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Early Deprivation Impairs the Development of Balance and Bilateral Coordination

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Abstract

This study examined balance and bilateral coordination skills in a sample of internationally adopted, post-institutionalized (PI) children. We compared the performance of these PI children to two age-matched groups. One was a group of children who were internationally adopted from foster care (FC). The second group consisted of non-adopted children being raised in their birth families, who served as controls (Control). Both PI and FC children scored lower than control children on balance, while PI children scored lower than both FC and control children on bilateral coordination. These results suggest that aspects of institutional rearing impact the development of bilateral coordination, while factors common to internationally adopted children other than institutionalization impact the development of balance. Region of birth (Asia, Latin/South America, Russia/Eastern Europe) did not moderate associations between institutional duration and bilateral coordination.

Keywords

early experience; motor; plasticity

INTRODUCTION

The last 20 years were a time of enormous growth in the number of international adoptions in the United States. At one time, most children adopted internationally came from Korea, a country that maintained a well-run foster care (FC) system for orphaned and abandoned children. With the fall of communism in Russia and Eastern Europe and the opening of China, however, there was a shift in pre-adoption conditions for young children. By the late 1990s and early 2000s nearly 85% of all international adoptions were of children who had lived all or most of their lives in institutional settings with highly variable caregiving conditions (Gunnar, Bruce, & Grotevant, 2000). These children are referred to as previously institutionalized, or post-institutionalized (PI) children.

The environments experienced by children in institutions around the world often fall well below what is needed to sustain typical development (Gunnar, 2001; Johnson, 2000; Nelson et al., 2007; Rutter, 1998). The deprivation in these environments is known to affect a wide range of domains including, but not limited to, physical growth, hormonal development, cognitive development, and emotional development (van IJzendoorn et al., 2011). Longer periods of institutionalization have been linked to increased difficulties in areas such as memory and attention (Pollak et al., 2010), reactivity to sensory stimulation (Wilbarger, Gunnar, Schneider, & Pollak, 2010), and mental health (Wiik et al., 2011). Not as much is known, however, about the effects of institutional environments on children's motor development. As noted by Smyke (2012), different aspects of institutional care likely impact different areas of development. Questions remain in this field of research about sensitive periods, and catch-up, and whether children can fully recover from the effects of deprivation.

MOTOR DEVELOPMENT

Motor development reflects both central nervous system maturation as well as experiential learning (Larson et al., 2007). During the first years of life, there is tremendous growth in the nervous system involving progressive myelination and maturation of different brain regions, notably the cerebellum, the corticospinal and thalamocortical tracts, the corpus callosum (Larson et al., 2007), as well as the basal ganglia and caudate nucleus (Diamond, 2000). Ontogeny of these brain regions occurs at different times both prenatally and postnatally, leading to varied periods of vulnerability. The most dramatic increase in synaptogenesis and myelination occurs between the ages of 6 months and 3 years (Rice & Barone, 2000).

Two brain regions, the cerebellum and the corpus callosum, are particularly implicated in motor development. The cerebellum, most often noted for its role in motor function and motor learning, evidences its peak rate of growth at approximately 7 months of age (Rice & Barone, 2000) and is noteworthy because it is highly susceptible to both genetic and environmental perturbations (Bauer, Hanson, Pierson, Davidson, & Pollak, 2009; Diamond, 2000; Swinny, van der Want, & Gramsbergen, 2005). Some of these perturbations include, but are not limited to, prenatal health, postnatal nutrition, and environmental stimulation (Bauer et al., 2009; de Barros, Fragoso, de Oliveira, Filho, & de Castro, 2003; Piek, Dawson, Smith, & Gasson, 2008; Venetsanou & Kambas, 2010).

The corpus callosum is most noted for its role in the rapid exchange of information between the cerebral hemispheres, particularly motor, sensory, and cognitive information. The corpus callosum is implicated in eye movement, hand-eye coordination, and visual and auditory memory. A recent study by Steele, Bailey, Zatorre, and Penhune (2013) suggests evidence for a sensitive period in the development of the corpus callosum occurring in early childhood.

Acquisition and maintenance of posture and movement depends on the learning and repetition of a wide assortment of movement activities in active play settings that lead to sensory feedback and a cascade of neurological events (de Barros et al., 2003; Gallahue &

Cleland, 2003; Gallahue & Ozmun, 2006; Rice & Barone, 2000; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). Animal studies further emphasize that early exposure to complex environments, and the resulting physical activity required, increases neurogenesis (Lewis, 2004). Differing neurological maturation patterns of boys and girls are often noted as the reason for observed differences in the trajectory of motor development, with girls outpacing boys on a variety of measures of motor function (Gidley Larson et al., 2007).

DEPRIVATION AND MOTOR DEVELOPMENT

Delayed motor skills can have a broad impact on a child's development. Exercise and motor development are closely related to physical and mental health; hence, motor delays place children at risk for problems in both physical and social development (Cairney, Hay, Weldhuizen, Missiuna, & Faight, 2010; Haga, 2009; Largo, Fischer, & Rousson, 2003; Poulson & Ziviani, 2004; Skinner & Piek, 2001). Children with motor problems are often stigmatized, with poor motor performance leading to exclusion from social activities. As a result, motor delays are implicated in a cycle of decreasing participation in peer play, decreasing social competence, and low self-esteem (Piek & Coleman-Carman, 1995).

Institutional rearing may be problematic for motor development. Because of poor adult/child ratios in many institutions, infants spend long periods supine in their cribs. Objects to manipulate, when available, are provided for limited periods and floor time is rare (Gunnar et al., 2000). Yet the effects of early deprivation on children's motor development have received relatively little attention. Landgren, Svensson, Stromland, and Andersson Grönlund (2010) noted that 34% of PI children who had been in their adoptive homes for an average of 5 years were identified with developmental coordination disorder (DCD). Lin, Cermak, Coster, and Miller (2005) noted that duration of institutional care was associated with higher levels of problems in sensory discrimination, praxis, and sensory modulation. These data, however, are based on small samples of clinic-referred patients and may not be representative; indeed, 90% of the Landgren et al. (2010) sample was diagnosed with neurological and/or neurodevelopmental disorders.

Recently we reported results of a study examining the effect of environmental enrichment on the motor skills of children adopted from orphanage settings (Roeber, Tober, Bolt, & Pollak, 2012). Institutional deprivation appeared to impact two aspects of motor functioning as assessed in 8- to 16-year-old children adopted from Romania and Russia compared to children being raised in their birth families in the United States. The two motor functions impacted were balance and bilateral coordination, with PI children demonstrating delays in both skills compared to the non-adopted, non-institutionalized control group. Duration of deprivation, indexed as time in institutional care prior to adoption, predicted balance delays. The severity of caregiving deprivation was correlated with decreased bilateral coordination skills. The PI children were not catching-up in their motor skill development despite years in an enriched environment. These findings suggest a number of important points: (1) institutionalization does not provide the early life experience needed for the development of age-level motor skills later in childhood, (2) simple environmental enrichment following adoption is not enough to remediate skills, and (3) there appears to be a sensitive period for motor development.

There were two important limitations in the Roeber et al. (2012) study that motivated the present investigation. First, motor development can be affected by prenatal alcohol exposure (Tarr & Pyfer, 1996). Drinking during pregnancy is common among individuals who place children in institutional care in Russia and Eastern Europe (Gunnar et al., 2000). Although all children in the 2012 Roeber et al. study were screened for fetal alcohol exposure using the FAS Facial Photographic Analysis Software (Astley, 2003), children with alcohol exposure that was not enough to affect facial morphology would not be identified by this method. Therefore, studying children adopted from regions of the world (e.g., China) where it is believed that prenatal exposure to alcohol is not common would reduce the likelihood of this explanation for the findings. Second, nutrition during pregnancy impacts motor development due to its effect on brain development (deRegnier, Long, Georgieff, & Nelson, 2007). Given that poverty is the primary reason for child abandonment worldwide (Gunnar et al., 2000), children placed in institutional care are highly likely to have had mothers living in poverty whose nutrition during pregnancy was less than adequate. To help isolate the effects on motor development to the type of deprivation experienced in institutional settings, an international adoption comparison group is needed who also come from poverty backgrounds, but who experienced predominantly family care conditions prior to adoption. Children from countries using FC rather than institutions provide such a comparison.

In the present study, balance and bilateral coordination were assessed in PI children from around the world. The scores of these children were examined against those of two comparison groups. First, we compared them to children raised in their birth families (non-adopted, Control) and whose parents had incomes and educations that approximated those of families who adopt internationally. Next, we also included an international adoption comparison group of children who were adopted from FC overseas after experiencing little to no time in an institutional setting. The PI children were all adopted at 12 months of age or older, while the FC children were adopted at 8 months of age or younger. Although it might have been preferable to equate time in the enriched environment, it is the case that countries that use FC for wards of the state tend to move children to permanent placement earlier than countries that use institutions (Gunnar et al., 2000).

Based on Roeber et al. (2012) we predicted that PI children would score lower on tests of both balance and bilateral coordination relative to the children in the control group. We further predicated that the children from FC would look more like the controls in the performance of these two skills given that these children did not experience much or any of a severe institutional setting prior to adoption. Finally, to examine whether the effects of institutional care were specific to birth region, we examined whether birth region moderated the key results.

METHOD

Participants

Participants in this study were 132 children, aged 8 and 9 years, from three distinct groups: 48 internationally adopted, PI children who joined their families between 12 and 78 months of age (median = 20 months) after spending at least 75% of their pre-adopted life in an institution (e.g., baby home, orphanage, hospital); 40 internationally adopted, FC children

who joined their families at 8 months of age or younger (median = 5 months) and spent all or most of their lives in FC prior to adoption with little or no hospital or institutional care (83% = 0 months); and 44 non-adopted, comparison children (Control) being raised in their birth families in the United States. Children in the FC group had been in their families longer (median = 98 months) than PI children (median = 81 months). Birth regions for the PI children were Russia/Eastern Europe (55%), Asia (40%), Africa and Latin American (5%). Birth regions for the FC children were Latin America (32%) and Asia (68%). See Table 1 for details.

The internationally adopted children were recruited from international adoption agencies in Wisconsin and Minnesota. Comparison children in Wisconsin were recruited through flyers and advertisements in the community, while those in Minnesota were drawn from a registry of families who expressed interest in being recruited for research. Seventy-four children were tested at the University of Minnesota and 58 were tested at the University of Wisconsin-Madison. Children were not included in the study if they had a diagnosis of neurologic disease or autism, had an IQ below the normal range, or failed a screening for fetal alcohol exposure (Loman, Wiik, Frenn, Pollak, & Gunnar, 2009). In addition, comparison children were not included in the study if they were domestically adopted. As recommended by other adoption researchers, we recruited comparison families who were similar to the adoptive families in maternal level of education and median family income to ensure similar current family environments.

Procedures and Measures

This study was reviewed and approved by the institutional review boards at both universities. All parents provided informed consent. Testing was conducted in the universities' research laboratories by a trained set of examiners with advanced degrees. Children were individually administered the balance and bilateral coordination subtests of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP; Bruininks, 1978). These subtests were chosen based on Roeber et al. (2012). The balance subtest includes eight items assessing static and dynamic balance. The bilateral coordination subtest includes eight items, seven items assessing sequential and simultaneous coordination of arms and legs, and one item assessing arm coordination. Scoring of these subtests uses a mean of 15 and a standard deviation of 5.

To assess whether adoptive and comparison families provided similar opportunities for motor development, we asked parents to indicate, from a possible list of 27 items, the enrichment opportunities that had been made available to their child over the previous year. The list included common items and activities such as swing sets or climbing structures in the yard, swimming lessons outside of school, sending the child to camp, etc. Out of a possible range of 0–27 opportunities for such environmental enrichment, families in all groups endorsed approximately 80% of the items: PI $M = 21.38$, $SD = 3.20$; FC $M = 21.83$, $SD = 2.36$; and Control $M = 21.73$, $SD = 2.49$; $F(2,129) = 0.34$, *ns*. There were no differences by group regarding which items were endorsed.

RESULTS

Following descriptive analyses to characterize the sample (see Tables 1 and 2), we computed a 2 (sex) by 3 (group) MANOVA on the motor assessment scores using general linear models. Sex was included in the MANOVA for exploratory reasons. We then used Pearson correlations to assess the association between age at adoption and time in an institution with motor scores for the adopted groups of children. Within the two regions with substantial numbers of PI children, Russia/Eastern Europe and Asia, we examined associations between duration of institutional care and motor scores.

We found a main effect of group on balance and bilateral coordination scores (*Wilks'* $\lambda = .848$, $F(4, 248) = 5.35$, $p < .001$). Follow-up univariate tests indicated a significant effect of group for balance ($F(2, 142) = 5.50$, $p = .005$), and for bilateral coordination ($F(2, 112) = 6.00$, $p = .003$). Post-hoc tests revealed that for balance, both children in the PI ($M = 12.10$, $SD = 5.73$) and FC groups ($M = 11.98$, $SD = 4.87$) scored lower than the children in the control group ($M = 15.25$, $SD = 5.47$). The PI and FC children were not significantly different from one another in balance scores. In the area of bilateral coordination, PI children scored lower ($M = 14.00$, $SD = 4.12$) than both controls ($M = 16.73$, $SD = 4.17$) and FC children ($M = 16.76$, $SD = 4.92$). The FC children were not significantly different from the controls in bilateral coordination scores.

The MANOVA indicated a main effect of gender on balance and bilateral coordination scores (*Wilks'* $\lambda = .866$, $F(2, 124) = 9.56$, $p < .001$). Follow-up univariate ANOVAs indicated that girls had higher balance scores ($F(1, 405) = 15.68$, $p < .001$). Bilateral coordination scores were also higher in girls ($F(1, 132) = 7.08$, $p = .009$). There was no gender by group interaction for balance ($F(2, 57) = 2.19$, *ns*) or bilateral coordination ($F(2, 6) = .338$, *ns*).

Among the children who experienced FC, there was no association between age at adoption and motor scores, r 's .03 and .13, n 's = 41. Among the PI children, age at adoption was associated with bilateral coordination ($r = -.34$, $n = 46$, $p < .05$), but not balance ($r = -.13$, $n = 47$, *ns*). As age at adoption and duration of institutional care were highly correlated, $r = .98$, $n = 47$, $p < .001$, duration of institutional care was also correlated with bilateral coordination for the PI children, $r(46) = -.35$, $p = .017$.

Because of the confounding of type of care with region of birth, we compared PI and FC children who were adopted from Asia, the only birth region to supply a sufficient number of children from each type of care. There was no difference between PI and FC for balance, $t(45) = -.21$, *ns*, but there was a significant difference for bilateral coordination, $t(45) = -2.74$, $p < .008$, in the same direction as in the full sample. To determine whether duration of institutional care was similarly associated with bilateral coordination in different birth regions, we examined the two regions with sufficient children to compute correlations. The correlations were not significantly different for PI children from Russia/Eastern Europe, $r = -.42$, and Asian, $r = -.35$, $z = -.21$, *ns*.

DISCUSSION

Our results lend support to previous findings that early deprivation impacts children's motor development over time. The present data support three conclusions. First, these results replicate the findings of Roeber et al. (2012) confirming that internationally adopted, PI children have not caught up with their peers in bilateral coordination after being in an enriching family context for approximately 7 years. Second, children who experienced primarily FC continue to lag behind in balance. This is striking because some of the children were adopted as early as 2 months of age. Finally, although the children were adopted from many different regions of the world, these data suggest that the type of care, rather than other risk factors associated with region of birth, may be the operative factor for bilateral coordination. Each of these findings will be discussed in turn.

Motor Catch-Up

Studies of developmental catch-up in adopted children have produced mixed results. While van IJzendoorn and Juffer (2006) demonstrated meta-analytic evidence that adoption was an effective intervention leading to massive catch-up, they noted that adopted children continue to lag behind their current peers and that catch-up remains incomplete in some domains (e.g., areas of physical growth, attachment, intelligence). Our study would suggest that another of those domains would be motor development, specifically the skills of balance and bilateral coordination.

Balance

Balance was impaired for both PI and FC international adoptees and was not more severe for those adopted later from institutional care relative to those adopted earlier from FC. In addition, duration of institutional care was not a factor related to balance. This strongly suggests that factors common to both groups of children, and factors operating early in life, are involved in the impairments in balance we observed. Several possibilities exist and will each be discussed in turn.

First, children who are in FC and institutional care worldwide typically come from conditions of poverty. Factors common to poverty, including poor prenatal nutrition and environmental toxicity, may account for poorer development of balance. Malnutrition can affect myelination and this process is especially vulnerable during late gestation in humans while myelination, synaptogenesis, and differentiation of the nervous system are susceptible to environmental agents including, but not limited to, ethanol, nicotine, methyl mercury, and lead (Rice & Barone, 2000).

Second, the cerebellum is implicated in motor development and it reaches its peak rate of growth early, around 7 months of age. Thus it may be influenced by prenatal and early postnatal conditions, including nutrition. In fact, van IJzendoorn and Juffer (2006) report that the first few years after birth may be a sensitive period for brain growth with malnutrition during this time potentially causing permanent brain damage, while Miller, Kiernan, Mathers, and Klein-Gitelman (1995) report that the combined negative effects of neglect and malnutrition may act synergistically to delay development.

Third, all the children, regardless of whether they were placed in institutions or FC, experienced disruptions in care in the first months of life. These disruptions included relinquishment by the parent(s), a temporary placement while a more permanent situation was found, and then placement either in FC or institutional care. For the FC children, another major change was experienced before 8 months of age when they were adopted into the care of their families in the United States. These disruptions in care and/or the poorer nutrition of families living in poverty worldwide may have produced negative effects on the development of the cerebellar-striatal systems involved in balance. While we cannot be certain of the factors impacting the development of balance in these internationally adopted children, we can be assured that the influence was early, prior to the age of 8 months when the FC children were placed in families where the socioeconomic conditions and stimulation provided to the children were comparable to the children in the control group.

Bilateral Coordination

The findings were markedly different for bilateral coordination. Here children who experienced FC were not impaired relative to the children in the control group, while the PI children were impaired. Moreover, in this domain we observed increased impairments with longer duration of institutional care. Several possibilities exist to attempt to explain this finding. Bilateral coordination relies on the rapid exchange of information between the cerebral hemispheres via the corpus callosum, with the speed of interhemispheric transfer increasing with age (Marion, Kilian, Naramor, & Brown, 2003). Jeeves, Silver, and Milne (1988) indicated that poor bilateral coordination in younger children was attributed to inefficient hemispheric transfer of information due to incomplete callosal myelination. Marion et al. (2003) challenged the strongly held earlier finding that bilateral coordination performance reaches adult levels by about age 10 and instead argued that there is a linear trend in performance improvement continuing at least through age 14. Our results may suggest that institutional care, and longer institutional care, impact the development of the corpus callosum resulting in delayed bilateral coordination later in childhood. Furthermore, it would be interesting to determine if bilateral coordination improves as these children mature into their twenties and if the size of the corpus callosum increases as expected.

Sex Differences

Although we found that girls, overall, were more advanced in their motor development than boys, which is a common finding in typically developing children (Largo et al., 2003; Larson et al., 2007; Nolan, Grigorenko, & Thorstensson, 2005), we did not find any interaction of sex and group. Thus, in our study, PI boys and PI girls were equivalently impaired in the development of balance and bilateral coordination.

Study Limitations

First, this was a cross-sectional study. Such a design makes causal explanation of associations more difficult. A longitudinal design could lend more insight into the balance and bilateral coordination deficits seen in our PI and FC participants and ever improving research methods could tease out more precise explanations. Second, this study is limited by factors that are common to most studies of children adopted from FC and orphanage settings overseas: namely, a lack of detailed information about pre- and postnatal risk factors. For

example, it is often not possible to gather precise data on maternal substance abuse, preterm birth, toxic exposures, nutrition, or a host of other factors affecting internationally adopted children. Finally, while our two groups of internationally adopted children (PI and FC) had been with their adoptive families in the United States for years at the time of testing, there were differing amounts of time between these groups. Therefore, our groups experienced differing amounts of environmental stimulation. Although the PI group had experienced an average of 7 years in their adoptive homes, it is possible that given more time in the enriched environment these children will catch up to their peers in the development of balance and bilateral coordination.

Future Directions

Promising future directions may involve adapting existing effective treatments and interventions for PI children. Neuromuscular data suggest that children with DCD use inconsistent and less efficient motor-control strategies to organize and execute movements (Huh, Williams, & Burke, 1998). Future studies might examine whether similar interventions to those used for DCD might be effective at remediating motor delays in PI children given that Langren, Svensson, Stromland, and Andersson Gronlund (2010) reported a finding of DCD in 34% of PI children.

There is close to a 50% overlap between ADHD and motor deficits (Steger et al., 2001). Children with ADHD tend to have motor problems associated with cerebellar dysfunction (Diamond, 2000). Wiik et al. (2011) found increased ADHD symptoms and a higher number of children above the clinical ADHD cutoff in their group of PI children. Gilbert, Isaacs, Augusta, MacNeil, and Mostofsky (2011) noted that reduced short interval cortical inhibition (SICI) in the motor cortex was a quantitative, biologically based maker of both the diagnosis of ADHD and the severity of ADHD symptoms in children. To a lesser extent, SICI also correlated with the development of motor skills. MRI scans of children with ADHD implicate a smaller cerebellum, frontal cortex, and caudate nucleus along with both reduced and elevated prefrontal activity, and an absence of the frontal asymmetry found in typically developing children (Diamond, 2000). Bauer et al. (2009) reported a smaller volume of the left and right superior-posterior cerebellar lobes in PI children as well as under-developed neural pathways between the cerebellum and the cortex. Given that there is no medical test for diagnosing ADHD, SICI, and MRI may provide ways to look further into any relationship between ADHD and delayed motor skills in PI and FC children. Notably, Diamond (2000) reported that at least half of all children with ADHD have such poor motor coordination as to fit the diagnosis of DCD.

Finally, children are not randomly assigned to early life conditions, nor are they randomly assigned to adoption. Thus, we need to be cautious in interpretation of our results. However, as it seems likely that children with more health problems and poorer development were *less* likely to be adopted, it may be that the present results under-estimate the impact of adverse early life conditions on the development of balance and bilateral coordination. As we expand our understanding of the effects of early deprivation and neurobehavioral development, this information must result in targeted interventions to optimize the development of internationally adopted children.

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Research Highlights

- Early experience impacts the development of balance and bilateral coordination.
- Long lasting effects are seen in children with very early experiences of deprivation, before 8 months of age.
- Balance is delayed in internationally adopted children with and without institutional care.
- Bilateral coordination is only impaired in children adopted from institutions.
- Duration of institutionalization correlates with worse bilateral coordination.
- Region of birth (Asia, Latin America, Russia/Eastern Europe) does not moderate the associations between duration of institutionalization and bilateral coordination.

Table 1

Sample Characteristics

	PI = 48	FC = 40	Control = 44
Mean age (years, months)	8.7 (0.49)	8.7 (0.50)	8.6 (0.50)
	Range 8.1–9.11	Range 8.1–9.11	Range 8.1–9.10
Gender (% female)	50	47.5	54.5
Mean age at adoption (months)	23.38 (12.81)	5.21 (1.76)	
	Range 12.0–78.0	Range 2.0–8.0	
Mean time in institution (months)	22.02 (12.30)	0.33 (0.76)	
	Range 9.0–78.0	Range 0.0–3.0	
Mean time in U. S. (months)	84.15 (14.33)	102.61 (6.21)	
	Range 19.0–103.0	Range 90.0–116.0	

Table 2

Descriptive Data on Assessment Results

	Mean (SD), Range		
	PI = 48	FC = 40	Control = 44
Balance ^a	12.10 (5.73), 1–29	11.98 (4.87), 1–20	15.25 (5.47), 6–29
Bilateral coordination ^a	14.00 (4.12), 7–25	16.87 (4.92), 8–27	16.73 (4.17), 6–27

^a Bruininks-Oseretsky test of motor proficiency subtest.