Long-term effects of institutional rearing, foster care, and brain activity on memory and executive functioning

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Edited by Seth D. Pollak, University of Wisconsin–Madison, Madison, WI, and accepted by Editorial Board Member Renée Baillargeon December 13, 2018 (received for review May 28, 2018)

Children experiencing psychosocial deprivation as a result of early institutional rearing demonstrate many difficulties with memory and executive functioning (EF). To date, there is scant evidence that foster care placement remediates these difficulties during childhood. The current study examined longitudinal trajectories of memory and EF from childhood to adolescence in the Bucharest Early Intervention Project, a randomized controlled trial of foster care for institutionally reared children. We demonstrate that both ever- and never-institutionalized children show age-related improvements on several measures of memory and EF from age 8 to 16. Distinct patterns were observed for different domains of functioning: (*i*) Early-emerging disparities in attention and short-term visual memory, as well as spatial planning and problem solving, between ever- and never-institutionalized children persisted through adolescence; (*ii*) the gap in spatial working memory between ever- and never-institutionalized children widened by adolescence; and (*iii*) early difficulties in visual-spatial memory and new learning among children in foster care were mitigated by adolescence. Secondary analyses showed that higher resting EEG alpha power at age 8 predicted better EF outcomes in several domains at age 8, 12, and 16. These results suggest that early institutional rearing has enduring consequences for the development of memory and EF, with the possibility of catch-up among previously institutionalized children who start out with higher levels of problems. Finally, interindividual differences in brain activity relate to memory and EF across ages, thus highlighting one potential biological pathway through which early neglect impacts long-term cognitive functioning.

executive functioning | institutional rearing | early neglect | foster care | brain activity

Memory and executive functioning (EF) are cognitive faculties that underlie children's capacity to regulate behavior and emotion. EF is an umbrella term for a group of skills involved in goal-directed action and problem solving, including working memory, cognitive flexibility, response inhibition, and attentional control. Gradients in these cognitive and self-regulatory abilities predict key outcomes in childhood, such as academic achievement and mental health (1), and in turn forecast educational attainment, income, and other indicators of psychosocial well-being into adulthood (2–4). Thus, uncovering sources of variation in memory and EF is important not only in understanding how they develop but also in leveraging resources to promote gains in these abilities and mitigate risk of downstream problems in many domains.

Various indicators of early adversity have been associated with poor memory and EF in childhood, including maltreatment and socioeconomic disadvantage (5, 6). Among the most pernicious experiences for children's cognitive development is psychosocial neglect, which is often experienced by those raised in large, depriving institutions. Globally, many abandoned or orphaned children spend their early lives in institutions characterized by low caregiver-to-child ratios, high caregiver turnover, and inadequate social and cognitive stimulation. Longitudinal studies show that institutionally reared children have poorer memory and EF than noninstitutionalized children through middle childhood (7–9). On standardized assessments of memory and EF, specific problems in the areas of inhibitory control, visual-spatial memory and learning, working memory, cognitive flexibility, initiation, and planning have been observed among postinstitutionalized children (7–12).

The effects of institutional rearing on memory and EF in adolescence remain largely unexplored, in part due to a paucity of longitudinal studies that have tracked children into this period.

Significance

UNICEF estimates that there are approximately 8 million children worldwide who live in institutions. Institutional rearing often involves severe psychosocial neglect associated with suboptimal brain and behavioral development. This study uses data from the only existing longitudinal RCT of foster care for institutionally reared children to examine trajectories of memory and executive functioning from childhood to adolescence. We show that institutional rearing is associated with persistent problems in certain functional domains, and developmental stagnancy in others, across this transitional period. There is suggestive evidence that children assigned to early foster care may demonstrate some catch-up over time. Brain activity in childhood is associated with long-term outcomes through age 16, together underscoring the impact of early neglect on children's neurocognitive development.

Author contributions: M.W., N.A.F., C.H.Z., and C.A.N. conceptualized the study; N.A.F., C.H.Z., and C.A.N. designed research; N.A.F., C.H.Z., and C.A.N. performed research; N.A.F., C.H.Z., and C.A.N. contributed new reagents/analytic tools; M.W. analyzed data; and M.W. wrote the paper with assistance from N.A.F., C.H.Z., and C.A.N.

Conflict of interest statement: C.A.N. has received grant support from the NIH, Jacobs Foundation, John D. and Catherine T. MacArthur Foundation, James S. McDonnell Foundation, Binder Family Foundation, Lumos Foundation, Bill and Melinda Gates Foundation, and Harvard University. He has received royalties from MIT Press and Harvard University Press. He has received honoraria for lectures to professional audiences, and legal consulting fees. C.H.Z. has received grant support from the NIMH, Palix Foundation, Irving Harris Foundation, Substance Abuse and Mental Health Services Administration, and Lumos Foundation. He has received royalties from Guilford Press and Harvard University Press. He has received honoraria for lectures to professional audiences. N.A.F. receives grant support from the NIMH, NICHD, NSF, NIH ECHO consortium, Russell Sage Foundation, and Lumos Foundation. He has received royalties from Guilford Press and Harvard University Press. He has received honoraria for lectures to professional audiences.

This article is a PNAS Direct Submission. S.D.P. is a guest editor invited by the Editorial Board.

Data deposition: The raw data and study protocol can be found on the Databrary (https://nyu.databrary.org/volume/819).

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1809145116/-/DCSupplemental.

This is crucial, as adolescence is a unique stage of development in which adaptation is the product of interactions between prenatal, early childhood, and adolescent-specific social and biological changes that accompany puberty (13, 14). In turn, the physical, cognitive, and socioemotional health of adolescents has implications for the burden of disease in adulthood, as well as the intergenerational transmission of health and adversity (15). The first goal of the current study was to examine trajectories of memory and EF from childhood to adolescence among children with histories of institutional rearing.

The Bucharest Early Intervention Project (BEIP) is a randomized controlled trial (RCT) of foster care as an alternative to institutional care (16, 17). The design of the BEIP limits sources of selection bias inherent to many other studies of postinstitutionalized children. In the BEIP, children reared in Romanian institutions were randomly assigned to a care as usual group (CAUG), or removed from institutions and placed into high-quality foster homes (foster care group; FCG). The development of these children has been tracked longitudinally and compared with a matched sample of never-institutionalized children (never-institutionalized group; NIG). Results from the BEIP are consistent with findings from other studies of postinstitutionalized children in demonstrating deficits in several domains of memory and EF through late childhood (18–20). With the exception of one specific domain of EF, inhibitory control (21), no benefits of foster care intervention have been observed up to age 12.

Two pieces of evidence inspire the hypothesis that some dimensions of memory and EF may be amenable to foster care during the transition to adolescence. First, resting electroencephalogram (EEG) power, especially in the high-frequency alpha band, has been shown to normalize among FCG compared with CAUG by age 8 (22), and persists to age 12 (23). This is believed to reflect enhanced cortical maturation of children assigned to early foster care. This change in brain electrophysiology may precede and predict later cognitive functioning (24). Second, recent evidence suggests that there is remediation in basic associative learning processes, including implicit pattern learning, among FCG compared with CAUG children (25). Together, these findings raise the possibility of improvement in some EF domains—particularly those related to basic learning processes—among children assigned to early foster care. These improvements may be related to individual differences in brain activity. Thus, the primary goal of the current study is to chart trajectories of memory and EF from middle childhood (age 8) to adolescence (age 16) among CAUG, FCG, and NIG children. A secondary goal is to examine whether resting EEG alpha power in middle childhood is associated with better memory and EF outcomes across this formative period of development.

Results

Table 1 presents the growth parameters (intercept and slope) within groups and pairwise comparisons between groups. Model fit, estimated from the posterior predictive *P* value, was acceptable for all four Cambridge Neuropsychological Test Automated Battery (CANTAB) domains (*P*s > 0.05 and 95% CIs all included zero).

On measures of attention and short-term visual memory (delayed match to sample; DMS), NIG had a higher percent correct and lower probability of making errors than CAUG and FCG at age 8 (intercept). In terms of rate of change (slope), children in all groups improved as they got older (i.e., all within-group slopes were significant). Between groups, there were minimal slope differences, suggesting that all children improved at approximately the same rate. By age 16, NIG continued to outperform CAUG and FCG on percent correct responses and response latency. There were no significant intervention effects for any DMS outcome. Fig. 1*A* presents this pattern for percent correct responses.

On a measure of spatial planning and problem solving (Stockings of Cambridge; SOC), a similar pattern emerged to the DMS (Fig. 1*B*). Significant differences among the groups were not observed at age 8 (intercept). In terms of rate of change, children in all groups solved more problems as they got older, and there were no slope differences between groups. By age 16, NIG solved significantly more problems than CAUG, who did not differ statistically from FCG.

On measures of spatial working memory (SWM), NIG had better strategy and made fewer errors than CAUG and FCG at age 8 (intercept). No differences between FCG and CAUG were observed at age 8. In terms of rate of change, children in all groups showed improvements in strategy and made fewer errors as they got older. However, the rate of change between groups was not the same: NIG had significantly steeper slopes than CAUG and FCG, who did not differ from one another. By age 16, the gap between NIG and CAUG and FCG was considerably wider than it was at age 8 (Fig. 1*C*).

On measures of visual-spatial memory and new learning (paired-associate learning; PAL), FCG made more errors and took more trials to have success than NIG, who did not differ from CAUG, at age 8 (intercept). In terms of rate of change, children in all groups made fewer errors and took fewer trials to have success as they got older. However, the rate of change between groups was not the same: FCG had significantly steeper slopes than both NIG and CAUG, who did not differ from one another. By age 16, there were no observable differences in either errors or trials to success across groups (Fig. 1*D*).

Group differences on resting EEG alpha power at age 8 are presented in *SI Appendix*, Fig. S2. Planned comparisons showed that CAUG had lower relative alpha power than NIG, whereas FCG did not differ from either NIG or CAUG. *SI Appendix*, Table S1 presents results from the secondary regression analyses examining the relation between resting EEG alpha power at age 8 and growth parameters for each outcome. There were significant associations between EEG power and most CANTAB measures. Specifically, higher EEG alpha power predicted better performance on DMS percent correct at age 8, 12, and 16 y, as well as significantly greater growth from age 8 to 16 (slope). Higher alpha power also predicted lower DMS probability of making an error at age 8, and marginally so at age 12, but not at age 16 or the rate of change. Alpha power was not related to DMS latency at any age, nor was it related to SOC problems solved in the minimum number of moves. Higher alpha power significantly predicted lower SWM errors at age 8, 12, and 16, as well as better SWM strategy at age 12 and 16, but not rate of change for either outcome. Finally, higher alpha power was marginally associated with fewer PAL errors at age 12 and 16, and fewer PAL trials to success at age 8, 12, and 16. Higher alpha power positively predicted the rate of change in PAL trials to success from age 8 to 16. There were no significant group x EEG interactions for any outcome (all *P*s > 0.05), suggesting the relationship between alpha power and cognitive performance did not vary as a function of group status.

Finally, we examined whether the timing of placement into foster care was associated with performance on each CANTAB domain at 8, 12, and 16 y, splitting children according to whether they left the institutions for foster care at <24 mo or >24 mo of age. Consistent with previous results from the BEIP, no differences were observed for any CANTAB outcome at any age (*SI Appendix*, Table S3). We then split the children at 0 to 18 mo, 18 to 24 mo, 24 to 30 mo, or 30+ mo. A single outcome showed significant group differences—children who entered foster care at 30+ mo had lower spatial planning and problem solving than all other groups at age 16 only. However, there were only four children in the 30+ mo group. Thus, our confidence in this result is substantially tempered.

Discussion

In the current study, we examined the long-term consequences of institutional rearing on memory and EF in childhood and adolescence, and the potential remedial effects of foster care on

Table 1. **Growth parameters within and between groups for each CANTAB outcome**

Growth parameter	CAUG intercept [95% CI]	FCG intercept [95% CI]	NIG intercept [95% CI]	Group difference
DMS: percent correct (all delays)				
Intercept (age 8)	59.51*** [55.09,64.03]	59.43*** [56.04,63.98]	68.12*** [63.76,72.09]	NIG > CAUG,** FCG**
Slope (age 8 to 16)	9.35*** [6.28,11.46]	10.10*** [7.37,12.33]	9.41*** [6.72,12.31]	No differences
Intercept (age 16)	78.20	80.14	86.56	NIG > CAUG,** FCG*
DMS: probability of an error				
Intercept (age 8)	0.32*** [0.26,0.38]	0.29*** [0.24,0.34]	0.23*** [0.18,0.28]	NIG < CAUG,** FCG†
Slope (age 8 to 16)	−0.10*** [−0.15,−0.07]	−0.08*** [−0.11,−0.05]	−0.08*** [−0.11,−0.05]	No differences
Intercept (age 16)	0.13	0.13	0.08	NIG < FCG†
DMS: mean correct latency				
Intercept (age 8)	4441.48*** [3974.29,4926.36]	4044.57*** [3575.37,4532.12]	4113.75*** [3660.95,4554.75]	CAUG > FCG†
Slope (age 8 to 16)	−338.48** [−604.65,−86.93]	−246.40* [−517.43,7.57]	−447.93*** [−717.31,−207.43]	NIG > FCG†
Intercept (age 16)	3723.06	3512.40	3140.46	NIG < CAUG,** FCG*
SOC: problems solved (minimum moves)				
Intercept (age 8)	5.91*** [5.37,6.39]	5.86*** [5.40,6.42]	6.30*** [5.83,6.78]	No differences
Slope (age 8 to 16)	0.83*** [0.46,1.22]	0.96*** [0.60,1.30]	1.05*** [0.66,1.42]	No differences
Intercept (age 16)	7.60	7.75	8.43	NIG > CAUG,* FCG†
SWM: total errors				
Intercept (age 8)	68.10*** [63.79,72.46]	65.83*** [62.35,70.46]	56.95*** [53.28,61.41]	NIG < CAUG,*** FCG**
Slope (age 8 to 16)	−12.49*** [−16.00,−9.46]	−13.79*** [−16.83,−10.55]	−16.69*** [−20.39,−13.21]	NIG > CAUG,** FCG†
Intercept (age 16)	43.27	38.22	22.71	NIG < CAUG,*** FCG***
SWM: strategy				
Intercept (age 8)	39.80*** [38.91,40.88]	39.07*** [38.13,39.99]	37.70*** [36.66,38.67]	NIG < CAUG,*** FCG*
Slope (age 8 to 16)	−2.07*** [−2.80,−1.27]	−1.84*** [−2.72,−1.02]	−2.94*** [−3.73,−1.87]	NIG > FCG*
Intercept (age 16)	35.82	35.60	31.93	NIG < CAUG,*** FCG***
PAL: mean errors to success				
Intercept (age 8)	1.70*** [1.17,2.19]	2.26*** [1.75,2.77]	1.51*** [1.03,1.96]	FCG > NIG,* CAUG†
Slope (age 8 to 16)	−0.29*** [−0.49,−0.07]	−0.53*** [−0.75,−0.31]	−0.26** [−0.47,−0.08]	FCG > NIG,* CAUG*
Intercept (age 16)	1.12	1.20	0.96	No differences
PAL: mean trials to success				
Intercept (age 8)	1.68*** [1.52,1.85]	1.82*** [1.66,2.01]	1.56*** [1.42,1.72]	FCG > NIG*
Slope (age 8 to 16)	−0.14*** [−0.21,−0.07]	−0.21*** [−0.29,−0.15]	−0.11*** [−0.17,−0.05]	FCG > NIG,* CAUG†
Intercept (age 16)	1.40	1.40	1.35	No differences

***$P < 0.001$, **$P < 0.01$, *$P < 0.05$, $^{\dagger}P < 0.10$. All effects are based on one-tailed directional tests and control for gender and birth weight (BW). Coefficients are unstandardized and reflect estimates at the mean of BW and gender.

development in these domains. Our findings align with previous studies in documenting deficits in attention and short-term visual memory, spatial planning and problem solving, spatial working memory, and visual-spatial memory and new learning among institutionally reared children through age 8. At this discrete age, little evidence was found for the benefit of foster care placement (19), supporting the notion that early psychosocial deprivation exerts a significant influence on cognitive development through middle childhood.

A particularly novel contribution of the current study was that it mapped trajectories of memory and EF from childhood to adolescence among ever- and never-institutionalized children. This focus on longitudinal patterns of change provides a powerful method for examining the effects of psychosocial deprivation and foster care placement on memory and EF during a period in which the neural substrates governing cognition are still evolving (26). We observed that children in all three groups (CAUG, FCG, and NIG) showed maturational improvements in memory and EF from age 8 to 16. For institutionalized children, this growth may partially reflect accrual of social and cognitive stimulation as a function of more time spent outside institutions, due in part to our policy of noninterference. Thus, while children with histories of institutional rearing have poorer memory and EF than never-institutionalized children at age 8, all children demonstrate growth in these skills over the transition to adolescence (from age 8 to 16).

Interestingly, we observed different trajectory patterns across domains of memory and EF. First, ever-institutionalized children demonstrated relative difficulties on tasks assessing attention and short-term visual memory at age 8. These difficulties persisted into adolescence, with no group differences on the rate of change. In other words, there were early-emerging and stable disparities in attention and short-term visual memory between ever- and never-institutionalized children, and foster care had no observable effect on these trajectories. A similar pattern was observed for spatial planning and problem solving. On measures of spatial working memory, modest differences between ever- and never-institutionalized children at age 8 became more pronounced by age 16 (i.e., the gap widened over time). In other words, never-institutionalized children showed more growth than ever-institutionalized children, suggesting stagnant development among those with histories of institutionalization. There were no intervention effects on this outcome. Finally, on measures of visual-spatial memory and new learning, FCG children started out with more difficulties than NIG children at age 8 but demonstrated

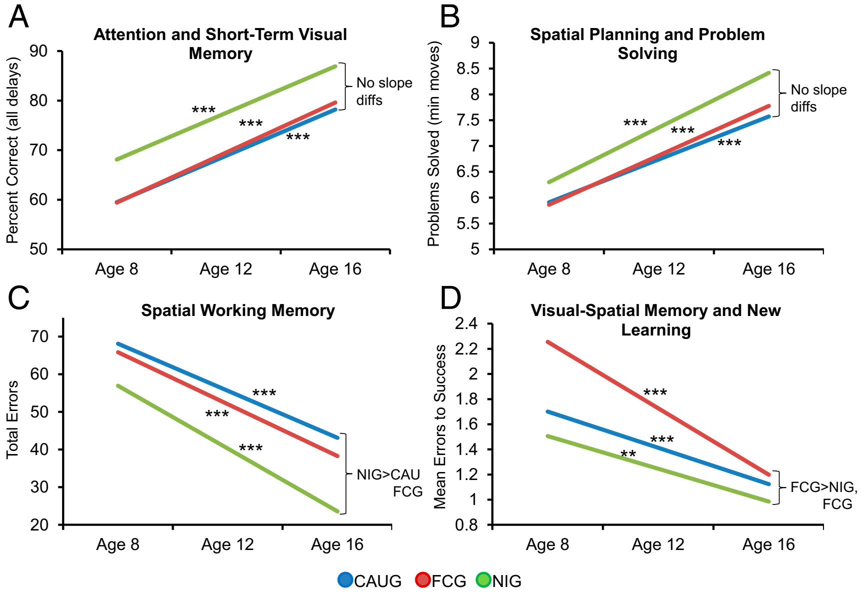

Fig. 1. Trajectories of memory and EF estimated using latent growth modeling for (*A*) attention and short-term visual memory, (*B*) spatial planning and problem solving, (*C*) spatial working memory, and (*D*) visual-spatial memory and new learning. Intercept and slope parameters are presented in Table 1. Significance values for within-group rate of change (slope) are indicated for NIG (green), CAUG (blue), and FCG (red). $^{**}P < 0.01$, $^{***}P < 0.001$.

significantly steeper trajectories of growth than both NIG and CAUG. By age 16, there were no discernible group differences. These results are suggestive of "catch-up" among those assigned to early foster care; however, this interpretation is qualified by the finding that FCG, for unknown reasons, started out with more difficulties than NIG, and marginally more than CAUG. This finding is not simply explained by ceiling effects at age 16, as there was adequate variability on PAL measures at this age (*SI Appendix*, Table S2). However, we cannot rule out that this effect reflects regression to the mean, where children with more early difficulties have more room for improvement. It is nonetheless encouraging that these previously institutionalized children were able to close the gap in visual-spatial memory and new learning over time. These results are consistent with a recent report showing remediation in implicit pattern learning among FCG children at age 12 (25), together underscoring the possibility of emergent benefits of foster care for basic memory and learning processes over the transition to adolescence.

A secondary objective of this study was to examine whether neural activity was associated with memory and EF from childhood to adolescence. To this end, higher resting alpha power at age 8 (the "start point" in our trajectories) was associated with better attention and short-term visual memory, spatial working memory, and visual-spatial memory and new learning at age 8, 12, and 16 y. Higher alpha power also predicted more growth on specific measures of attention and short-term visual memory, as well as visual-spatial memory and new learning. No associations between alpha power and spatial planning and problem solving were observed. These effects were not conditional upon group status, suggesting that EEG alpha power in middle childhood predicts both concurrent and later memory and EF for all children.

Previous studies have shown stable benefits of foster care on alpha power normalization from middle to late childhood (23). The only intervention effect demonstrated in the current study was that FCG showed more rapid improvements in visual-spatial memory and new learning than CAUG from age 8 to 16. Although EEG alpha power predicted the rate of change in this domain, this effect was not confined to FCG children. Thus, while higher alpha power is associated with better visual-spatial memory and new learning across developmental epochs, it does not necessarily explain the catch-up effect among FCG children. It is possible that the current study was underpowered to detect these effects, and future studies with larger samples are clearly needed.

The relation between institutionalization and EEG alpha power has been shown to be mediated by cortical white matter volume (27). Given that previously institutionalized children generally underperformed relative to their never-institutionalized peers, and given that lower performance across tasks was associated with lower resting EEG alpha power, our results raise the possibility that delays in white matter development provide an anatomical link between institutional rearing and cognitive functioning of these children. We and others have shown that children with histories of early deprivation have reduced structural connectivity of white matter tracts involved in limbic circuitry, frontostriatal circuitry, and sensory processing (28–30). Reduced integrity of white matter tracts connecting the temporal lobe and prefrontal cortex is associated with poorer neurocognitive functioning among neglected children (31). Perhaps more interestingly, we have also reported improved integrity of tracts involving the medial temporal lobes among FCG compared with CAUG children at age 8 (30). Since performance on the PAL—the outcome for which FCG improved most rapidly—involves medial temporal lobe functions, these results conjure the possibility that remediation of certain fiber tracts may account for the catch-up in visual-spatial memory and new learning among these children. This hypothesis is speculative, however, and requires explicit testing in future studies that map trajectories of neural structure and function onto measures of memory and EF.

Finally, it is interesting to note that lower EEG alpha power has been shown to mediate the relationship between institutional rearing and symptoms of ADHD (32). As children with ADHD often have pronounced deficits in EF (33), our findings suggest that one cognitive mechanism through which these effects operate is by disrupting memory and EF. In fact, children with histories of severe neglect show marked problems in many other domains, including psychopathology (34), social competence (35), emotional reactivity (36), and academic achievement (37). Each of these domains is supported by memory and EF processes (38). Consequently, while the effects of severe early neglect are not specific to memory and EF, it is plausible that deficits in these abilities provide a foundational link between early deprivation and many later problems. Future studies that track trajectories of brain structure and function, memory and EF, and other phenomenologically complex outcomes will improve our understanding of the cascading effects of early neglect on development in many areas of functioning.

A potential drawback of this study is the relatively small sample, which may have limited power to detect certain effects, including timing of intervention effects, which were not observed for any CANTAB outcome (*SI Appendix*, Table S2 and *Text*). Different studies of postinstitutionalized children have yielded mixed results regarding sensitive periods in which the benefits of foster care or adoption are most prominent. While we too have shown timing effects for certain outcomes (39), these have not been observed for memory and EF. Previous studies showing timing effects for EF have generally documented these before the average age of 22 mo at which children in the BEIP were randomized to foster care. Thus, it is possible that the deleterious effects of early institutional rearing had become more embedded in the current sample compared with others. Second, while we demonstrated several significant effects, most of these were small in magnitude, especially between-group differences. That several effects were detected despite the small sample increases our confidence in their robustness. Nonetheless, replication in larger samples of postinstitutionalized children is encouraged, even if they cannot reproduce the RCT component. Third, it is not clear from the present study how the current socioeconomic or living circumstances of children relate to memory and EF. Follow-up analyses revealed a trend such that foster care children who remained in their original placements through age 16 had fewer difficulties across CANTAB domains compared with those who had changed placements (*SI Appendix*, Fig. S3). While these effects were modest due to small group sizes, they suggest that stability of care or prolonged high-quality caregiving may be a crucial protective factor against later difficulties. Fourth, our study relied on a single standardized battery of neuropsychological functioning (i.e., the CANTAB). The CANTAB has been validated for use from childhood to adulthood, and has been shown to correlate with traditional neuropsychological measures in both typically and atypically developing individuals (40, 41). Nevertheless, studies that examine other dimensions of EF are warranted to determine which abilities are most impacted by early neglect and which are most amenable to early foster care. Finally, we cannot rule out that other prenatal factors not captured by birth weight may have contributed to individual differences in memory or EF observed in the current study. Such information is difficult to acquire for children placed into institutions shortly after birth, with little information available on prenatal or immediate postnatal history. Future studies aiming to examine the effects of foster care placement on cognitive development should actively consider collecting this information from medical records when possible.

In summary, we demonstrate the importance of the early caregiving environment in scaffolding children's cognitive and self-regulatory abilities. We provide evidence that the noxious effects of early deprivation on multiple domains of memory and EF persist or worsen over the transition to adolescence; however, children placed into foster care show growth in visual-spatial memory and learning such that they are indistinguishable from other children by age 16. Moreover, performance on tasks assessing memory and EF in childhood and adolescence relates to individual differences in resting EEG alpha power at age 8, providing a possible neural mechanism supporting cognitive development among both ever- and never-institutionalized children. Efforts to uncover the specific facets of the early caregiving environment that support memory and EF among children with histories of institutional rearing will provide essential targets for prevention and intervention initiatives that aim to optimize development in this uniquely vulnerable group of children.

Materials and Methods

The present study examined data from the BEIP, the details and ethical issues of which have been discussed previously (16, 42). Briefly, institutionally reared infants were recruited from six institutions in Bucharest, Romania. These institutions were characterized by rigid schedules and deficient social, cognitive, and linguistic input that is typically provided in the first years of life. The institutions lacked the presence of stable caregivers due to rotating shifts and low caregiver-to-child ratios. At the baseline assessment, children ranged in age from 6 to 31 mo (*M*, 22 mo). Exclusionary criteria included the presence of genetic syndromes, fetal alcohol syndrome, and micro- or macrocephaly, which were assessed by developmental pediatricians at baseline, before randomization. There were a total of 136 ever-institutionalized children who met the inclusion criteria.

Following baseline assessment, half of the children were randomly assigned to a care as usual group (CAUG), and half were assigned to a foster care group (FCG). As part of the RCT, foster parents received training on the specialized needs of the children placed into their care, and social workers supported the development of high-quality relationships between caregivers and children during regular home visits. Assessments took place at 30, 42, and 54 mo. The trial then concluded, at which point the foster network was turned over to local child protection authorities. Some children were reunited with their biological families, and others were placed into another foster home. A noninterference policy was adopted throughout the study so that Romanian child protection authorities made all decisions about the placement of children in both groups. Thus, several children experienced changes in their placements (*SI Appendix*, Fig. S1). A group of 72 never-institutionalized children was recruited from local pediatric clinics to serve as a comparison sample.

Follow-up assessments have been conducted at age 8, 12, and 16 y. At each age, children completed the Cambridge Neuropsychological Test Automated Battery, a computerized battery of tasks assessing different domains of memory and EF (43). There were 161 children who contributed CANTAB and covariate data at one or more time points (CAUG, 47; FCG, 52; NIG, 62). The current study used data from all three time points to assess trajectories of memory and EF from age 8 to 16 (see CONSORT diagram, *SI Appendix*, Fig. S1, for a detailed description). Sample demographics are presented in Table 2.

Select subtests of the CANTAB were administered at age 8, 12, and 16: (*i*) Delayed match to sample assesses attention and short-term visual memory. Participants are shown a pattern and asked to choose which of four key patterns exactly matches the original. On some trials, the four choices are presented with the original pattern simultaneously, and on others the original pattern is obscured before the choices appear, or there is a delay between these steps. Outcome measures include accuracy, errors, and response latency; (*ii*) Stockings of Cambridge is a spatial planning and problem-solving task based on the Tower of London (44). Participants attempt to reproduce a pattern displayed on the screen by moving colored circles one at a time. A key outcome measure is the minimum number of moves required to solve the problem; (*iii*) spatial working memory assesses the ability to continually update spatial information in memory. Participants are asked to search through boxes to find a hidden token. They are told that once a token in a box has been found, that box will not contain any more tokens. Outcomes include total number of errors committed and a composite strategy score, where a higher score reflects poorer strategy; and (*iv*) paired-associate learning assesses visual-spatial memory and new learning. Participants need to remember patterns associated with different locations on the screen. A series of boxes is displayed, opened one at a time in random order, with some revealing a pattern and others empty. After all the boxes have been opened and closed, a pattern appears on the screen and the participant identifies where the pattern was previously located. If the location is not correctly identified, the trial repeats. Once all trials are completed, the next set of patterns is presented, with an increasing number of boxes and patterns displayed. Outcomes include mean trials and errors to success. The outcomes selected in the current study were chosen a priori to

Table 2. Demographic characteristics of children in the Bucharest Early Intervention Project

Child characteristic	CAUG (*n* = 47)	FCG (*n* = 52)	NIG (*n* = 62)
Gender, %			
Male	53.2	46.2	51.6
Female	46.8	53.8	48.4
Ethnicity, %			
Romanian	55.3	55.8	90.3
Roma (gypsy)	34.0	30.8	8.1
Unknown	8.5	11.5	0.0
Other	2.1	1.9	1.6
Birth weight, g	2877.7*	2730.8*	3207.0*
Age entered institution, mo	1.95	2.72	—

*NIG > CAUG and FCG on birth weight.

mirror those examined in previous reports and to facilitate cross-study comparison (19, 20). Outlier values that were >3 times the interquartile range were winsorized.

At age 8, EEG was recorded from 12 electrode sites (F3, F4, Fz, C3, C4, P3, P4, Pz, O1, O2, T7, and T8) according to the International 10–20 system. EEG was collected in reference to Cz, with AFz serving as the ground. Electrode impedances were kept at <10 kΩ. Vertical electrooculogram was used to record blinks and other eye movements. The EEG signal was amplified with a gain of 5,000, and band pass-filtered from 0.1 to 100 Hz using custom bioamplifiers from James Long Company, as described by Vanderwert et al. (22). Resting EEG was recorded while children sat quietly in a chair, alternating between eyes open and eyes closed for 1 min each, for a total of 6 min. Following previous investigations (22, 23), the eyes-open condition was chosen for the analysis, as this best represents awake-behaving EEG signal. EEG data were processed using the EEG Analysis System from James Long Company following the procedures described by Vanderwert et al. (22). Spectral power (μV^2) was computed for the alpha band (7 to 12 Hz), averaged across F3, F4, C3, C4, P3, P4, O1, and O2 sites. We focused on relative alpha power, which minimizes interindividual differences in absolute power due to factors such as skull thickness.

Trajectories of memory and EF from age 8 to 16 were estimated using multigroup latent growth modeling (LGM) within a Bayesian framework (45) in Mplus version 7.3 (Muthén & Muthén). Growth parameters were estimated both within and between groups, enabling a direct comparison of where children start out (intercept) and rate of change (slope) in memory and EF across groups. As performance at age 16 had yet to be assessed, this was examined by resetting the intercept to age 16 within the LGM model. All three groups (CAUG, FCG, and NIG) were compared. The intervention effect (i.e., FCG–CAUG comparison) was tested using an intent-to-treat analysis. All analyses controlled for gender and birth weight. We report one-tailed *P* values based on the posterior distributions and 95% Bayesian credibility interval. For the secondary analyses, individual growth parameters (intercepts and slopes) were then extracted and used as outcomes in a series of regression models with resting EEG alpha power as the predictor.

Institutional review boards from the University of Maryland, Boston Children's Hospital, and Tulane University approved all procedures, as did an institutional review board established in Romania. In addition, informed written consent was obtained from each of the six local Commissions for Child Protection in Bucharest and/or the biological parents.

The raw data and study protocol can be found at the following link: https://nyu.databrary.org/volume/819.

ACKNOWLEDGMENTS. We thank the families and the children who participated in this study, as well as the research team and staff in Romania for their support and investment in this project. Support for this study was provided by the John D. and Catherine T. MacArthur Foundation, Binder Family Foundation, and NIMH (Grant R01MH091363) (to C.A.N.). A Banting postdoctoral fellowship (to M.W.) supported study execution.

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