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Motor Development in 9-Month-Old Infants in Relation to Cultural Differences and Iron Status

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ABSTRACT: Motor development, which allows infants to explore their environment, promoting cognitive, social, and perceptual development, can be influenced by cultural practices and nutritional factors, such as iron deficiency. This study compared fine and gross motor development in 209 9-month-old infants from urban areas of China, Ghana, and USA (African-Americans) and considered effects of iron status. Iron deficiency anemia was most common in the Ghana sample (55%) followed by USA and China samples. Controlling for iron status, Ghanaian infants displayed precocity in gross motor development and most fine-motor reach-and-grasp tasks. US African-Americans performed the poorest in all tasks except bimanual coordination and the large ball. Controlling for cultural site, iron status showed linear trends for gross motor milestones and fine motor skills with small objects. Our findings add to the sparse literature on infant fine motor development across cultures. The results also indicate the need to consider nutritional factors when examining cultural differences in infant development. © 2010 Wiley Periodicals, Inc. *Dev Psychobiol* 53: 196–210, 2011.

Keywords: gross motor; fine motor; cultural practices; breastfeeding; iron deficiency

INTRODUCTION

Advances in motor development allow infants to explore their environment, promoting cognitive, social, and perceptual development (Kariger et al., 2005). Adequate motor development is necessary for visual–perceptual and cognitive development in infancy. With increased locomotion, infants are able to reach new objects and new places, increasing opportunities for exploration (Adolph, Eppler, & Gibson, 1993). Similarly, increased maturity of infants' hand movement abilities may facilitate their

opportunities to learn/understand about properties of the objects (Bushnell & Boudreau, 1993). Around 9 months of age is an important period for motor development, because it marks the onset of standing and skillful grasping. Most infants at this age are transitioning from one motor milestone to another.

Motor development has been traditionally divided into gross and fine. Gross motor development, which includes overall body movement abilities, has been shown to influence infants' independence and self-care. For example, walking without assistance is followed by emotional changes reflecting autonomy and assertiveness, promoting social skills, attachment, and such interactions as social referencing (Biringen, Emde, Campos, & Appelbaum, 1995). Experience with independent locomotion has also been related to enhancement of perceptual–cognitive skills such as spatial search (Bertenthal, Campos, & Barrett, 1984). In “Westernized” cultures, infants 8–10 months of age generally

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accumulate experience with independent crawling. The onset of standing with lateral progression, that is, cruising, also occurs at about 9 months of age, as does the ability to pull from a sitting to a standing position (Bayley, 1965; Bertenthal et al., 1984; Bril, 1986).

Fine movement has been defined as the ability to coordinate the use of the eyes and the hands together in precise and adaptive movement patterns (Williams, 1983). According to Halverson's (1931) 10 stages of grasping development, at the age of 9 months, the fingers wrap around an object by pointing medially rather than down. Halverson (1931) noted that a primitive power grip squeeze of an object is available at about 5 months of age, with further differentiation allowing a superior-palm grasp around 8 months of age, and finally a superior-forefinger precursor type grasp around 12–13 months of age. This orderly sequence in the development of grip configurations is still widely accepted (Newell, McDonald, & Baillargeon, 1993). Therefore, most infants at 9 months of age will be performing within the range of an advanced power grasp and a more rudimentary precision pincer.

Society and culture can have a profound impact on an infant's movement behaviors (Clark, 1995). For the purposes of this study, and according to the Lexico Publishing Company dictionary, "culture" is defined as "the social rules, habits, morals and values that characterize the functioning of a population and induce prescribed behavioral patterns." Sociocultural factors, such as national origin, can influence future motor development because beliefs and attitudes may encourage or discourage some forms of motor behavior (Cintas, 1988). According to Super (1976), Kipsigis infants from Western Kenya (Africa) were exposed to cultural practices that assisted in their gross motor development. For example, to encourage sitting upright, infants were set down in a special hole in the ground that had been made to help support their backs or blankets were nestled around them. As a likely result of these cultural practices, infants in the Kipsigis culture learned to sit earlier than urban white infants in the USA, where such "sitting-ritual" was not practiced. Related studies by Bril (1986), Werner (1972), and Hopkins and Westra (1988) also found slower development of gross motor skills among infants in more "Westernized" cultures. In addition, rural infants showed accelerated gross motor development compared to their urban counterparts (Werner, 1972). Although genetic influences likely play a role (Goetghebuer et al., 2003), current perspectives of behavioral development recognize the combined influence and interaction of gene and environment, but give priority to the environment in the case of complex behaviors such as motor or emotional responses (Cooper, Kaufman, & Ward, 2003).

In contrast to the African precocity in gross motor development (Super, 1976), the few studies conducted in infants of East Asian heritage suggest delayed gross motor development (Freedman & Freedman, 1969). In a US study, Chinese-American babies were delayed in their milestones. The authors related this behavior to protective childcare practices. Infants were less likely to be purposely stimulated in ways to provide additional movement experiences, such as being placed on the floor for free play. A study in Brazil (Santos, Gabbard, & Goncalves, 2001) also considered that protectiveness of Asian mothers contributed to later achievement of gross motor milestones in their young infants. It should be emphasized, however, that in both the Brazilian- and US-Asian studies, infants eventually "caught up" with their Western counterparts, that is, their developmental delay was temporary.

Cultural differences are well accepted for gross motor development (WHO Multicentre Growth Reference Study Group, 2006), but the existence of culture-dependent differences in the fine motor skills of young infants is not well documented. However, several studies consider fine motor development in children older than 2 years. According to Crowe, McClain, and Provost (1999), children from different cultures may have different experiences; children in one culture may practice one fine motor skill while children from another culture may not.

The critical role of nutrition is frequently acknowledged in studies of motor development in different cultures (Capute, Shapiro, Palmer, Ross, & Wachtel, 1985; Moscardino, Nwodu, & Axia, 2006; Pollitt, 2000; Santos et al., 2001). Studies have shown that nutrition, including micronutrients such as iron and zinc, plays an important role in infant motor development (Black, Baqui, Zaman, & Peterson, 2004; Grantham-McGregor & Ani, 2001; Lozoff, 2007; Oelofse et al., 2002; Walka & Pollitt, 2000). We were particularly interested in iron deficiency, since iron is required for myelination, the functioning of several neurotransmitter systems, and metabolic activity (Algarin, Peirano, Garrido, Pizarro, & Lozoff, 2003; Beard & Connor, 2003; Connor & Menzies, 1996; Walker et al., 2007). All these might affect motor development, but myelination is perhaps the most relevant for emerging motor functions in infancy. Infants with iron deficiency anemia (IDA) consistently have lower motor scores, with the majority of studies showing persisting lower scores despite iron treatment, but complete correction of motor deficits has also been reported (Walker et al., 2007). IDA during infancy is also associated with electrophysiologic auditory and visual dysfunctions that are long-lasting (Algarin et al., 2003). Considering the intimate relation between motor and sensory systems, it seems that IDA has an overall impact

on sensorimotor skill acquisition, potentially via altered myelination processes.

The primary purpose of this study was to assess the differences in fine and gross motor development in 9-month-old infants in three cultural sites: Chinese from Beijing (China), African from Accra (Ghana), and African-American from Detroit (USA). A second goal was to consider the effects of iron status on motor development among these infants. Based on prior research, we predicted that the population from Accra would have the most advanced gross motor development, followed by the population from Detroit, and then that of Beijing. Given the limited literature, we had no specific predictions about cultural differences in fine motor development at this particular age. We also predicted that infants with IDA would show less advanced development of fine and gross motor skills, compared to iron-sufficient infants, within and across samples.

METHODS

Participants

Infants were recruited from pediatric clinics during routine clinic appointments and daycare centers, with follow-up invitation by telephone. For the Accra and Beijing samples, advertisements for research subjects were placed in local daycares and pediatric clinics at two hospitals (University of Ghana Medical School-Korle Bu Teaching Hospital in Accra, Ghana, and Peking University First Hospital in Beijing, China). Infants in the African-American sample were recruited from the General Pediatric Clinic of the Children's Hospital of Michigan in Detroit, USA. Infants with hemoglobinopathies at the Accra and Detroit sites received care at specialty clinics and therefore were not part of the sample. Initial entrance criteria at each site were assessed by a 15-min questionnaire. Participation was restricted to healthy infants aged 9–10 months. An effort was made to recruit a balanced number of male and female infants. Exclusion criteria were multiple birth, maternal diabetes, moderate–heavy alcohol consumption, or substance use during pregnancy, prenatal complications, general undernutrition (<10th percentile for weight or length), low birth weight (<2,500 g), prematurity (<37 weeks), major congenital anomalies, acute or chronic illness, and multiple or prolonged hospitalizations (>5 days). The total sample consisted of 113 infants from Detroit, 47 infants from Beijing, and 49 infants from Accra. Details of the Detroit study have been previously published (Lozoff et al., 2008; Shafir, Angulo-Barroso, Jing, Jacobson, & Lozoff, 2008). Background characteristics of infants and families are described in Table 1.

The study was approved by the appropriate Institutional Review Boards at the University of Michigan, Wayne State University, Peking University, and the University of Ghana. Signed informed consent was obtained from the infants' mothers or primary caregivers.

Procedure

Infants were recruited by the clinic coordinator at the country's site. Infants were tested in the clinic in a quiet room by some of the authors and undergraduate students trained by the first author. The duration of motor testing was no longer than 45 min. To examine infants' gross motor abilities, infants were encouraged to demonstrate such skills as rolling, crawling, sitting, standing, and walking. Testers encouraged infants to perform gross motor skills when they were not spontaneously observed, and directly assessed the presence or absence of 19 gross motor milestones, based on a pictorial milestone chart, ranging from sitting to running, ordered by age of expected achievement (modified from Walka & Pollitt, 2000) (Tab. 2).

For the fine motor test, the infant was seated on the parent's lap in front of a table with the examiner seated on the other side. The fine motor test was mainly designed by the first author and consisted of five object-grasp or object-manipulation tasks: small wooden pellet (13 mm diameter), large wooden pellet (24 mm diameter), small ball (5.5 cm diameter), large ball (12 cm diameter), and a bi-manual coordination task (Bojczyk & Corbetta, 2004) of retrieving a rattle from a translucent, plastic box (20 cm × 12 cm × 6 cm) (see Fig. 1). Objects of different diameters were selected to better assess the developmental level of reaching and grasping. The toy retrieval task specifically assessed bimanual and sequential movements. The task required a sequence of movements in which the two hands had to perform movements with a specific timing. One hand had to open the lid and maintain the open position against light pressure exerted by the examiner, while the other hand reached for the toy rattle inside the box and brought it out. Each pellet and ball task was presented three times (maximum 30 s per trial). The box task was presented five times (maximum 30 s per trial). Infants' anthropometric measurements (length, weight, head circumference, and hand size) were taken after the fine and gross motor tests. All testing procedures were videotaped for further analysis and coding.

At the end of the testing session, the clinic coordinator, maternal interviewer, or translator obtained information on infant and family background by parent questionnaire (see Tab. 1). The survey included such questions as sex of the infant, birth weight, duration of breastfeeding, previous hospitalization, mother's use of cigarettes, alcohol, or drugs during pregnancy, mother's education, and family income. Poverty in the Detroit sample was defined according to the HHS Poverty Guidelines (2002), which take into account income and family size, for example, \$15,020 or \$18,100 for a family of 3 or 4, respectively. Families from Accra were considered to be below the poverty line if their income was below 900,000 cedis per month (Pattern and Trends of Poverty in Ghana, 1991–2006). The poverty line in Beijing was defined as earning less than .384 wan yuan (*note*: $320 \text{ yuans} \times 12/10,000 = .384 \text{ wan yuan} = 38.72\text{USD}$, 1 wan yuan = 10,000 yuan, 1 yuan = .121USD) per person, per year (Ministry of Civil Affairs of the People's Republic of China, 2008). The reported yearly household income was divided by the number of people residing in the household (typically three) to attain the income per person (see Tab. 1).

A blood test was obtained for a complete blood count to determine infant iron status (finger-stick for Accra and Beijing

Table 1. Description of Infants and Their Families by Cultural Site

Infant	Accra (<i>N</i> = 49)	Beijing (<i>N</i> = 47)	Detroit (<i>N</i> = 113)
Prior to testing			
Sex (% , <i>n</i> male)	49.0, 24 [†]	53.2, 25	54.9, 62
Birth weight (kg)	3.4 ± .4 ^{a‡}	3.4 ± .5 ^a	3.2 ± .4 ^b
Gestational age (weeks)	38.8 ± 2.0 ^a	39.6 ± .8 ^b	39.7 ± 1.2 ^b
Breastfed (% , <i>n</i>)	100, 49 ^a	91, 41 ^b	46.9, 53 ^c
Duration of breastfeeding (months) ^a	8.8 ± .8 ^a	7.2 ± 2.6 ^b	4.5 ± 3.3 ^c
Weaned before 9 months (% , <i>n</i>)	12.2, 6 ^a	43.9, 18 ^b	75.5, 40 ^c
Hospitalized (%)	14.3	6.4	8.8
At testing			
Age (months)	9.5 ± .32 ^a	9.4 ± .29 ^a	9.7 ± .38 ^b
HAZ	.37 ± 1.03 ^a	.61 ± .80 ^a	-.42 ± .98 ^b
WAZ	-.33 ± .84	-.10 ± 2.06	-.16 ± 1.09
Hand size (mm)	43.0 ± 5.5 ^a	37.9 ± 4.6 ^b	43.1 ± 5.4 ^a
Head circumference (cm)	44.9 ± 1.3	44.9 ± 1.5	45.0 ± 1.5
Hematology			
Hb (g/L)	106.4 ± 19.7 ^a	112.2 ± 17.9	113.3 ± 10.6 ^b
Hb < 110 (% low)	55.3 ^a	31.8 ^b	39.8
MCV (fl)	67.5 ± 5.8 ^a	76.6 ± 3.8 ^b	75.2 ± 4.8 ^b
MCV < 74 (% low)	91.5 ^a	22.7 ^b	35.4 ^b
RDW	17.2 ± 1.8 ^a	13.7 ± 1.4 ^b	13.8 ± 1.3 ^b
RDW ≥ 14 (% high)	97.9 ^a	38.6 ^b	38.1 ^b
Iron status (composite)	-1.64 ± 1.3 ^a	.59 ± 1.0 ^b	.45 ± 1.0 ^b
Family			
Mother smokes (%)	0 ^a	0 ^a	16.8 ^b
Mother drinks (%)	6.1	0	2.7
Mother's education (%)	a	b	c
Level 1 (elementary)	16.3	8.7	0
Level 2 (junior high)	38.8	17.4	0
Level 3 (high school)	22.4	26.1	51.3
Level 4 (beyond HS)	18.4	47.8	48.7
Single mother (%)	10.2 ^a	.0 ^b	87.8 ^c
Below poverty level (%)	92.9 ^a	21.7 ^b	56.4 ^c

HAZ, height-for-age Z-score (CDC, 2000); WAZ, weight-for-age Z-score (CDC, 2000); Hb, hemoglobin; MCV, mean corpuscular cell volume; RDW, red cell distribution width.

^aValues computed for those infants who were breastfed.

[†]Values are mean ± SD for continuous variables and % for categorical variables.

[‡]Different superscripts (a, b, c) indicate statistically significant differences between cultural sites for a given variable ($p < .05$).

samples, venous for the Detroit sample). Parental reluctance to have venous blood sampling in infants and limited funds prevented us from obtaining venous blood and additional iron measures for infants from Accra and Beijing. Hemoglobin (Hb), mean corpuscular cell volume (MCV), and red cell distribution width (RDW) were analyzed by automated cell counter (Detroit: Beckman Coulter Max-M or Sysmex SE-900; Accra and Beijing: Sysmex KX-21 Hematology Analyzer, TOA Medical Electronics, Kobe, Japan). If the infant had received a blood test in the previous month, existing data were used.

Data Reduction

Scoring Gross Motor Milestones. Infants received pass (1) or fail (0) in each of the 19 gross motor milestone items. The sum of passed items yielded a total score.

Scoring Fine Motor Skills. Fine motor development was scored from videotape. Infants' reaching skills were scored from least to most advanced during tasks involving the small and large pellets and balls. Each pellet was scored as attempt (1), successful grasp with more than one contact (2), or grasp on first contact (3). To examine quality of the reach, infants were scored on (a) whether their forearm made contact with the table during the movement and (b) the type of grasp they used to pick up the object. Type of grasp was classified as most advanced grasp (precision pincer grasp), followed by precision multiple, power-radial, and power-ulnar (Halverson, 1931). In a precision pincer grasp only two fingers are used (thumb and index finger or thumb and middle finger) with no palm or other fingers contacting the pellet.

In the ball trials, infants' attempts (1), successes to touch (2), and grasps (3) were scored for the small and large balls.

Table 2. Gross Motor Assessment (Modified From Walka and Pollitt, 2000)

Motor milestone ^a
1. Sits with Support
2. Supports Weight on Hands & Feet 1
3. Sits without Support 1
4. Sits without Support 2
5. Supports Weight on Hands & Feet 2
6. Crawls
7. Hands and Knees Crawling
8. Pulls to Stand
9. Supports Weight on Feet and Legs
10. Walks with Assistance
11. Stands with Support
12. Walks with Support
13. Stands Alone
14. Walks Up Stairs with Support
15. Walks Alone 1
16. Walks Alone 2
17. Walks Alone 3
18. Runs
19. Stands on One Foot Alone

Walks Alone 1 = Child walks alone 3 steps looking for balance.

Walks Alone 2 = Child walks alone 8 steps; his back is a little bent. He has better balance and support on his legs.

Walks Alone 3 = Child walks alone across the room; his back is straight; steps with confidence.

^aAll gross motor items were either spontaneously observed or encouraged following the procedures established in the Peabody Developmental Motor Scale manual.

Ability to correctly predict the size of the ball by reaching and grasping with the appropriate number of hands was also assessed. For the small ball, a higher score was earned when the infant grasped with one hand. For the large ball, a higher score was earned for grasping with both hands.

For the box task, infants were scored by whether they tried to touch the toy (1), touched the toy (2), or retrieved the toy (3). The quality of their bi-manual and sequencing coordination was also scored. Good coordination was defined as follows: when one hand held and pushed the lid away from the body while the other retrieved the toy and moved it toward the body, with both hands acting in opposite directions in a coordinated fashion. Poor coordination was characterized by the lid closing on the hand retrieving the rattle or both hands moving in the same direction. Scoring was 0 for poor coordination and 1 for good coordination.

Creation of a 3-Step Sequence Variable. As described above, there was a sequence of three steps that needed to be completed in order to perform each task correctly. This sequence was defined as a 3-step variable. For a given task, each step in the sequence could not be achieved without successfully completing the previous step. An example of a 3-step sequence is: (1) trying to grasp the pellet, (2) succeeding in grasping the pellet, and (3) retrieving the pellet on the first attempt.

For each task there were also one or two variables that described qualitatively the performance of a successful trial.

These variables described, for example, what type of grasp was used in the pellet task, how many hands were used in the ball task, or whether the infant retrieved the toy from the box with good or poor bi-manual coordination.

Reliability

We computed point-by-point agreement, and coders were trained to 90% inter-coder reliability on video coding scores with the first author and among themselves (mean = 93.3%, range = 89.6–96.7%). Point-by-point reliability was reexamined in the middle (mean = 92.5%, range = 89.6–95.9%) and end of the study (mean = 93.4%, range = 89.6–96.8%).

Iron Status Classification Criteria

IDA was defined as hemoglobin (Hb) < 110 g/L, together with mean cell volume (MCV) < 74 fl and/or red blood cell distribution width (RDW) > 14% (CDC, 1998, 2001). Iron deficiency without anemia (NAID) was defined as Hb ≥ 110 g/L, together with MCV < 74 fl and/or RDW > 14%. Iron sufficiency (IS) was defined as Hb ≥ 110 g/L, MCV ≥ 74 fl, and RDW ≤ 14%. Infants whose hematology parameters did not fall into one of these three groups (IDA, NAID, IS) were considered unclassified and were not included in iron status analyses. Out of the total sample of 209, 5 infants lacked blood information and 21 could not be classified (14 in Detroit and 7 in China). We also generated a composite iron index score based on Hb, MCV, and RDW using principal component analysis (Lozoff, Kaciroti, & Walter, 2006). A higher value of this continuous variable indicates better iron status. This composite iron status variable was used as a covariate in cultural comparisons.

Statistical Analysis

All analyses were carried out using SAS 9.1. To compare samples across cultural sites on the variables described in Table 1, one-way ANOVA was used for continuous variables and logistic regression for dichotomous variables. Post hoc pair-wise comparisons were also conducted when the overall test was significant ($p < .05$) or suggestive ($p < .10$). The same statistical procedures were also used to compare anthropometric and hematologic data across iron groups stratified by cultural site.

Comparison of gross motor scores across cultural sites was analyzed by the general linear model. The data for 3-step sequence variables of the fine motor tests were fitted using ordinal regressions utilizing generalized estimating equations (GEE). PROC GENMOD in SAS was used to compare the cumulative odds across the different cultural sites. The odds ratio measured the likelihood that infants in a particular cultural site advanced farther in the sequence than those in another cultural site. Cultural site differences in the qualitative variables of the fine motor assessment were analyzed using logistic regression. Sex, age at testing, weight-for-age Z-score (WAZ), and iron status composite were used as covariates in the above analyses, based on their relations with each dependent variable. Mother's education, percent of infants breastfed, and poverty level did not relate to gross or fine motor scores with the exception of poverty



FIGURE 1 Examples of fine motor assessment apparatus, including small pellet, large pellet, and box task.

and percent breastfeeding for the box task. Therefore, poverty and percent breastfeeding were included as covariates only for the box task. A similar statistical procedure was repeated to examine iron status differences in our secondary analyses; sex, age at testing, WAZ, and cultural site were used as covariates based on their relations with the dependent variables. Poverty and percent of infants breastfed were also included as covariates for the box task. All statistical tests were two-sided with the level of significance set at .05. Trends at the .1 level were also considered due to the high variability observed in infancy.

RESULTS

Primary Analyses: Cultural Site Differences

Participants and Family Background. All infants were full term and weighed over 3 kg, but there were statistically significant differences among sites in gestational age and birth weight. However, the differences were relatively small (less than a week for gestational age and less than 200 g for birth weight). In contrast, duration of breastfeeding differed markedly across the samples ($p < .0001$). All infants in the Accra sample were breastfed, with a mean

duration of 8.8 months. Almost all infants in the Beijing sample were also breastfed but weaned 2 months earlier, on average, whereas less than half in the Detroit sample were breastfed and they were weaned even earlier. Infants in the Detroit sample took iron fortified formula, solid foods, and juices, and none reported taking cow's milk prior to the conclusion of the study (Tab. 1).

At the time of testing, infants in the Detroit sample were older and shorter for their age compared to the other two samples (p values $< .0001$). Hand size was smaller in infants from Beijing compared to Detroit and Accra ($p < .0001$). None of the other current growth measures were different across the samples. Infants in Accra had mothers with less education than those in Beijing or Detroit ($p < .0001$), and a greater proportion of the families in the Accra and Detroit samples lived below the poverty line than families in the Beijing sample ($p < .0001$).

Iron Status. Infants from Accra had significantly more abnormal levels of Hb, MCV, and RDW compared to the other two sites (p values $< .05$). The sites also differed in the iron status composite, with infants from Accra having

the worst iron status compared to those from Detroit and Beijing (see Tab. 1).

Gross Motor Milestones. The effect of cultural site on gross motor scores showed a suggestive trend ($\chi^2(2) = 5.5, p = .06$). Planned comparisons showed a significant difference between the Beijing and Accra samples ($\chi^2(1) = 5.3, p = .02$) and the Detroit and Accra samples ($\chi^2(1) = 4.1, p = .04$). The scores in the Accra sample were higher than the other two samples, indicating that the infants from Accra had more developed gross motor capabilities, such as standing and walking with support than the infants from Beijing or Detroit. Age at testing of the infants ($\chi^2(1) = 4.9, p = .03$) and iron status composite ($\chi^2(1) = 9.1, p = .003$) were significant covariates (Fig. 2).

Fine Motor Development. Overall, infants from Detroit performed worse on most reach and grasp tasks than infants from Accra or Beijing, and infants from Accra performed better than those from Beijing (see Tab. 3).

Small Pellet

Infants from Accra demonstrated more advanced performance in reach and grasp for the small pellet than infants from the other two cultural sites. For the 3-step sequence variable (three steps needed to complete the task), there was a significant cultural site effect ($\chi^2(2) = 7.6, p = .02$). The pair-wise group comparisons

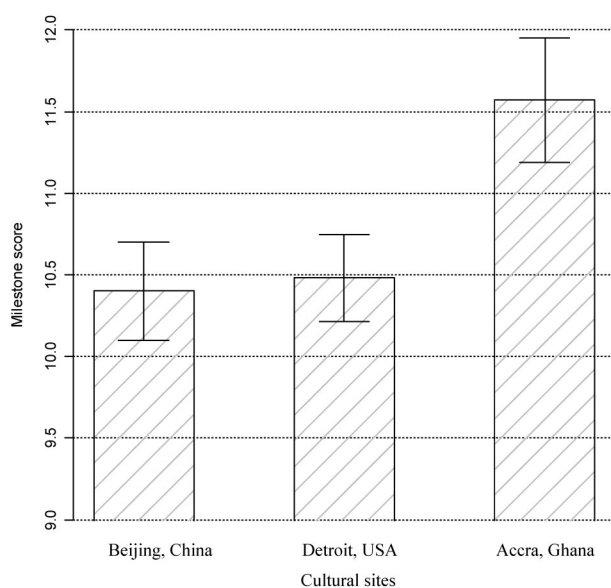


FIGURE 2 Mean and SE of gross motor milestone scores for infants from Beijing, Detroit, and Accra controlling for sex, age at testing, weight-for-age Z-score, and iron status composite ($\chi^2 = 5.5, p = 0.06$).

showed better performance for the Accra sample compared to the Detroit sample ($\chi^2(1) = 6.6, p = .01$). The odds ratio of infants from Accra completing the sequence was 2.5 times higher than those from Detroit. None of the covariates was significant.

For contact with the surface while reaching, there was also a significant effect of cultural site ($\chi^2(2) = 8.1, p = .02$). The Accra group again showed more advanced performance than the Detroit sample ($\chi^2(1) = 8.9, p < .01$). The odds ratio of infants in Accra of performing the task without using arm contact was 3.9 times higher than those from Detroit. The difference between the Accra and Beijing samples was also significant ($\chi^2(1) = 4.2, p = .04$), indicating better performance of infants from Accra (Accra 2.7 times greater than Beijing). Covariates were not significant.

For the type of grasp used, there was again a significant effect of cultural site ($\chi^2(2) = 6.4, p = .04$). The odds of infants from Accra to use a precision grasp was 2.2 times higher than infants from Beijing ($\chi^2(1) = 4.5, p = .03$) or Detroit ($\chi^2(1) = 5.7, p = .02$). None of the covariates was significant. Performance did not differ between the Beijing and Detroit samples for any of the small pellet variables.

Large Pellet

There were no significant cultural differences for performance on the large pellet 3-step variable, reaching on first contact, or arm contact with the surface.

With respect to the type of grasp used with the large pellet, there was a significant difference among the cultural sites ($\chi^2(2) = 20.7, p < .0001$). The odds to use the appropriate type of grasp to obtain the large pellet of infants from Beijing and Accra were 3.2 and 2.5 times greater, respectively, than infants from Detroit ($\chi^2(1) = 18.7, p < .0001$ and $\chi^2(1) = 7.7, p < .01$, respectively). There was no difference between infants from Beijing and Accra. None of the covariates was significant.

Small Ball

For the 3-step sequence variable, there was a significant difference among the infants by cultural site ($\chi^2(2) = 24.3, p < .001$). The infants from Detroit scored significantly lower than the infants from the other two cultural sites (vs. Beijing $\chi^2(1) = 17.8, p < .0001$; vs. Accra $\chi^2(1) = 17.3, p < .0001$), indicating that they are less probable to complete the 3-step sequence with the small ball.

There was also a significant cultural site effect for the number of hands used to obtain the small ball ($\chi^2(2) = 31.5, p < .0001$). Infants from both Beijing and Accra performed this task better than those from Detroit. The odds ratio to use one hand in infants from Beijing was

Table 3. Mean and \pm SD of Fine Motor Variables by Cultural Site

	Accra	Beijing	Detroit
Small pellet (SP)			
Contact forearm	.48 \pm .50 ^{a‡}	.35 \pm .48 ^b	.24 \pm .42 ^c
Grasp type	10.45 \pm 3.43 ^a	8.82 \pm .41 ^b	8.75 \pm 4.76 ^b
3-Step sequence	2.32 \pm .79 ^a	2.27 \pm .72	2.16 \pm .56 ^b
Large pellet (LP)			
Contact forearm	.54 \pm .50 ^a	.42 \pm .49 ^a	.33 \pm .47 ^b
Grasp type	6.96 \pm 4.77 ^a	6.34 \pm 4.66 ^a	4.74 \pm 4.81 ^b
3-Step sequence	2.51 \pm .67	2.56 \pm .59	2.51 \pm .58
Small ball (SB)			
Number of hands	.82 \pm .38 ^a	.81 \pm .39 ^a	.39 \pm .49 ^b
3-step sequence	2.72 \pm .59 ^a	2.66 \pm .68 ^a	2.35 \pm .60 ^b
Large ball (LB)			
Number of hands	.92 \pm .27	.95 \pm .23	.97 \pm .18
3-Step sequence	2.10 \pm .85 ^a	2.13 \pm .79 ^a	2.48 \pm .72 ^b
Box (B)			
Good coordination	.53 \pm .51 ^a	.47 \pm .50 ^a	.76 \pm .43 ^b
3-Step sequence	1.72 \pm 1.23 ^a	2.46 \pm 1.08 ^b	2.66 \pm 1.13 ^c

[‡]Different superscripts (a, b, c) indicate statistically significant differences between cultural sites for a given variable ($p < .05$). A larger number means better performance.

8.4 times higher ($\chi^2(1) = 16.2, p < .0001$), and that from Accra was 5.6 times greater ($\chi^2(1) = 14.1, p = .0002$), than infants from Detroit. None of the covariates was significant.

Large Ball

For the 3-step variable, there was a significant cultural site effect ($\chi^2(2) = 8.6, p = .01$). The odds of infants from Detroit successfully completing the sequence were 2.5 times higher than those from Beijing ($\chi^2(1) = 9.7, p = .002$). There were no significant differences in the number of hands used to reach. No covariates were found to be significant.

Box Task

For the 3-step variable, there was a significant difference in infant performance across cultural sites ($\chi^2(2) = 15.51, p = .0004$). The odds of infants from Beijing and Detroit successfully completing the 3-step box task were 4.6 and 4.7 times greater, respectively ($\chi^2(1) = 14.62, p = .0001$ and $\chi^2(1) = 17.88, p < .0001$), than infants from Accra. WAZ was a significant covariate ($\chi^2(1) = 4.92, p = .027$). No other covariates were significant.

There was a nearly significant cultural site effect for good/poor hand coordination during the box task ($\chi^2(2) = 5.22, p = .073$). The odds of infants from Detroit performing this task with good coordination were 3.4 times higher compared to Beijing ($\chi^2(1) = 5.06, p = .024$). Poverty yielded a suggestive significance

($\chi^2(1) = 3.25, p = .071$). None of the covariates was significant.

Secondary Analyses: Iron Status Effects

The secondary analysis examined differences in infant performance according to iron status, controlling for cultural site.

Growth and Hematology by Iron Status and Site.

Overall, infants in the IDA, NAID, and IS groups had similar height, weight, and head circumferences (p values $> .05$). By definition, hematology variables were different among the iron groups within each cultural site. However, there was little overlap in iron status across sites, especially Accra and Beijing. Iron deficiency with or without anemia was much more common and more severe in Accra than the other two sites. Over half of the infants from Accra had IDA, compared to 19% and 32% in the Beijing and Detroit samples, and the iron composite showed much more abnormal iron measures (iron status composite = -1.64 , compared to .45 and .59 for Detroit and Beijing samples, respectively). Furthermore, only one infant from Accra was iron-sufficient compared to 39% and 46% in the Detroit and Beijing samples respectively (Tab. 4).

Gross Motor Milestones. There was a suggestive linear relation ($\chi^2(2) = 3.61, p = .057$) between gross motor milestone scores and iron status (IDA, NAID, IS). With better iron status, infants seemed to score better on gross motor milestones. Infants from the IS group appeared to

Table 4. Infants' Current Growth and Hematology by Iron Group and Cultural Site

Site	IDA	NAID	IS
Accra			
Sample growth			
% (N)	55 (26)	43 (20)	2 (1)
Age (months)	9.5 ± .38 [†]	9.5 ± .25	9.2 ± 0
HAZ	.59 ± .85	.25 ± 1.18	-.80 ± 0
WAZ	-.11 ± .69	-.60 ± 1.0	-.20 ± 0
Head circumference (cm)	45.3 ± 1.13 ^{a‡}	44.4 ± 1.37 ^b	45.2 ± 0
Blood			
Hb (g/L)	96.3 ± 21.03 ^a	118.9 ± 6.21 ^b	121.0 ± 0
MCV (fl)	66.7 ± 5.9	68.2 ± 5.4	76.0 ± 0
RDW	17.7 ± 1.83 ^a	16.6 ± 1.49 ^b	13.5 ± 0
Iron composite	-2.19 ± 1.31 ^a	-1.04 ± 1.0 ^b	.85 ± 0
Beijing			
Sample growth			
% (N)	19 (7)	35 (13)	46 (17)
Age (months)	9.5 ± .35	9.4 ± .40	9.4 ± .19
HAZ	.47 ± .98	.59 ± .82	.75 ± .82
WAZ	-.04 ± 1.62	-.60 ± 2.94	.01 ± .90
Head circumference (cm)	45.2 ± .97	45.0 ± 1.68	45.0 ± 1.80
Blood			
Hb (g/L)	100.4 ± 5.56 ^a	119.8 ± 4.83 ^b	119.2 ± 6.36 ^b
MCV (fl)	71.3 ± 3.13 ^a	76.0 ± 2.94 ^b	78.9 ± 2.71 ^c
RDW	15.4 ± 1.33 ^a	14.3 ± .49 ^b	12.8 ± 1.28 ^c
Iron composite	-.85 ± .81 ^a	.57 ± .28 ^b	1.32 ± .51 ^c
Detroit			
Sample growth			
% (N)	32 (31)	29 (29)	39 (39)
Age (months)	9.7 ± .43	9.8 ± .32	9.7 ± .35
HAZ	-.58 ± .79	-.44 ± 1.12	-.31 ± 1.11
WAZ	-.52 ± .79 ^a	-.09 ± 1.41	.07 ± 1.07 ^b
Head circumference (cm)	44.6 ± 1.48	45.0 ± 1.60	45.2 ± 1.60
Blood			
Hb (g/L)	101.5 ± 5.52 ^a	119.2 ± 5.31 ^b	121.6 ± 6.61 ^b
MCV (fl)	71.8 ± 4.61 ^a	73.3 ± 4.50 ^a	78.5 ± 2.93 ^b
RDW	14.7 ± 1.43 ^a	14.2 ± .92 ^a	13.0 ± .65 ^b
Iron composite	-.56 ± .81 ^a	.28 ± .70 ^b	1.31 ± .53 ^c

HAZ, height-for-age Z-score; WAZ, weight-for-age Z-score; Hb, hemoglobin; MCV, mean corpuscular cell volume; RDW, red cell distribution width.

N = number of infants within a specific cultural site and iron status group.

% = Proportion of infants within a specific cultural site and iron status group.

[†]Values are mean ± SD for continuous variables and % for categorical variables.

[‡]Different superscripts (a, b, c) indicate statistically significant differences between iron status groups for a given variable ($p < .05$).

perform more advanced gross motor tasks than infants from the IDA group ($\chi^2(1) = 3.4$, $p = .06$). The only significant covariate was age at testing ($\chi^2(1) = 3.82$, $p = .051$). Cultural site was not statistically significant (Fig. 3).

Fine Motor Development. In general, tasks with small objects (pellet and ball) also suggested a relationship between iron status and level of performance. Performance was better as infants' iron status was also better

controlling for cultural site. In contrast, the tasks with the large ball and the box did not show effects of iron status when cultural site was included as a covariate. For all fine motor outcomes, cultural site was a significant covariate. The specific results are considered below.

Small Pellet

There were no significant iron group effects for the 3-step sequence variable or contact with the surface while

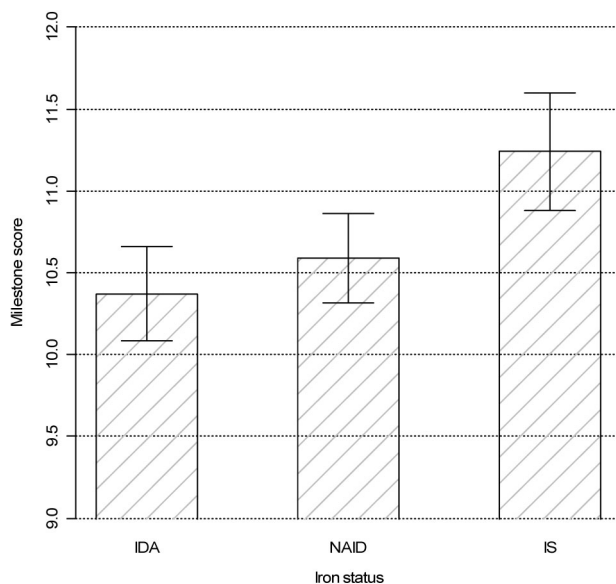


FIGURE 3 Mean and SE of gross motor milestone scores depending on iron status (iron-sufficient IS, iron-deficient nonanemic NAID, and iron-deficient with anemia IDA), controlling for sex, age at testing, weight-for-age Z-score, and cultural site ($\chi^2 = 3.61, p = .057$).

reaching, but cultural site was a significant covariate in both analyses ($\chi^2(2) = 7.38, p = .02$ and $\chi^2(2) = 7.36, p = .02$, respectively).

For the type of grasp used, there was a suggestive linear relation between iron status and performance ($\chi^2(1) = 3.06, p = .08$). The odds ratio to use a precision grasp in infants in the IS group were 1.7 times greater than the infants with IDA ($\chi^2(1) = 3.4, p = .06$). Cultural site was the only significant covariate ($\chi^2(2) = 8.0, p = .02$).

Large Pellet

There were no significant iron status effects for the 3-step variable, arm contact with the surface, or the type of grasp. Cultural site was a significant covariate for type of grasp ($\chi^2(2) = 25.53, p < .0001$); sex was a significant covariate for arm contact with the surface ($\chi^2(1) = 3.95, p = .048$). Other covariates were not significant.

Small Ball

For the 3-step variable, there was a significant linear relation between iron status and performance ($\chi^2(1) = 4.36, p = .04$). The infants from the IS group completed this task better than those from the NAID or IDA groups. The odds to complete the 3-step variable sequence in infants from the IS group were 1.84 ($\chi^2(1) = 3.44, p < .06$) and 1.90 ($\chi^2(1) = 3.93, p = .047$) times greater than those from the IDA and

NAID groups, respectively. Cultural site was also a significant covariate ($\chi^2(2) = 26.18, p < .0001$).

There was no effect of iron status for the number of hands used to obtain the small ball. Cultural site was the only significant covariate ($\chi^2(2) = 36.10, p < .0001$).

Large Ball

For the 3-step variable, there were no significant iron effects. Cultural site was a significant covariate ($\chi^2(2) = 9.81, p = .007$). There were no significant iron effects in the number of hands used to reach, and no covariates were significant.

Box Task

There were no significant differences for the 3-step variable of the bi-manual coordination box task with respect to iron status classification. However, cultural site and WAZ were significant covariates ($\chi^2(2) = 14.48, p = .0007$; $\chi^2(1) = 5.11, p = .024$, respectively).

For the good/poor coordination there was a suggestive linear trend ($\chi^2(1) = 3.06, p = .08$). The odds of performing with good coordination in the IS group was 2.29 times higher than in the IDA group ($\chi^2(1) = 2.87, p = .09$). Culture was also a significant covariate ($\chi^2(2) = 7.15, p = .028$) and poverty yielded a suggestive significance ($\chi^2(1) = 2.74, p = .09$). None of the other covariates was found to be significant.

DISCUSSION

Primary Analysis: Cultural Site Differences

This study examined cultural effects on gross and fine motor development in 9-month-old infants by comparing infants from Beijing, Accra, and an African-American population in Detroit. A secondary analysis considered the effects of iron status on motor development.

In keeping with previous literature, we expected to find cross-cultural differences in gross motor development. Due to the precocity of motor development frequently reported in African cultures, we specifically expected that the sample from Accra would show the most advanced motor development. Our results for the gross motor milestone scores supported this expectation: infants from Accra performed the more advanced gross motor skills, such as stand with support and walk with support. A recent study by the WHO Multicentre Growth Reference Study Group (2006) also found country differences in gross motor scores. Motor milestone onsets in infants from Ghana, Norway, India, Oman, and USA were assessed in the WHO study. Ghanaian infants showed the earliest

onsets for sitting without support, standing with assistance, and walking with assistance. The authors suggest culture-specific care behaviors as the most likely contributing factor for these differences.

These authors also suggest that gross motor milestones that require more coordination and control, such as crawling, are the least affected by cultural practice. Since many fine motor skills also require more coordination and control, their suggestion might also pertain. Unfortunately, the WHO study did not evaluate fine motor development. We found that infants from Accra showed enhanced development in most of the *simple* fine motor tasks, including the small pellet 3-step sequence, contact with the surface, and type of grasp used. Precise reaching, such as that required for the small pellet task, generally requires good postural control as well as fine motor control. Infants in Africa may have an advantage due to the early stimulation with balance and postural control that is typical of many cultures in Africa (Bril, 1986; Super, 1976; Werner, 1972; WHO Multicentre Growth Reference Study Group, 2006). We expected that infants from Beijing would be the most delayed due to the previously proposed cultural protectiveness and diminished opportunities for free motor exploration in infants of Chinese descendents living in USA. However, our findings did not support this prediction. Gross motor milestones scores for the infants in the Detroit and Beijing samples were approximately at the same level of development. Unexpectedly, the infants from Detroit scored lower than those from Accra and Beijing on most of the simple fine motor tasks. Their performance was significantly lower for such tasks as the type of grasp used for reaching the large pellet, the 3-step variable for the small ball, and the number of hands used to obtain the small ball. Infants from Detroit may have scored the lowest in many of the fine and gross motor tasks due to a combination of low socioeconomic status and other family factors. Above half of the families from Detroit (56.4%) were below the USA poverty line and most others were near poverty, while infants tested in Beijing were, for the most part, above the poverty line. This difference in socioeconomic conditions, may have contributed to offset the expected gross motor delay in the Chinese compared to the African-American population in the USA. Alternatively, practices in China may be changing rapidly in the urban areas, or the previously reported protective practices in Chinese-American infants may not be applicable in our China sample.

The infants from Detroit did, however, score the highest for the box task, a complex task that involves motor sequencing and coordination. It is possible that infants from Detroit were more accustomed to transparent plastic objects and colorful toy rattles, items that are typically available in the USA culture. Enhanced

familiarization and practice with such objects might have contributed to the higher scores for the bi-manual coordination task among infants from Detroit. It is important to note that poverty was included in the analysis as a covariate for the box task and it was not significant in the final analysis.

Growth and diet have been suggested as important independent factors affecting gross motor development (Kuklina, Ramakrishnan, Stein, Barnhart, & Martorell, 2004; Siegel, Stoltzfus, Kariger, & Katz, 2005). However, all infants in our study were above 3 kg at birth and had similar weights at 9 months of age. Therefore, growth factors seem unlikely to explain the observed differences in most motor skills. In contrast, diet or feeding practices might be factors, especially given our limited power to find relationships between feeding and motor variables due to limited overlap in feeding practices across the samples. The duration of breastfeeding differed across samples, with the most intense breastfeeding in Accra. Breastfeeding may potentially benefit development through a number of mechanisms, including nutrients in breast milk (such as essential fatty acids) and/or closer mother-child relationships (Grantham-McGregor, Fernald, & Sethuraman, 1999). Existing evidence suggests that breastfeeding is associated with small cognitive benefits (for a review see: Anderson, Johnstone, & Remley, 1999), but evidence for motor benefits is more scarce. Reports from developing countries on breastfeeding duration and child development show small improvements in motor development with greater duration of exclusive breastfeeding and poorer motor and cognitive function with early introduction of supplementary bottle-feeding (Clark et al., 2006; Daniels & Adair, 2005; Dewey, Cohen, Brown, & Rivera, 2001). In our study, the infants from Accra had the longest mean duration of breastfeeding (8.8 months) and breastfed infants from Detroit who were weaned at the time of testing, had the shortest duration (4.9 months). These differences in breastfeeding might contribute to the overall more advanced motor skills seen in the infants from Accra and the least developed motor skills among the infants from Detroit.

Secondary Analysis: Iron Status Effects

The secondary purpose of this study was to examine differences in fine and gross motor development depending on iron status. We postulated that infants with IDA should display the poorest advanced development of motor skills. Unfortunately, our ability to test this hypothesis was limited by the marked differences in iron status across the three cultural sites. This made it almost impossible to untangle the overlap between culture and iron status in the current study. Nevertheless, for several

motor outcomes there were independent effects of both iron status and culture. Iron status showed a suggestive linear trend for gross motor milestone scores. This result is in keeping with our finding that iron status was a significant covariate in the cultural site analysis for gross motor milestones as previously reported (Lozoff, Beard, et al., 2006; Shafir, Angulo-Barroso, Calatroni, Jimenez, & Lozoff, 2006; Shafir et al., 2008). It seems that good iron status is involved in the attainment of better gross motor development. Iron is essential for oligodendrocyte function and myelin production (Beard & Connor, 2003; Connor & Menzies, 1996; Siddappa et al., 2004). Therefore, neural pathways involved in motor skill acquisition, like the corticospinal and corticostriatal tracts, may be particularly vulnerable to the effects of early iron deficiency, since these pathways are not completely myelinated at birth (Rothwell, 1994).

Although evidence of iron status effects on fine motor skill is sparse, our results indicate linear trends for motor skills involving small objects (small pellet and small ball); infants with IDA performed worse than iron-sufficient infants. These results are in agreement with the findings of Shafir et al. (2009), where infants with IDA demonstrated worse reaching and grasping patterns than IS infants. It is important to note that both iron status and culture were independent predictors of fine motor performance with small objects, since we found both an iron status trend and cultural site as a significant covariate in the present study.

Limitations of this study include relatively small samples in each culture, limited overlap in potential control variables such as breastfeeding practices and poverty, and potential misclassification of IDA in Accra and Beijing due to the use of capillary blood (Morris, Ruel, Cohen, Dewey, de la Briere, & Hassan, 1999; Neufeld Garcia-Guerra, Sanchez-Francia, Newton-Sanchez, Ramirez-Villalobos, & Rivera-Dommarco, 2002; Thomas & Collins, 1982). The samples may not be representative of the entire culture, and results may not generalize. In addition, the samples were limited to quasi-urban settings; truly rural populations were not included. All infants in our study were well-nourished, yet presence of other micronutrient deficiencies besides iron was not evaluated. Vitamin D deficiency is widespread in urban African-American infants (Merewood et al., 2010) and, at least in adolescent and adults, may contribute to weakness in proximal muscles (Visser, Deeg, & Lips, 2003) and lower muscle power and force (Ward et al., 2009). Similarly, excess of other substances such as lead could affect fine motor development (Despres et al., 2005; Wasserman et al., 2000), but lead levels were not generally available in this study. Another limitation of our study is that it cannot determine if the observed differences are transient or persistent. Previous studies indicate that cultural differences in early motor development seem to

be temporary and infants eventually catch-up (Santos et al., 2001). Furthermore, we did not evaluate some relevant parental practices. Therefore, we do not know whether infants from Accra in our study were actually more stimulated and those from Beijing were more protected. Future studies should examine cross-cultural differences or lack thereof in infants across a larger age range. Ideally, further research should explore these issues in longitudinal designs with close attention to cultural practices, socioeconomic status, growth and nutrition, including micronutrient deficiencies.

In conclusion, infants in Accra were the most advanced in gross motor development and several fine motor skills, compared to the other cultural sites, despite they were immersed in poverty environments, had caregivers with the lowest levels of education, and had the most iron deficiency. On the contrary, they were mainly breastfed and probably received the largest amount of early motor stimulation. It seems that the latter two factors may be sufficient to provide some motor development advantage, regardless of poor iron status and socioeconomic constraints. These findings (a) add to the sparse literature on infant fine motor development across cultures, (b) stress the importance of controlling for iron status when examining gross motor differences across cultures, and (c) highlight the relevance of early motor stimulation to ameliorate, at least partially, the potential motor delays associated with early iron deficiency. In fact, adequate motor development promotes the necessary activities and interactions with the environment to generate *experience-dependent* exposures that facilitate brain development (Johnson, 2003) and overall health. Similarly, adequate nutrition, including iron, affects brain development (Beard, 2003; McCann & Ames, 2007) and therefore motor development (Shafir et al., 2006). Given that iron deficiency is one of the most prevalent deficiencies in the world, future research should examine the complex interaction among cultural practices, developmental progression, health, and brain development.

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REFERENCES

- Adolph, K. E., Eppler, M. A., & Gibson, E. J. (1993). Crawling versus walking infants' perception of affordances for locomotion over sloping surfaces. *Child Development*, 64(4), 1158–1174.
- Algarin, C., Peirano, P., Garrido, M., Pizarro, F., & Lozoff, B. (2003). Iron deficiency anemia in infancy: Long-lasting effects on auditory and visual system functioning. *Pediatric Research*, 53(2), 217–223.
- Anderson, J. W., Johnstone, B. M., & Remley, D. T. (1999). Breast-feeding and cognitive development: A meta-analysis. *American Journal of Clinical Nutrition*, 70, 525–535.
- Bailey, N. (1965). Comparisons of mental and motor test scores for ages 1–15 months by sex, birth, order, race, geographical location, and education of the parents. *Child Development*, 36, 379–411.
- Beard, J. L. (2003). Iron deficiency alters brain development and functioning. *Journal of Nutrition*, 133 (Suppl 1), 1468S–1472S.
- Beard, J. L., & Connor, J. R. (2003). Iron status and neural functioning. *Annual Review of Nutrition*, 23, 41–58.
- Bertenthal, B. I., Campos, J. J., & Barrett, K. C. (1984). Self-produced locomotion: An organizer of emotional, cognitive, and social development in infancy. In: R. Emde, & R. Harmon (Eds.), *Continuities and discontinuities in development* (pp. 175–210). New York: Plenum.
- Biringen, Z., Emde, R. N., Campos, J. J., & Appelbaum, M. I. (1995). Affective reorganization in the infant, the mother, and the dyad: The role of upright locomotion and its timing. *Child Development*, 66(2), 499–514.
- Black, M. M., Baqui, A. H., Zaman, K., & Persson, L. A. (2004). Iron and zinc supplementation promote motor development and exploratory behavior among Bangladeshi infants. *American Journal of Clinical Nutrition*, 80(4), 903–910.
- Bojczyk, K. E., & Corbetta, D. (2004). Object retrieval in the 1st year of life: Learning effects of task exposure and box transparency. *Developmental Psychobiology*, 40(1), 54–66.
- Bril, B. (1986). Motor development and cultural attitudes. *Themes in Motor Development*, 35, 297–313.
- Bushnell, E. W., & Boudreau, J. P. (1993). Motor development and the mind: The potential role of motor abilities as a determinant of aspects of perceptual development. *Child Development*, 64, 1005–1021.
- Capute, A. J., Shapiro, B. K., Palmer, F. B., Ross, A., & Wachtel, R. C. (1985). Normal gross motor development: The influences of race, sex, and socioeconomic status. *Developmental Medicine and Child Neurology*, 27, 635–643.
- Centers for Disease Control and Prevention. (1998). Recommendations to prevent and control iron deficiency in the United States. *MMWR Morbidity and Mortality Weekly Report*, 47, 1–29.
- Centers for Disease Control and Prevention. (2000). National Center for Health Statistics, CDC growth charts: United States. <http://www.cdc.gov/growthcharts/>. Accessed on July 7, 2008.
- Centers for Disease Control. (2001). *Healthy People—2000 National Health Promotion and Disease Prevention Objectives Final Review*. Hyattsville, MD: Department of Health and Human Services.
- Cintas, H. M. (1988). Cross-cultural variation in infant motor development. *Physical and Occupational Therapy in Pediatrics*, 8(4), 1–20.
- Clark, J. E. (1995). On becoming skillful: Patterns and constraints. *Research Quarterly for Exercise & Sport*, 66(3), 173–183.
- Clark, K. M., Castillo, M., Calatroni, A., Walter, T., Cayazzo, M., Pino, P., et al. (2006). Breast-feeding and mental and motor development at 5(1/2) years. *Ambulatory Pediatrics*, 6, 65–71.
- Connor, J. R., & Menzies, S. L. (1996). Relationship of iron to oligodendrocytes and myelination. *Glia*, 17, 83–93.
- Cooper, R. S., Kaufman, J. S., & Ward, R. (2003). Race and genomics. *New England Journal of Medicine*, 348, 1166–1170.
- Crowe, T. K., McClain, C., & Provost, B. (1999). Motor development of Native American children on the Peabody Developmental Motor Scales. *American Journal of Occupational Therapy*, 53(5), 514–518.
- Daniels, M. C., & Adair, L. S. (2005). Breast-feeding influences cognitive development in Filipino children. *Journal of Nutrition*, 135, 2589–2595.
- Despres, C., Beuter, A., Richer, F., Poitras, K., Veilleux, A., Muckle G. et al. (2005). Neuromotor functions in Inuit preschool children exposed to Pb, PCBs, and Hg. *Neurotoxicology & Teratology*, 27(2), 245–257.
- Dewey, K. C., Cohen, R. J., Brown, K. H., & Rivera, L. L. (2001). Effects of exclusive breastfeeding for four versus six months on maternal nutritional status and infant motor development: Results of two randomized trials in Honduras. *Journal of Nutrition*, 131, 262–267.
- Freedman, D. G., & Freedman, N. C. (1969). Behavioral differences between Chinese-American and European-American Newborns. *Nature*, 224, 1227.
- Goetghebuer, T., Ota, M. O., Kebbeh, B., John, M., Jackson-Sillah, D., Vekemans, J., et al. (2003). Delay in motor development of twins in Africa: A prospective cohort study. *Twin Research*, 6(4), 279–284.

- Grantham-McGregor, S. M., Fernald, L. C., & Sethuraman, K. (1999). Effects of health and nutrition on cognitive and behavioural development in children in the first three years of life. Part 1: Low birth weight, breastfeeding and protein-energy malnutrition. *Food Nutrition Bulletin*, 20, 53–75.
- Grantham-McGregor, S., & Ani, C. (2001). A review of studies on the effect of iron deficiency on cognitive development in children. *Journal of Nutrition*, 131, 649S–668S.
- Halverson, H. M. (1931). An experimental study of prehension in infants by means of systematic cinema records. *Genetic Psychology Manuscripts*, 10, 107–286.
- HHS Poverty Guidelines, (2002). <http://aspe.hhs.gov/poverty/02poverty.htm>. Accessed on July 26, 2010.
- Hopkins, B., & Westra, T. (1988). Maternal handling and motor development: An intracultural study. *Genetic, Social, & General Psychology Monographs* 114(3), 377–408.
- Johnson, M. H. (2003). Development of human brain functions. *Biological Psychiatry*, 54(12), 1312–1316.
- Kariger, P. K., Stoltzfus, R. J., Olney, D., Sazawal, S., Black, R., Tielsch, J. M., et al. (2005). Iron deficiency and physical growth predict attainment of walking but not crawling in poorly nourished Zanzibari infants. *Journal of Nutrition*, 135(4), 814–819.
- Kuklina, E. V., Ramakrishnan, U., Stein, A. D., Barnhart, N. H., & Martorell, R. (2004). Growth and diet quality are associated with the attainment of walking in rural Guatemalan infants. *Journal of Nutrition*, 134(12), 3296–3300.
- Lozoff, B., Beard, J., Connor, J., Barbara, F., Georgieff, M., & Schallert, T. (2006). Long-lasting neural and behavioral effects of iron deficiency in infancy. *Nutrition Review*, 64(5 Pt 2), S34–S43; discussion S72–S91.
- Lozoff, B., Kaciroti, N., & Walter, T. (2006). Iron deficiency in infancy: Applying a physiological framework for prediction. *American Journal of Clinical Nutrition*, 84, 1412–1429.
- Lozoff, B. (2007). Iron deficiency and child development. *Food Nutrition Bulletin*, 28, S560–S571.
- Lozoff, B., Clark, K. M., Jing, Y., Armony-Sivan, R., Angelilli, M. L., & Jacobson, S. W. (2008). Dose–response relationships between iron deficiency with or without anemia and infant social-emotional behavior. *Journal of Pediatrics*, 152, 696–702.
- McCann, J. C., & Ames, B. N. (2007). An overview of evidence for a causal relation between iron deficiency during development and deficits in cognitive or behavioral function. *American Journal of Clinical Nutrition*, 85, 931–945.
- Merewood, A., Mehta, S. D., Grossman, X., Chen, T. C., Mathieu, J. S., Holick, M. F., & Bauchner, H. (2010). Widespread vitamin D deficiency in urban massachusetts newborns and their mothers. *Pediatrics*, 125(4), 640–647.
- Ministry of Civil Affairs of the People's Republic of China. <http://dbs.mca.gov.cn/article/csdb/llyj/200712/20071200006224.shtml?> Accessed on July 8, 2008.
- Moscardino, U., Nwobu, O., & Axia, G. (2006). Cultural beliefs and practices related to infant health and development among Nigerian immigrant mothers in Italy. *Journal of Reproductive Psychology*, 24(3), 241–255.
- Newell, K. M., McDonald, P. V., & Baillargeon, R. (1993). Body scale and infant grip configurations. *Developmental Psychobiology*, 26(4), 195–205.
- Neufeld, L., Garcia-Guerra, A., Sanchez-Francia, D., Newton-Sanchez, O., Ramirez-Villalobos, M. D., & Rivera-Dommarco, J. (2002). Hemoglobin measured by Hemocue and a reference method in venous and capillary blood: A validation study. *Salud Publica de Mexico*, 44(3), 219–227.
- Morris, S. S., Ruel, M. T., Cohen, R. J., Dewey, K. G., de la Briere, B., & Hassan, M. (1999). Precision, accuracy, and reliability of hemoglobin assessment with use of capillary blood. *American Journal of Clinical Nutrition*, 69, 1243–1248.
- Oelofse, A., Van Raaij, J. M., Benade, A. J., Dhansay, M. A., Tolboom, J. J., & Hautvast, J. G. (2002). Disadvantaged black and coloured infants in two urban communities in the Western Cape, South Africa differ in micronutrient status. *Public Health Nutrition*, 5(2), 289–294.
- Pattern and Trends of Poverty in Ghana 1991–2006; Ghana Statistical Service April 2007. <http://www.mofep.gov.gh/2006%20Results%20CG.pdf>. Accessed on July 8, 2008.
- Pollitt, E. (2000). A developmental view of the undernourished child: Background and purpose of the study in Pangalengan, Indonesia. *European Journal of Clinical Nutrition*, 54 (Suppl 2), S2–S10.
- Rothwell, J. (1994). Control of human voluntary movement. Chapman & Hall: London.
- Santos, D. C., Gabbard, C., & Goncalves, V. M. (2001). Motor development during the first year: A comparative study. *Journal of Genetic Psychology*, 162(2), 143–153.
- Shafir, T., Angulo-Barroso, R., Calatroni, A., Jimenez, E., & Lozoff, B. (2006). Effects of iron deficiency on patterns of motor development over time. *Human Movement Science*, 25, 821–838.
- Shafir, T., Angulo-Barroso, R., Jing, Y., Jacobson, S., & Lozoff, B. (2008). Iron deficiency and infant motor development. *Early Human Development*, 84, 479–485.
- Shafir, T., Angulo-Barroso, R. M., Jing, Y., Angelilli, M. L., Jacobson, S. W., & Lozoff, B. (2009). Iron deficiency anemia in infancy and reach and grasp development. *Infant Behavior and Development*, 32(4), 366–375.
- Siddappa, A. M., Georgieff, M. K., Wewerka, S., Worwa, C., Nelson, C. A., & Deregnier, R. A. (2004). Iron deficiency alters auditory recognition memory in newborn infants of diabetic mothers. *Pediatric Research*, 55(6), 1034–1041.
- Siegel, E. H., Stoltzfus, R. J., Kariger, P. K., & Katz, J. (2005). Growth indices, anemia, and diet independently predict motor milestone acquisition of infants in South Central Nepal. *Journal of Nutrition*, 135(12), 2840–2844.
- Super, C. M. (1976). Environmental effects on motor development: The case of Africa precocity. *Developmental Medicine and Child Neurology*, 18, 561–567.
- Thomas, W. J., & Collins, T. M. (1982). Comparison of venipuncture blood counts with microcapillary measurements in screening for anemia in one-year-old infants. *The Journal of Pediatrics*, 101(1), 32–35.
- Visser, M., Deeg, D. J., & Lips, P. (2003). Low vitamin D and high parathyroid hormone levels as determinants of loss of

- muscle strength and muscle mass (sarcopenia): The Longitudinal Aging Study Amsterdam. *J Clin Endocrinol Metab*, 88, 5766–5772.
- Walka, H., & Pollitt, E. (2000). A preliminary test of a developmental model for the study of undernourished children in Indonesia. *European Journal of Clinical Nutrition*, 54(2), S21–S27.
- Walker, S. P., Wachs, T. D., Meeks Gardner, J., Lozoff, B., Wasserman, G. A., Pollitt, E., et al. (2007). Child development in developing countries: Child development: Risk factors for adverse outcomes in developing countries. *The Lancet*, 369(9556), 145–158.
- Ward, K. A., Das, G., Berry, J. L., Roberts, S. A., Rawer, R., Adams, J. E., & Mughal, Z. (2009). Vitamin D status and muscle function in post-menarchal adolescent girls. *J Clin Endocrinol Metab*, 94(2), 559–563.
- Wasserman, G. A., Musabegovic, A., Liu, X., Kline, J., Factor-Litvak, P., & Graziano, J. H. (2000). Lead exposure and motor functioning in 4(1/2)-year-old children: The Yugoslavia prospective study. *Journal of Pediatrics*, 137(4), 555–561.
- Werner, E. E. (1972). Infants around the worlds: Cross-cultural studies of psychomotor development from birth to two years. *Journal of Cross-Cultural Psychology*, 2(3), 111–134.
- WHO Multicentre Growth Reference Study Group. (2006). Assessment of sex differences and heterogeneity in motor milestone attainment among populations in the WHO Multicentre Growth Reference Study. *Acta Paediatrica Supplement*, 450, 66–75.
- Williams, H. (1983). *Perceptual and motor development*. Englewood Cliffs, NJ: Prentice-Hall.