Some Indicators of Nutritional Status Are Associated with Activity and Exploration in Infants at Risk for Vitamin and Mineral Deficiencies1–4

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Abstract

Severe malnutrition, both protein-energy and micronutrient deficiency, results in decreased activity, but the results regarding mild-to-moderate malnutrition are equivocal. Our objective in this investigation was to describe the activity and exploratory behavior of Mexican infants and describe the relationship among nutritional status, activity, and exploration in this population at high risk for mild-to-moderate micronutrient deficiency, but at low risk for severe malnutrition. The participants were infants, 4–12 mo old, of low socioeconomic status from 3 states in southern Mexico. We measured anthropometrics using standard techniques. We measured hemoglobin (Hb) concentration in the field and adjusted values for altitude before analysis. We measured activity and exploration by direct observation during 15 min of individual play in a novel environment. Cluster analysis generated mutually exclusive activity clusters and exploration clusters based on patterns of bodily movement and exploratory behavior, respectively. We categorized the clusters as higher or lower activity or higher or lower exploration. A higher Hb concentration and height-for-age Z-score (HAZ) significantly increased the odds of being in the high-activity cluster. Iron deficiency, stunting, and wasting significantly decreased the odds of being in the high-activity cluster. Higher HAZ and weight-for-age Z-score significantly increased the odds of being in a higher exploration cluster. In Mexican infants at risk for mild-to-moderate micronutrient deficiency but at low risk of severe malnutrition, some indicators of nutritional status were related to increased activity and exploration. J. Nutr. 139: 1751–1757, 2009.

Introduction

Both acute and chronic severe protein-energy malnutrition result in decreased physical activity in children (1–3) that can be reversed with nutritional supplementation (4–6). There is also evidence that mild-to-moderate protein-energy malnutrition can reduce activity (7–10), but the evidence is equivocal (11,12). A number of animal and human studies have reported that micronutrient deficiencies, especially of iron and zinc, also result in reduced activity levels (13–20).

Most evidence suggests that poor nutritional status is related to reduced exploration of the environment, which could have adverse developmental consequences (21,22). In Jamaica, stunted infants had less enthusiasm and variety in exploration than did nonstunted infants (21). In Bangladeshi infants, iron and zinc supplementation for 6 mo improved orientation-engagement scores, a test of exploration, and improved arousal, positive affect, and fearlessness compared to controls (23). A study of Indonesian infants who were moderately protein-energy malnourished reported that energy and iron supplementation increased time separated from the mother, one definition of exploratory behavior, compared with controls (24); however, the same study also reported that supplementation reduced object manipulation, another definition of exploratory behavior (25). Some research suggests that reduced activity results in reduced exploration. Studies from Jamaica and Guatemala reported a reduction in physical activity simultaneous to a reduction in exploration in malnourished compared to well-nourished children; however, neither study had the a priori objective of examining the relationship between activity and exploration (2,4). Definitive conclusions regarding the relationship among
nutrition, activity, and exploration are lacking, because few studies have measured all 3 simultaneously and because different studies use different definitions for these behaviors and even use the terms interchangeably (23–25).

Another limitation in the literature is the paucity of data regarding the relationship among nutrition, activity, and exploration in a mixed population of infants ranging from well-nourished to malnourished. Studies have compared children with stunting, severe wasting, severe micronutrient deficiency, or iron-deficiency anemia to well-nourished controls (2,3,19,21,26,27). The study of less severe malnutrition is important, because globally, an estimated 2 billion persons suffer some form of mild-to-moderate malnutrition (28). Wasting is very rare in Mexican infants [prevalence of weight-for-height Z-score (WHZ) < −2 SD is <2%], even among the urban and rural poor (29). There are, however, high rates of iron and zinc deficiencies (34 and 38%, respectively) and the prevalence of linear growth faltering is high (13% nationally), particularly among the economically vulnerable (37%) (29,30).

Additionally, intake of zinc, vitamin A, and iron is well below recommendations in a large percentage of Mexican children (31).

The objective of this investigation was to use cluster analysis to define 2 sets of clusters, one set based on physical activity and the other based on exploratory behavior, and then, using these clusters, describe the relationship among nutritional status, activity, and exploration in a mixed population of infants at high risk of mild-to-moderate micronutrient deficiency but at low risk of severe malnutrition.

**Materials and Methods**

**Participants** We conducted an investigation on physical activity and exploratory behavior in infants using the baseline data from a randomized supplementation trial, the main objective of which was to compare the impact of 3 different micronutrient supplement types on a variety of nutritional, health, and behavioral outcomes. All study participants were beneficiaries of the poverty-alleviation program Oportunidades (32). Beneficiaries are a vulnerable population at high risk for linear growth faltering, delayed development, and multiple micronutrient deficiencies (30). The main study recruited beneficiaries 4–12 mo old living in 54 urban communities in 4 states in southern Mexico. Infants with congenital abnormalities, chronic disease, or severe anemia [hemoglobin (Hb) <7 g/dL (<70 g/L)] were excluded from participation. Those with severe anemia were referred to a medical professional for treatment. Prior to data collection, we obtained informed consent from a parent or guardian of the study infant. The study was reviewed and approved by the Research, Ethics, and Biosecurity Commissions of the National Institute of Public Health, Cuernavaca, Mexico.

From the main study sample, we selected a subsample of infants for the physical activity and exploration measurement based on the number of participants needed to detect a difference of 3% in higher-intensity activity (0.5 SD) among the 3 treatment groups after 4 mo of supplementation. We needed a minimum sample of 15 infants in 4 communities per supplementation type or a total of 180 infants from 12 communities. We used baseline data from the intervention study for the analysis conducted for this study.

**Data collection.** Local health center staff in each community identified potential participants. The health center and project staff invited the potential participants and a parent or guardian to an informational meeting where project staff explained the study in detail and then took baseline measurements. Fieldworkers assessed socioeconomic status (SES) and medical history using questionnaires previously used in Mexico and adapted for this study. Trained and standardized fieldworkers measured weight and recumbent length using standard procedures (33). Specially trained fieldworkers measured Hb concentration using a capillary blood sample analyzed in the field with a portable photometer (HemoCue).

Using methodology adapted from that used in the WHO multicenter growth reference study (34), we measured gross motor development by assessing specific motor milestones accomplished by the infant. Specially trained fieldworkers obtained a venous blood sample through venipuncture of the forearm and chemists at the Nutrition Laboratory of the National Institute of Public Health measured serum ferritin and serum C-reactive protein (CRP) concentrations using the nephelometry method (Behring Nephelometer B-N 100). Due to financial constraints, serum ferritin and serum CRP concentrations were analyzed on a randomly selected subsample of participants (n = 69).

To measure physical activity and exploratory behavior, we adapted methodology developed by (M. Ramirez-Zea, M. E. Bentley, B. Torun, and L. H. Allen, unpublished data) at the Institute of Nutrition of Central America and Panama. This method measures spontaneous physical activity through direct observation of an infant’s behavior in a novel environment during a discrete time period. This method is similar to observational techniques commonly used to measure child behavior, play, and exploration (19,35,36). The observation of activity, attachment, and play during 15 min of free-play compared to 7 repeated home observations gave similar results when iron-deficient anemic infants were compared to healthy children (19). Observation of infant behavior gave similar results when conducted as one 15- to 30-min observation of spontaneous behavior or when done as the combination of 2 45-min observations of habitual behavior (37). Additionally, a 20-min observation of play behavior was found to have high test-retest reliability and testing in a clinic environment had a high correlation with testing in the home environment (38). The results from multiple studies using discrete observation of spontaneous play or behavior have reported the same relationship between play and nutritional status as have reports using extended observation of habitual activity of ≥4 h (19,24,26,35–37).

Details of the methodology are published elsewhere (39). In summary, a fieldworker set up a portable 9-m² playpen with a variety of novel, age-appropriate toys in a private area of the health clinic. The fieldworker instructed the mother to show the infant the environment and encourage him to play with the toys before placing him in the playpen. The fieldworker stayed in the room and recorded the infant’s behavior for 15 min while the infant played alone. The mother was also in the room but was instructed not to interact with the infant and to only pick up the infant after he cried for 1 min and return to him to the pen as soon as he was pacified. Two coders, unaware of the child’s age and treatment group and uninformed of the child’s nutritional status, viewed the videos twice, first coding for activity and then for exploration.

For the measure of activity, coders used continuous observation to quantify time in each of 5 intensities of bodily movement and time being carried. The intensity of bodily movement was divided into sedentary, light, light/moderate, moderate, and vigorous, defined using a field guide developed at Institute of Nutrition of Central America and Panama (Supplemental Material) and based on energy cost of physical activities in children (40,41). Sedentary was the absence of movement other than manipulation of toys with the hands. Light activities required very little energy and included activities such as turning the head or moving one extremity. Light/moderate activities required more energy but not a high level of energy and included activities such as walking slowly while taking pauses and gently moving 2 extremities. Moderate activities required greater energy such as walking quickly with support or pushing a toy with force. Vigorous activities required a great deal of energy and included running or jumping. For the measure of exploration, coders used continuous observation to quantify time in each of 5 categories of exploratory behavior: no exploration, touching object without looking, looking at object without touching, touching and looking at object simultaneously, and being carried. We summed the time spent “touching without looking” and “looking without touching” and defined this category as exploration in one modality. Time spent “touching and looking simultaneously” was defined as exploration in 2 modalities, a higher exploratory behavior. Coders practiced until they reached an intercoder overall agreement of at least 85% on both activity and

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**Abbreviations used:** CRP, C-reactive protein; HAZ, height-for-age Z-score; Hb, hemoglobin; OR, odds ratio; SES, socioeconomic status; WAZ, weight-for-age Z-score; WHZ, weight-for-height Z-score.
exploration. Restandardization exercises for altitude of the community using the method by Maluccio et al. (42) in Guatemala.

We calculated WHZ, height-for-age z-scores (HAZ), and weight-for-age z-scores (WAZ) based on WHO international reference standards (43) using the WHO Anthro Software (WHO Anthro 2005) (44). We defined stunting as HAZ < -2 SD below the reference mean and wasting as WHZ < -2 SD below the reference mean.

We adjusted Hb concentration for altitude of the community using the method of Cohen and Haas (45). We defined anemia as an adjusted Hb concentration of < 110 g/L (< 11 g/dL). We defined iron deficiency as a serum ferritin concentration of < 12 µg/L (< 27 pmol/L) (46). We report all descriptive statistics as mean ± SD or median (25th, 75th percentile) for continuous variables and as percentage for categorical variables.

We used cluster analysis to develop activity and exploration clusters for use as the outcome variable in logistic regression analysis. Cluster analysis classifies individuals into mutually exclusive groups, or clusters, as suggested by the data and not defined by the investigator, such that individuals within a cluster are more similar to one another than they are to individuals in other clusters based on the variables entered in the analysis (47). In the first cluster analysis, we entered the variables of percentage of time in each intensity of bodily movement and percentage of time being carried to produce activity clusters. In the second cluster analysis, we entered the 5 variables of percentage of time in each category of exploratory behavior (including time being carried) to form exploration clusters. To define the clusters as high, medium, or low activity or exploration, we compared the median time in each intensity of bodily movement and each category of exploratory behavior between the clusters using a nonparametric test of equality of populations with significance of α = 0.05.

We used logistic regression to test the association between nutritional indicators and physical activity and exploration. In the first set of models, we used activity cluster as the response variable and nutritional indicators as predictor variables and in the second set of models, we used exploration cluster as the response variable and nutritional indicators, as well as physical activity, as predictor variables. We used the continuous variables of Hb, serum ferritin, HAZ, WAZ, and WHZ and the categorical variables of anemic, iron deficient, stunted, and wasted (defined as 0 = no and 1 = yes) as indicators of nutritional status. We tested for potential confounding by gender, age, motor development, home SES, maternal education, birth order, and prematurity at birth. These variables remained in the final model if they were significant in that model at an α = 0.05. To test for significance, we calculated robust standard errors to account for the interclustering effect of community on activity and exploration. Analyses were performed using Stata (Stata Statistical Software, release 9.2).

**Results**

This investigation included a total of 206 infants. Because of field complications, not all infants had 15 min of behavior time recorded. The majority (94%) did have 12 min; therefore, we used the coding of the first 12 min of all videos in the analyses. Thirteen infants had < 12 min of behavior recorded and were removed from the analysis for a sample size of 193. Although we only recruited infants 4–12 mo old for the study, one infant of 3.5 mo and 2 infants of 13 mo were erroneously included in the study. Because the results with and without these 3 infants did not differ, they remained in the sample for the analyses. The mean age of the 193 participants was 7.9 ± 2.5 mo (Table 1). The sample was divided fairly evenly between boys (48.7%) and girls (51.3%). There was a much higher prevalence of stunting (16.6%) than wasting (2.6%) and the majority of the sample was anemic (56.5%).

**Table 1** Select characteristics of participants

<table>
<thead>
<tr>
<th>n</th>
<th>193</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, mo</strong></td>
<td>7.96 ± 2.50</td>
</tr>
<tr>
<td><strong>HAZ</strong></td>
<td>-1.12 ± 0.94</td>
</tr>
<tr>
<td><strong>WAZ</strong></td>
<td>-0.37 ± 1.02</td>
</tr>
<tr>
<td><strong>WHZ</strong></td>
<td>0.43 ± 0.05</td>
</tr>
<tr>
<td><strong>Milestones completed, n</strong></td>
<td>1.45 ± 1.64</td>
</tr>
<tr>
<td><strong>Mother’s schooling, y</strong></td>
<td>6.02 ± 3.46</td>
</tr>
<tr>
<td><strong>Hb, g/L</strong></td>
<td>108.0 ± 13.1</td>
</tr>
<tr>
<td><strong>Serum ferritin, µg/L</strong></td>
<td>19.33 (8.4, 51.0)</td>
</tr>
</tbody>
</table>

1 Values are means ± SD, median (25th, 75th percentiles), or %.  
2 Defined as Hb (adjusted for altitude) < 110 g/L.  
3 Defined as serum ferritin < 12 µg/L, n = 69.  
4 Defined as having a medium (vs. low) marginalization index by the National Population Council of Mexico (53).  
5 Lived as < 800 m above sea level.

The percentage of time in each intensity of bodily movement and each category of exploratory behavior followed a nonnormal distribution (P < 0.05; skewness and kurtosis test of normality); therefore, we report their median (25th, 75th percentile) (Table 2). The infants spent the majority of the time in light or light/moderate activities. They spent very little time being sedentary or participating in moderate or vigorous activities. Most infants spent the majority of time in some type of exploratory behavior and little time not exploring.

The cluster analysis generated 3 activity clusters based on the 5 intensities of bodily movement and time carried. The clusters differed with respect to all variables other than time in moderate and vigorous activity (Fig. 1). Cluster 2 passed more time in light activities than the other clusters, and cluster 3 passed more time

**Table 2** Percentage of time in each intensity of bodily movement and category of exploratory behavior in 193 Mexican infants 4–12 mo old

<table>
<thead>
<tr>
<th>Intensity of bodily movement</th>
<th>% of time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>0.00 (0.00, 0.69)</td>
</tr>
<tr>
<td>Light</td>
<td>29.58 (14.86, 44.31)</td>
</tr>
<tr>
<td>Light/moderate</td>
<td>56.42 (39.58, 69.44)</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.00 (0.00, 0.00)</td>
</tr>
<tr>
<td>Vigorous</td>
<td>0.00 (0.00, 0.00)</td>
</tr>
</tbody>
</table>

1 Values are median (25th, 75th percentiles).  
2 One modality defined as “looking at object without touching” or “touching object without looking.”  
3 Two modalities defined as “looking and touching object simultaneously.”

Statistics. We derived a SES index based on household possessions and building materials using principal components analysis similar to the method used by Maluccio et al. (42) in Guatemala.
in light/moderate activities than the other clusters. Cluster 1 passed more time being carried by mother than clusters 2 and 3. Cluster 1 also spent less time in light activity than clusters 2 and 3 and less time in light/moderate activity than cluster 3. Based on the distribution of the 6 variables, we defined cluster 3 as having higher activity and cluster 2 as having lower activity. In cluster 1, the majority of the time was spent being carried by the mother (median 58.5%). Therefore, we could not evaluate the activity of cluster 1 participants and did not include this group in further activity analyses.

The cluster analysis using the exploration variables generated 3 clusters, which differed in the 4 categories of exploratory behavior (Fig. 1). Cluster 1 had the lowest exploration, because the subjects spent more time being carried by the mother and less time in exploration in one or 2 modalities than clusters 2 and 3. Cluster 2 was intermediate in exploratory behavior. Cluster 2 spent more time in no exploration or exploration in one modality than cluster 1 and less time in exploration in 2 modalities than cluster 3. Cluster 3 had the highest exploratory behavior, spending more time in exploration in 2 modalities than either of the other 2 clusters. Because infants were only carried by the mother after they had cried for at least 1 min and mothers stopped carrying infants when they stopped crying, we used “carried by the mother” as a proxy for “attached to mother,” a nonexploratory behavior (4,19,25). Therefore, all 3 groups were maintained for the subsequent analyses.

For each 1-g/L increase in the concentration of Hb, the odds of being in the high-activity cluster were 1.04 (P < 0.05). For every 1 SD increase in HAZ, the odds of being in the high-activity cluster were 1.97 (P < 0.01). The odds of being in the high-activity cluster decreased if the infants were stunted [odds ratio (OR) = 0.45; P < 0.01] or wasted (OR = 0.15; P < 0.05) (Table 3). Anemia, WAZ, and WHZ did not have a significant association with the odds of being in the high-activity cluster.

The participants in the subsample with serum ferritin (n = 69) measures did not differ from the remainder of the sample in SES, gender, age, anthropometric status, motor development, or Hb status (data not shown). Serum ferritin concentration had no relationship with activity. Being iron deficient decreased the odds of being in the high-activity cluster (OR = 0.18; P < 0.01). All models containing serum ferritin included serum CRP concentration in the model to control for the potential increase in serum ferritin concentration due to inflammation. We also analyzed the models excluding participants with a serum CRP >3 mg/L and again with a serum CRP >10 mg/L and the results were consistent with those using serum CRP as a continuous variable in the model (data not shown).

Based on ordinal logistic regression, for each 1 SD increase in HAZ, the odds of being in a higher exploration cluster (the highest cluster compared to the intermediate and lower clusters combined or the highest and intermediate clusters combined compared to the lowest cluster) were 1.84 (P < 0.01), and for each 1 SD increase in WAZ, the odds of being in a higher exploration cluster were 1.86 (P < 0.01) (Table 4). No other indicators of nutritional status had a relationship with exploration. Being in the high-activity cluster increased the odds of being in a higher exploration cluster (OR = 4.38; P < 0.01).

Discussion

In this sample of urban Mexican infants, we used a field method to evaluate the 2 distinct behaviors of physical activity and exploration. A theory explaining the effect of poor nutrition on cognitive and motor development posits that poor nutrition decreases activity, which in turn decreases exploration of the environment and negatively affects cognitive development; and reduced activity directly results in reduced motor development.

![Figure 1](https://academic.oup.com/jn/article-abstract/139/9/1751/4670540)

**FIGURE 1** Percentage of time in each of the 5 intensities of bodily movement and percentage of time being carried in 3 activity clusters (A) and percentage of time in each of the 4 categories of exploratory behavior in 3 exploration clusters (B) generated through cluster analysis based on observed behavior in 193 Mexican infants 4–12 mo old. Within an intensity (A) or category (B), values for clusters 1–3 without a common letter differ, P < 0.05 (nonparametric test of equality of populations).

**TABLE 3** Odds of inclusion in the high-activity cluster based on logistic regression modeling in a sample of 175 Mexican infants 4–12 mo old.

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Categorical variables</td>
<td></td>
</tr>
<tr>
<td>Anemic†,‡</td>
<td>0.70 (0.35, 1.39)</td>
</tr>
<tr>
<td>Iron deficient§</td>
<td>0.18 (0.05, 0.67)</td>
</tr>
<tr>
<td>Stunted</td>
<td>0.45 (0.23, 0.83)</td>
</tr>
<tr>
<td>Wasted</td>
<td>0.15 (0.02, 0.93)</td>
</tr>
<tr>
<td>Continuous variables</td>
<td></td>
</tr>
<tr>
<td>Hb, g/L</td>
<td>1.04 (1.00, 1.08)</td>
</tr>
<tr>
<td>Serum ferritin, μg/L</td>
<td>1.60 (0.67, 3.81)</td>
</tr>
<tr>
<td>HAZ (1 SD)</td>
<td>1.97 (1.32, 2.94)</td>
</tr>
<tr>
<td>WAZ (1 SD)</td>
<td>1.27 (0.90, 1.79)</td>
</tr>
<tr>
<td>WHZ (1 SD)</td>
<td>0.91 (0.60, 1.38)</td>
</tr>
</tbody>
</table>

1 Values are OR (95% CI).
2 Controlling for motor development.
3 Serum ferritin concentration log-transformed and controlling for age, birth order, and serum CRP concentration, n = 65.
4 Defined as serum ferritin < 12 μg/L and controlling for age, birth order, and serum CRP concentration, n = 65.
We used cluster analysis to develop both activity and exploration clusters for use in logistic regression analysis. One advantage of this statistical technique is that it allows the grouping of participants based on a set of variables without a priori knowledge of the distribution of these variables. When groups are formed, investigators can then compare individual group membership by evaluating a number of variables simultaneously instead of comparing individuals on a singular variable (47). Our field method for observing the behavior of infants was novel and there was little a priori information on the distribution of these variables. When reporting results on nutrition and behavior (38,48). Some studies have defined exploration as number of toys played with or amount of space played in (2,19), whereas others have used these definitions to describe activity (4) or play (10). In this study, we described physical activity by measuring the time spent engaged in different intensities of bodily movement and evaluated exploration separately by measuring the time spent engaged in different exploration modalities. This distinction allowed us to quantify the relationship between physical activity and exploration in this population.

We used cluster analysis to develop both activity and exploration clusters for use in logistic regression analysis. One advantage of this statistical technique is that it allows the grouping of participants based on a set of variables without a priori knowledge of the distribution of these variables. When groups are formed, investigators can then compare individual group membership by evaluating a number of variables simultaneously instead of comparing individuals on a singular variable (47). Our field method for observing the behavior of infants was novel and there was little a priori information on the 2 observed behaviors (bodily movement, exploration). We could not predict the distribution of the intensity of bodily movement or the distribution of the categories of exploratory behavior. Using cluster analysis, however, we were able to characterize infants based on these variables. A number of studies have used cluster analysis to describe dietary and activity behaviors in adolescents and adults (49–51). A study from China used this methodology to differentiate between active and inactive youth based on a series of responses on a physical activity questionnaire (50). We successfully used cluster analysis to divide our sample of infants based on all of the observed activity variables and, separately, on all of the observed exploratory behavior variables. We were then able to show that some nutritional indicators were associated with activity and also with exploration.

The infants in our study sample were at risk of multiple micronutrient deficiencies, as reflected by the high prevalence of anemia (57%) and stunting (17%). However, they did not appear to suffer from an energy deficit, as reflected by the mean WHZ of 0.43 ± 1.05. We found a relationship between some measures of nutritional status (as indicated by iron deficiency, Hb concentration, stunting, and HAZ score) and physical activity in this sample. Our results are similar to those of studies reporting decreased activity in iron-deficient anemic infants compared with iron-replete infants and between stunted compared to nonstunted children (3,19,21,26,27). Only one other study in a group of infants suffering a high burden of malarial infection from Zanzibar reported a continuous relationship between HAZ and Hb concentration and activity, as opposed to reporting on differences in activity between 2 groups of different nutritional status (52). We also detected a continuous relationship between nutritional status, using the variables of HAZ and Hb concentration and activity, in a mixed population of infants not affected by malaria ranging from well-nourished to mild-to-moderately malnourished. Interestingly, both in our study and the study from Zanzibar, being iron deficient was related to reduced activity, whereas being anemic compared to nonanemic was not. These results suggest that reduced iron status adversely affects activity before anemia is manifest. The anemic and nonanemic groups therefore would both be comprised of infants whose activity was adversely affected by reduced iron status, making a relationship between anemia and activity difficult to detect.

Our results emphasize that declining nutritional status is associated with reduced activity in nutritionally at-risk infants and this association is detectable in a mixed population not suffering severe malnutrition. A number of studies comparing severely malnourished or stunted to well-nourished populations have reported that reduced activity and exploration adversely affect both cognitive and motor development during early life (4,20,21,27). The effect that reduced activity and exploration in populations such as ours is not fully understood. Future research should explore the meaningfulness of the differences in activity and exploration in our population on behavioral and developmental outcomes.

Two studies reported reduced activity in older, moderately protein-energy malnourished Colombian (6–16 y old) (9) and Kenyan (7–8 y old) children (8) compared to well-nourished counterparts when children were given the opportunity to expend energy in a camp or playground setting. Activity between well-nourished and malnourished children did not differ when the Colombian children were in a school setting where activity was not promoted (7). Our methodology included the promotion of activity and exploration through the selection of age-appropriate toys, a novel, colorful environment, and the instructions given to the mother to entice the child to play before placing him or her in that environment. The promotion of activity and exploration likely contributed to the similarity between our results in infants and those in older children found in the literature.

Some increased measures of nutritional status (indicated by HAZ and WAZ) were associated with higher levels of exploration. This finding is consistent with a study from Bangladesh in which infants with higher WAZ and WHZ scores had greater exploratory behavior, as measured by a complex orientation-engagement score (23). This finding is also consistent with a study from Jamaica that reported that stunted children had reduced diversity in exploration compared to nonstunted infants (21). Our measure of exploration included the category of "time

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>$P$-value</th>
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<tbody>
<tr>
<td>Serum ferritin, g/L</td>
<td>0.97 (0.94, 1.01)</td>
</tr>
<tr>
<td>Hb (SD)</td>
<td>1.05 (0.69, 1.84)</td>
</tr>
<tr>
<td>WAZ (SD)</td>
<td>1.94 (1.41, 2.40)</td>
</tr>
<tr>
<td>WHZ (SD)</td>
<td>1.86 (1.26, 2.72)</td>
</tr>
<tr>
<td>Hb concentration log-transformed and controlling for age, motor development, and serum CRP concentration, n = 61.</td>
<td>1.27 (0.56, 1.88)</td>
</tr>
<tr>
<td>Anemia (yes = 1, no = 0)</td>
<td>2.15 (0.79, 5.93)</td>
</tr>
<tr>
<td>Iron deficient</td>
<td>0.83 (0.27, 2.57)</td>
</tr>
<tr>
<td>Wasted</td>
<td>0.76 (0.18, 3.64)</td>
</tr>
<tr>
<td>High physical activity cluster</td>
<td>4.38 (1.67, 11.46)</td>
</tr>
</tbody>
</table>

1 Values are OR (95% CI).
2 Controlling for age, motor development, and maternal education.
3 Serum ferritin concentration log-transformed and controlling for age, motor development, and serum CRP concentration, n = 61.
4 Controlling for age and motor development.
5 Defined as Hb (adjusted for altitude) <110 g/L.
6 Defined as serum ferritin <12 μg/L and controlling for age, motor development, and serum CRP concentration, n = 61.
7 Controlling for age and maternal education.

Our results emphasize that declining nutritional status is associated with reduced activity in nutritionally at-risk infants and this association is detectable in a mixed population not suffering severe malnutrition. A number of studies comparing severely malnourished or stunted to well-nourished populations have reported that reduced activity and exploration adversely affect both cognitive and motor development during early life (4,20,21,27). The effect that reduced activity and exploration in populations such as ours is not fully understood. Future research should explore the meaningfulness of the differences in activity and exploration in our population on behavioral and developmental outcomes.

Two studies reported reduced activity in older, moderately protein-energy malnourished Colombian (6–16 y old) (9) and Kenyan (7–8 y old) children (8) compared to well-nourished counterparts when children were given the opportunity to expend energy in a camp or playground setting. Activity between well-nourished and malnourished children did not differ when the Colombian children were in a school setting where activity was not promoted (7). Our methodology included the promotion of activity and exploration through the selection of age-appropriate toys, a novel, colorful environment, and the instructions given to the mother to entice the child to play before placing him or her in that environment. The promotion of activity and exploration likely contributed to the similarity between our results in infants and those in older children found in the literature.

Some increased measures of nutritional status (indicated by HAZ and WAZ) were associated with higher levels of exploration. This finding is consistent with a study from Bangladesh in which infants with higher WAZ and WHZ scores had greater exploratory behavior, as measured by a complex orientation-engagement score (23). This finding is also consistent with a study from Jamaica that reported that stunted children had reduced diversity in exploration compared to nonstunted infants (21). Our measure of exploration included the category of "time
carried by mother." The mothers were given instructions not to interact with their child and to allow the child to cry for 1 min, then carry the child until pacified, and return him to the playpen as soon as crying stopped. Thus, "time carried by mother" was an indication of the child seeking his mother or attachment behavior. Our findings are, therefore, consistent with observational studies that reported infants with poorer nutritional status (measured by low WHZ, low energy intake, or iron-deficiency anemia) spent more time attached to the mother than did well-nourished infants (4, 19, 25). Other measures of nutritional status were not associated with higher exploration, which may be due to the relatively low variability in the exploratory behavior making relationships more difficult to detect.

Physical activity had a strong positive relationship with exploration. This finding is similar to the simultaneous increase in both activity and exploration with improvement in nutritional status reported in several studies that did not specifically examine the relationship between the 2 variables (24, 19). Our results, however, are contrary to those reported from Indonesia where increased activity resulted in decreased manipulation of objects (24). In that study, there were 2 cohorts of infants, 12 and 18 mo old at baseline, who were followed for 6 mo. The inverse relationship between activity and object manipulation was only significant in the 18-mo cohort when comparing previous activity to subsequent object manipulation. It is possible that the inconsistency between our findings and those from Indonesia is the result of the different methods used to measure exploration or a variation in the relationship between activity and exploration with increasing age and/or maturity.

Although our study was cross-sectional, and thus causal relationships cannot be established, our results suggest that poorer nutritional status (indicated by iron deficiency, lower Hb, lower HAZ, and stunting) is associated with lower physical activity and that lower WAZ and HAZ are associated with lower exploration. We detected these relationships in a population where no individuals suffered severe malnutrition in the form of severe anemia, severe wasting, and severe stunting. More longitudinal data in the area of nutrition, activity, exploration, and subsequent growth and development are needed to understand the consequences of reduced activity and exploration in such a population and to investigate the possible causal link between nutrition and growth and development through activity and exploration.

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Literature Cited


