler, 1998). If children scored below 1 *SD* on either WISC–III subtests, they were subsequently administered the Leiter International Performance Scale, Revised (Roid & Miller, 1997), a nonverbal IQ assessment, to avoid excluding children with normal IQs whose performance might have been affected by the English language demands of the WISC–III. Children were required to pass either the WISC or the Leiter to be included in this study; if they did not reach criterion on both the WISC and Leiter, then they were excluded. Eight children were assessed with the Leiter and of those, 4 (all PI) were excluded because of IQs in the study exclusion range.

To screen for possible FAS, we photographed front and side views of children's faces and analyzed these images using FAS Facial Photographic Analysis Software (Astley, 2003). Children scoring in the moderate range or higher on this screener were excluded and images where coders were uncertain were also reviewed by a pediatric dysmorphologist. Reliability among coders was 100%. Parents of children who failed the FAS screener were contacted and referred for further evaluation. Four children (2 PI, 2 EA) were excluded because of possible FAS. Note that this exclusion criterion only eliminated children with significant facial dysmorphology due to prenatal alcohol exposure. Children with exposures that did not affect facial morphology would not be identified by this method.

In addition to these assessments, children were also administered the Paragraph Comprehension subtest from the Comprehensive Assessment of Spoken Language battery (CASL). The tasks

employed in this study were selected because they required only rudimentary language comprehension. Nonetheless, children scoring 2 *SD* below the published norms of this tests were excluded to reduce the possibility that language problems might impair their performance. None of the PI or EA children needed to be excluded because of low CASL scores.

Four PI (8%), 2 EA (3%), and 1 NA (2%) were on stimulant medications for attention problems; these children were tested when parents agreed to withhold medication (e.g., weekends). Across all of the above-mentioned criteria, 1 NA, 4 EA, and 7 PI children were screened but not included in our final sample of 132.

For descriptive purposes, because low birth weight is associated with poorer cognitive functioning, as part of the screening examination parents provided information about the children's birth weight. Parents were asked to check baby books and other records for this information. Parents who were not able to find these records were asked to sign a medical release so that the child's pediatrician could be contacted for this information. Birth weight data were obtained from 97% of the NA, 85% of the EA, and 41% of the PI children. Notably, in cases in which the PI children were abandoned (e.g., typical for Chinese PI children), this information was unknown. Analysis of the birth weight data yielded means in grams for the PI, EA and NA children, respectively, of 2,893 (*SD* = 1,134), 2,982 (*SD* = 524), and 3,314 (*SD* = 699), $F(2, 94) = 5.9$, $p < .01$. Hockbergen post hoc tests indicated that both PI and EA groups were lower birth weight, on average, than NA children, although PI and EA birth weight did not differ. Because of the large number of EA children from Asia, we also compared EA and PI children only from that area of the world. The results failed to yield any difference between Asian EA and PI children, $t < .01$, *df* for unequal *ns* = 5.3, *ns*.

Procedure

Neuropsychological functioning was assessed through two well-validated test batteries. One of these, the Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition, Cambridge, United Kingdom), is a computerized series of neuropsychological tests that cover a wide range of cognitive domains. The second battery is the NEPSY Developmental Neuropsychological Assessment (Korkman, Kirk, & Kemp, 1998), a battery developed specifically for use with children. The CANTAB offers several strengths: It has been

used extensively with children (Luciana & Nelson, 2002), it has proved sensitive in discriminating various clinical populations from typically developing children, the individual tasks have been studied extensively to confirm their neural correlates (Joyce & Robbins, 1991; Owen, Downes, Sahakian, Polkey, & Robbins, 1990; Owen, Iddon, Summers, & Robbins, 1997; Owen, Morris, Sahakian, Polkey, & Robbins, 1996; Owen, Roberts, Polkey, Sahakian, & Robbins, 1991; Owen, Sahakian, Semple, Polkey, & Robbins, 1995; Saghal et al., 1991; Sahakian et al., 1988), it is computerized for standardized administration, the stimuli cannot be verbalized, and the subtasks require nonverbal responses; thus, performance is not confounded with subjects' verbal skills.

Neuropsychological test. Memory functions were evaluated with three different tests. The first, spatial working memory, tests the child's ability to retain spatial information and to manipulate remembered items in working memory. It is a self-ordered task, which also assesses heuristic strategy. The test begins with a number of colored squares displayed on a computer monitor. By touching the boxes and using a process of elimination, the child should find one blue "token" in each of a number of boxes and use them to fill up an empty column on the right-hand side of the screen. The number of boxes is gradually increased until it is necessary to search a total of eight boxes. The child's score is based upon errors (touching boxes that have already been found to be empty, and revisiting boxes that have already been found to contain a token) as well as response latency, which is age adjusted. Memory for faces assesses the ability to recognize faces after a single exposure. Children are presented 16 pictures of children one at a time for 5 s each, during which children are instructed to remember the faces and identify the sex of each child. Next, the children are presented with pictures of 3 children, 1 of which they previously saw, and they are then asked to identify the picture they saw previously. Thirty min later, this procedure is repeated. The score on this test is based on the sum of correct responses in immediate and delay tasks. Next, we administered a narrative memory test that assesses the ability to retell a story under both free and cued recall conditions. A story is told to the child. Following the story, children are asked to tell the examiner the same story. After the child has recalled as much as they can, the examiner cues details the child did not mention.

Learning processes were evaluated using the paired associates learning test, which assesses

visual memory and new learning. Boxes are displayed on the screen and are opened in a randomized order. One or more of them will contain a pattern. The patterns are then displayed in the middle of the screen, one at a time, and the subject must touch the box where the pattern was originally located. If the subject makes an error, the patterns are re-presented to remind the subject of their locations. The difficulty level increases through the test.

Attentional processes were evaluated using five different tasks. The auditory attention and response set test assesses children's ability to maintain selective auditory attention, as well as the child's ability to maintain a complex mental set. In the first part of the task, the child learns to manipulate a red item whenever they hear the word *red*. In the second part of the task, the child then must shift set and respond to red stimuli when hearing the word *yellow*. Match to sample visual search is a matching test, with a speed-accuracy trade-off. Children are shown a complex visual pattern in the middle of a computer screen, and then, after a brief delay, a varying number of similar patterns are shown in a circle of boxes around the edge of the screen. Only one of these boxes matches the pattern in the center of the screen, and the subject must indicate which it is by touching it. Reaction time is measured on the basis of the release of the press pad, which allows for its more accurate measurement. Rapid visual information processing is a test of visual sustained attention. A white box appears in the center of the computer screen, inside which digits appear in a pseudo-random order, at the rate of 100 digits per minute. Children are requested to detect target sequences of digits and to register responses using a press pad. Outcome measures are calculated using signal detection theory. The visual attention test assesses the speed and accuracy with which a child can scan an array and locate targets. Finally, the knock and tap test measures the child's ability to inhibit immediate impulses evoked by visual stimuli that conflict with a verbal direction. The child learns a pattern of motor responses and then must maintain that cognitive set and inhibit the impulse to imitate the examiner's action.

The working memory and knock and tap tasks also involve components of executive functions. We examined two additional aspects of executive function, rule acquisition and manipulation through reversal and planning, here labeled *executive processes*. The intra-extra dimensional shift set (ID/ED) test was used to measure rule acquisition and manipulation through reversal. Two artificial

dimensions are used in the test: color-filled shapes and white lines. Simple stimuli are made up of just one of these dimensions, whereas compound stimuli are made up of both, namely, white lines overlying color-filled shapes. Children begin by seeing two simple color-filled shapes and must learn which one is correct by touching it. Feedback teaches the child which stimulus is correct, and after six correct responses, the stimuli and/or rules are changed. These shifts are initially intradimensional (e.g., color-filled shapes remain the only relevant dimension), then later extradimensional (white lines become the only relevant dimension). Children progress through the test by satisfying a set criterion of learning at each stage. In addition, Stockings of Cambridge is a version of the Tower of London spatial planning test, which gives a measure of frontal lobe function (Baker et al., 1996; Owen et al., 1990; Robbins, 1996). Children are shown two displays containing three colored balls. The displays are presented in such a way that they can easily be perceived as stacks of colored balls held in stockings or socks suspended from a beam. The child must use the balls in the lower display to copy the pattern shown in the upper display. The balls may be moved one at a time by touching the required ball, then touching the position to which it should be moved. The time taken to complete the pattern and the number of moves required are taken as measures of the child's planning ability.

Results

Our first set of analyses sought to determine which domains of functioning were either minimally affected by early deprivation or may reflect developmental catch-up following family rearing. Although we could not distinguish between these explanations, we could determine tasks in which our three groups of children performed differently. Omnibus tests revealed group differences in memory functioning, $F_{\text{mult}}(6, 252) = 3.31, p = .004$; on tests of attentional functioning, $F_{\text{mult}}(10, 224) = 2.72, p = .004$; and on the test of learning, $F(2, 131) = 12.47, p = .001$. However, all three groups of children performed similarly on tests of executive processes, $F_{\text{mult}}(4, 254) = 1.20, ns$.

Next, we explored those domains (memory, attention, and learning) where multivariate tests suggested group differences to determine which specific tasks discriminated between groups of children. Table 2 shows the descriptive information for

Table 2
 Descriptive Data on Domains Exhibiting Significant Group Differences

	Postinstitutionalized	Groups early adopted	Control	Post hoc comparisons	Duration institutional care
Memory tasks					
Spatial working memory ^a (% errors)	52.7 (18.4)	40.9 (19.5)	39.0 (15.7)	PI < Con EA = Con	-.18
Memory for faces ^b (scaled score)	11.1 (3.1)	12.2 (2.8)	12.6 (3.3)	PI < Con EA = Con	-.11
Auditory narrative memory ^b (scaled score)	9.7 (4.1)	10.8 (3.3)	11.4 (3.2)	No significant difference	-.31*
Attention tasks					
Match to sample ^a (% correct)	95.3 (7.3)	96.2 (4.6)	97.4 (3.4)	No significant difference	-.16
Auditory attention ^b (scaled score)	9.2 (1.3)	9.6 (1.4)	9.7 (1.0)	No significant difference	-.06
Rapid visual processing ^a (% correct)	10.5 (6.1)	9.6 (3.9)	8.9 (4.6)	No significant difference	-.04
Visual attention ^b (scaled score)	10.1 (2.3)	12.2 (2.7)	11.7 (2.1)	PI < Con EA = Con	-.33*
Knock and tap ^b (raw score)	28.00 (2.93)	28.69 (1.81)	29.10 (1.05)	PI < Con EA = Con	-.35*
Executive control tasks					
ID/ED ^a (total errors)	41.2 (19.3)	38.3 (23.7)	33.7 (17.6)	No significant difference	.09
Stockings of Cambridge ^a (problems solved)	6.8 (1.8)	7.3 (1.7)	7.0 (1.5)	No significant difference	-.14
Learning task					
Paired associates learning ^a (total errors)	14.6 (13.8)	6.9 (5.9)	6.2 (5.2)	PI < Con EA = Con	-.46**

Note. EA = early adopted; ID/ED = intra-extra dimensional shift set; PI = postinstitutionalized.

^aCANTAB subtest. ^bNEPSY subtest.

* $p < .05$. ** $p < .01$.

these tasks, the pattern of post hoc comparison between groups, and the correlations of scores with duration of institutional care. We included sex in our analyses, but in no instance did we find an interaction of sex and group. Where main effects of sex were noted, girls performed better than boys; however, as sex differences did not modify the main effects of group, we do not discuss them further. Information on sex differences is available upon request.

Within the memory domain, the groups performed differently on the spatial working memory test, $F(2, 128) = 7.96$, $p = .001$. Hochberg post hoc tests revealed that PI children performed more poorly than both EA ($p = .008$) and controls ($p = .001$), but that EA children performed similarly to controls (ns). The memory for faces test resulted in a marginal group difference, $F(2, 128) = 2.95$, $p = .056$. On this test, PI children scored lower than NA children ($p = .057$), but the EA and NA groups performed similarly. The groups did not differ on auditory memory ability.

In terms of tests of learning, children's performance on the paired associates learning test differed, $F(2, 131) = 12.47$, $p = .001$. PI children performed lower than EA ($p = .003$) and NA ($p < .001$), but EA and NA groups performed similarly (ns).

Within the attention domain, groups performed similarly on tests of auditory attention $F(2, 116) = 2.30$, ns ; match to sample $F(2, 116) = 1.75$, ns ; and rapid visual processing $F(2, 116) = 1.03$, ns . However, the groups differed on the test of visual attention, $F(2, 116) = 8.96$, $p = .001$. Here, PI children performed more poorly than EA ($p = .001$) and controls ($p = .006$), but EA children performed similarly to controls ($p = ns$). There was also a marginal difference on the knock and tap test, $F(2, 116) = 2.92$, $p = .06$. Here, PI children showed more impulsivity than controls ($p = .05$), but there were no other differences between groups.

Discussion

The primary goal of this study was to determine which cognitive processes differentiated children who experienced early institutional deprivation and neglect. PI internationally adopted children differed from both groups of comparison children on tests of visual memory and attention, as well as visually mediated learning and inhibitory control. Yet, these children performed at developmentally appropriate levels on similar tests where auditory processing was also involved. These children also performed well on tests of executive processes

involving rule acquisition, manipulation, and planning.

This study was not designed to show precisely which neural circuits are affected by early experience, but the tasks that PI children had difficulty with do provide a useful guide for specifying neuroanatomical substrates that can be more directly examined in future studies. Next, we briefly highlight areas of brain circuitry associated with these tasks. Performance on the memory for faces task reflects an interaction between PFC and stimulus-specific visual cortical association areas that mediate visual working memory. The neurophysiological models of visual working memory developed in the nonhuman primate also holds for humans, based upon event-related functional magnetic resonance imaging (ER-fMRI) studies of facial delay recognition task similar to the one used in the present study (Druzgal & D'Esposito, 2003). Memory tasks such as the one used in the present study involve both visual memory and visual perception. But there is not yet agreement in the field about the neural bases of these processes. Some data suggest that visual memory and visual perception are associated with common neural substrates (Slotnick, 2004), whereas other data suggest that right medial temporal lobe structures are critically involved in retention, but not in the perception, of new faces (Crane & Milner, 2002).

Spatial working memory is a test of the child's ability to retain spatial information and to manipulate remembered items in working memory and also assesses heuristic strategy. The task is considered a sensitive measure of frontal lobe dysfunction based upon studies of nonhuman primates and patients with frontal lobe damage (Owen, Morris, et al., 1996; Owen et al., 1990; Owen et al., 1995; Passingham, 1995). Owen, Evans, and Petrides (1996) used positron emission tomography with magnetic resonance imaging to demonstrate the existence, within the human brain, of two functionally distinct subdivisions of the lateral frontal cortex, which subserved different aspects of spatial working memory. When the spatial working memory task required the organization and execution of a sequence of spatial moves retained in working memory, significant changes in blood flow were observed in ventrolateral frontal cortex (area 47) bilaterally. In contrast, when the task required active monitoring and manipulation of spatial information within working memory, additional activation foci were observed in mid-dorsolateral frontal cortex (areas 46 and 9). Both of these processing stages were required to successfully com-

plete a spatial working memory task (Owen, Evans, et al., 1996). Another study also linked poor performance on the CANTAB spatial working memory task in children to reduced dorsolateral PFC using fMRI (Luna et al., 2002).

It is difficult to link performance on tests of visual attention to distinct neural systems. A recent study used ER-fMRI to measure brain activity as subjects oriented visual attention to an upcoming target. This activation was lateralized to the left hemisphere and reflected a widely distributed network that included (a) structures in parietal and temporal cortices and thalamus usually associated with selective attention; (b) ventral-stream object processing structures in occipital, inferior-temporal, and parahippocampal cortex; and (c) structures in medial- and dorsolateral prefrontal cortex associated with cognitive control (Arrington, Carr, Mayer, & Rao, 2000). In visual attention tasks, subjects will undoubtedly make errors and need to reorient to targets. This same study revealed that brain areas specific to attentional reorientation were right-lateralized and included posterior temporal and inferior parietal regions, as well as prefrontal regions that likely subserved control processes related to inhibition of inappropriate responding (Arrington et al., 2000). In sum, selective visual attention results from distributed brain activity that includes maintenance of the selected object's representation accompanied by suppression of response to ignored objects (Duncan, 1993; Farah, 1990; Phaf, Van der Heijden, & Hudson, 1990), with control of these processes mediated by the medial DL PFC.

Paired associates learning is a stringent test for visual episodic memory and associative learning (Sahakian & Owen, 1992). To perform well, children had to learn the locations of a progressively increasing number of abstract stimuli. Although such a complex behavioral task undoubtedly draws upon widely distributed neural systems, ER-fMRI suggests that successful performance on this type of task relies heavily upon medial temporal lobe connections to the frontal lobe (Aizenstein et al., 2000). Similarly, the knock and tap test cannot be mapped onto discrete circuitry. The test measures the child's ability to inhibit immediate impulses evoked by visual stimuli that conflict with a verbal direction. The child learns a pattern of motor responses and then must maintain that cognitive set and inhibit the impulse to imitate the examiner's action.

Taken together, the present data suggest delayed maturation of select aspects of frontal circuitry, and perhaps reduced functional connectivity of frontal

cortex with other neocortical and subcortical regions, plays a key role in scholastic difficulties among children who experienced early institutionalized deprivation and neglect. Indeed, regions of the PFC have long been associated with cognitive processes similar to the ones assessed in this study (Fletcher & Henson, 2001; Owen, Morris, et al., 1996). Studies in nonhuman primates, lesion studies, as well as functional neuroimaging studies in humans, have documented that DLPFC is crucial for maintaining and manipulating information in ways assessed by the tasks used here (Carlson et al., 1998; Fuster, 2000; Goldman-Rakic, 1988; McCarthy et al., 1994; Owen, Evans, et al., 1996; Pierrot-Deseilligny, Rivaud, Gaymard, Muri, & Vermersch, 1995; Sweeney et al., 1996).

The distinction between the performance of PI and EA children suggests (but does not prove) that the ontogenesis of the PFC also includes an extensive postnatal interval. Such an interpretation is consistent with animal studies that reveal, for example, that the thickness of the PFC of the rat brain is not maximal until postnatal day 20, which marks the beginning of the postweaning period (e.g., roughly equivalent to adolescence in humans; Vincent, Khan, & Benes, 1995). Indeed, PI children are often noted to have problems in attention regulation and emotional control, functions presumably influenced by the development of the PFC and its distributed systems (see review by Gunnar, 2001; Shallice et al., 2002). Consistent with this view, Sanchez, Hearn, Do, Rilling, and Herndon (1998) studied rhesus monkeys that were socially deprived between 2 and 12 months of age. These monkeys exhibited cognitive deficits that had also been noted in earlier studies (e.g., Harlow, Harlow, & Suomi, 1971). Sanchez et al.'s MRI studies revealed that the animals' performance on executive function tasks was correlated with decreased neuronal development of prefrontal, medial temporal, and amygdala substrates. Two years later, these monkeys exhibited increased abnormalities in the PFC that were related to the monkeys' performance on learning and working memory tasks (Sanchez et al., 2001). In a separate study, Mathew et al. (2003) reported neuropathological alterations in the PFC of adult macaques with early adverse experience.

There are a number of features of the present study that are important to consider in interpreting these data. First, as described earlier, we excluded children with clear developmental delays or indications of fetal alcohol exposure, which would have artificially exaggerated group performance deficits. By avoiding a situation where a subset of PI chil-

dren may be experiencing global cognitive delays, we were also able to detect specific patterns of processing deficits. In general, executive function tasks are sensitive to perturbations in children's lives, but effects on these tasks are not specific to certain situations or conditions. If we observed broad or diffuse cognitive deficits in the PI sample, it would not be possible to rule out general attentional, IQ, motivational, motor, or emotional problems as driving children's performance. Yet, in the present study we observed that on a majority of tasks, PI children displayed performance equivalent to their peers, which permits stronger interpretation of those specific areas where deficits emerged. Second, this sample of children represents families who volunteered to participate in research; it may be the case that parents who believed their children were doing particularly well or poorly were more likely to participate. Yet, such sampling issues—if they exist—do not readily explain the pattern of results observed in this study. In addition, our unusual sampling procedures (see Hellerstedt et al., 2008) probably resulted in a group of children that are both diverse and representative.

The study of children reared in atypical situations requires opportunistic approaches that are also fraught with interpretive challenges. Our requirement that the EA group be adopted before 8 months of age and that these children had to spend ≤ 2 months in institutional care meant that none of the EA children were drawn from Eastern Europe, where adoption processes take more time. Most of the EA children spent most of their pre-adoptive lives in foster care overseas, an option that did not exist in Eastern Europe between 1990 and 1998, when the children that we tested were adopted. It is likely that prenatal conditions were less optimal for children who end up being placed in orphanage or institutional care overseas than for children born and raised in their families of origin in the United States. In part, the inclusion of a group of children adopted internationally with little or no institutional experience partly addressed this problem. We obtained birth weight data on the majority of both EA and NA children, and found, as might be expected, that the EA children were lower in birth weight than the NA children. Although we were only able to obtain birth weight data on 41% of the PI children, there was no evidence that birth weight differentiated PI from EA children. While we must be cautious in interpretation of these data because we lack evidence on the reliability of the information and are missing substantial data for the PI children, the pattern of

data suggests that EA and PI children tended to experience prenatal environments that were impoverished. This tends to clarify, but not resolve, the issue of whether pre- versus postnatal environmental impacts influenced the outcomes we examined.

In terms of the tasks administered to children, it is critical that measurement involves a sufficient level of task difficulty relative to the ability level of participants. In this regard, the specific tasks used in this study are particularly useful. For example, the test of spatial working memory ability and paired associates learning systematically varies the working memory load, which increases the amount of information that needs to be remembered and the number of trials over which it needs to be maintained. The children's pattern of performance across the tasks that we administered did not reveal clear performance deficits on auditory memory and attentional tasks. One possibility is that the deficits observed here are a function of how much information needs to be kept active in working memory over time, and how precisely that information needs to be encoded. At the same time, firm conclusions about neural activity cannot be made based solely on behavioral data. However, these data do underscore the need to employ specific assessments that have been used in imaging and lesion studies and that may allow more fine-grained analysis of the impact of institutional neglect on neurobehavioral development.

Why did the PI children perform better on tasks that relied primarily on auditory, as compared with visual, information? One possibility is that visual development is more vulnerable to postnatal influences. The auditory system starts functioning during the last trimester of gestation (Birnholtz & Benaceraff, 1983), whereas the visual system does not start functioning until after birth. Thus, both visual and auditory *functional* development reflect experience-dependent processes; the difference is that auditory experience starts before visual experience, when the brain is at a different point in its development (cf. Kellman & Arterberry, 2006; Saffran, Werker, & Werner, 2006). Sloutsky and colleagues (Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003) have demonstrated that young children, unlike adults, exhibit auditory dominance. This may reflect earlier maturation of the auditory system relative to the visual system. It may also be the case that attentional processes more easily engage some stimulus properties. For example, auditory stimuli are serial, transient events that must be perceived quickly whereas visual stimuli are presented episodically for longer periods of

time. Thus, attentional systems may allocate more resources to transient relative to stable stimuli. Similarly, Posner, Nissen, and Klein (1976) proposed that attention to visual stimuli must be learned, whereas attention to auditory stimuli is more automatic. Also consistent with the argument that postnatal experience is more likely to influence visual processing, Maurer, Lewis, Brent, and Levin (1999) have demonstrated that the neural circuitry responsible for adults' face expertise is not prespecified but requires early visual experience (see also Nelson, 2001; Pascalis et al., 2005). Because infants have poor visual acuity, their cortices are only exposed to low spatial frequency. Thus, early exposure to visual information sets up the neural architecture for more complex visual processing. These studies have demonstrated that when visual input is delayed by as little as 2 months, permanent visual deficits result (Le Grand, Mondloch, Mauer, & Brent, 1999, 2003; Maurer et al., 1999).

Models of the role of experience in neural development, and the mounting information on molecular processes in neural plasticity, indicate that neural activities (i.e., activity-dependent processes) are critical to brain development (see Fox, Levitt, & Nelson, 2010). This implies that in addition to the stimuli available in the environment, active engagement of the environment may be essential in order for some aspects of cognitive development to occur. While these opportunities abound in typical human rearing environments, institutionalized childrearing may restrict the kinds of dynamic experiences and input necessary for some aspects of neurobehavioral development. It is hoped that the more we understand about the specific aspects of neurodevelopment impacted by early deprivation, the more we can focus on identifying targeted intervention and training experiences that would optimize these children's outcomes.

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