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Growth and Visual Information Processing in Infants in Southern Ethiopia

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Abstract

Speed of information processing and recognition memory can be assessed in infants using a visual information processing (VIP) paradigm. In a sample of 100 infants 6–8 months of age from Southern Ethiopia, we assessed relations between growth and VIP. The 69 infants who completed the VIP protocol had a mean weight z score of -1.12 ± 1.19 SD , and length z score of -1.05 ± 1.31 . The age-appropriate novelty preference was shown by only 12 infants. When age was controlled, longest look duration during familiarization was predicted by weight ($sr^2 = .16$, $p = .001$) and length ($sr^2 = .05$, $p = .058$), and mean look duration during test phases was predicted by head circumference ($sr^2 = .08$, $p = .018$) implying that growth is associated with development of VIP. These data support the validity of VIP as a measure of infant cognitive development that is sensitive to nutritional factors and flexible enough to be adapted to individual cultures.

Keywords

Infant; Growth; Cognition; Development; Visual information processing; Novelty preference

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1. Introduction

Recent research recommendations suggest using measures closely linked to specific cognitive processes when examining the development of cognition in relation to nutritional status (Institute of Medicine, 2004). We implemented these research recommendations by examining the relation between growth, a well-accepted measure of general infant health and nutrition (R. E. Black, Morris, & Bryce, 2003; Wachs et al., 1993; World Health Organization, 1986), in infants from rural Southern Ethiopia and a circumscribed set of processes underlying cognition (visual information processing) using a modified novelty preference paradigm.

The speed at which information can be encoded is thought to be one of the main components of intelligence in adults (Vernon, 1987) as well as in infants (Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; Rose, Feldman, & Jankowski, 2002). Speed of processing and recognition memory both can be assessed using a novelty preference paradigm that measures an infant's tendency to direct visual attention toward a novel stimulus rather than a familiar one (Rose, Feldman, & Jankowski, 2004). The infant is first presented with a single visual stimulus, followed by the presentation of that now-familiar stimulus along with a novel stimulus. The preference for novel stimuli is thought to be based on the extent to which the familiar stimulus has been encoded, i.e., processed (Courage & Howe, 2001; Rose et al., 2002). If processing speed is less than optimal as a result of insult or immaturity, incomplete encoding of the familiar stimulus occurs and it cannot be distinguished from a novel stimulus. Thus, novelty preference¹ (NP) does not occur.

Additional measures (e.g., length of longest look and mean look duration) can also be calculated. In this paper, we will refer to these measures (including NP) collectively as visual information processing² (VIP). NP and VIP in general change with development, with older infants recognizing stimuli more quickly, recognizing more complex stimuli, and requiring less familiarization (Colombo, Shaddy et al., 2004; Rose et al., 2004). These measures have also been found to predict intelligence in childhood (McCall & Carriger, 1993). A recent meta-analysis (Kavšek, 2004) found a weighted average correlation of .37 between VIP measures and childhood cognitive performance.

Research suggests that the degree of novelty preference per se, though adequate, may not be the most sensitive measure of stimulus encoding. Processing speed, measured by look duration (the length of the longest look during familiarization), has been identified as potentially a more sensitive measure than NP (Colombo, Shaddy et al., 2004; Courage & Howe, 2001; Rose, Feldman, & Jankowski, 2003). Length of the longest look during familiarization accounts for the most variance in all other measures of looking (e.g., mean looking time and habituation rate; Colombo & Mitchell, 1990) and has been found to be very robust as a measure of attention with regard to both individual differences and developmental changes (Colombo, Kannass et al., 2004). This measure captures both the speed and the process of stimulus encoding (Colombo, Shaddy, et al., 2004; Courage, Howe, & Squires, 2004). Shorter fixations indicate faster processing speed, predict higher scores on intelligence tests in childhood, and discriminate between risk and non-risk infants (Rose, Feldman, & Jankowski, 2002; 2003). Look duration has been found to correlate positively with prenatal alcohol exposure (Jacobson, Jacobson, Sokol, Martier, & Ager, 1993) and has differentiated infants with varying

¹**Novelty preference (NP)** is a theoretical construct that refers to infants' attention being drawn to novel objects and events. **Novelty quotient**, that is, the time spent looking at the novel stimulus divided by the time spent looking at both novel and familiar stimuli, is a measure that tries to capture novelty preference. A novelty quotient greater than .50 indicates *novelty preference*. Similarly, *familiarity preference* refers to a novelty quotient less than .50.

²**Visual information processing (VIP)** refers to the full range of measures and constructs, including novelty preference, novelty quotient, processing speed, longest look, and shift rate. **Processing speed** is a theoretical construct that refers to how fast one's brain can encode and store information. **Longest look** and **shift rate** are measures that try to capture processing speed.

concentrations of docosahexaenoic acid (DHA) when the degree of NP did not (Colombo, Kannass et al., 2004; Werkman & Carlson, 1996).

Mean look duration is a measure similar to look duration but is often used during test trials (on which the infant views both the familiar and the novel stimulus), which are typically quite short (Rose, Feldman, Jankowski, & Van Rossem, 2005). When used in this manner, mean look duration is thought to represent retention of the familiar stimulus and thus the speed at which recognition is achieved (Courage et al., 2004). Novelty preference *per se* is viewed quite differently, that is, as an indication of the dishabituation that occurs when the familiar stimulus has been fully encoded and attention shifted to the novel stimulus (Kavšek, 2004).

A few studies have explored links between toxins, nutrients, or growth parameters and VIP measures. Lead exposure *in utero* is associated with reduced NP and head circumference (Emory, Ansari, Pattillo, Archibold, & Chevalier, 2003; Stanek, et al., 1998), while DHA, an omega-3 fatty acid, positively correlates with look duration in preterm infants who receive supplements (Werkman & Carlson, 1996) or whose mothers show high blood concentrations of DHA at birth (Colombo, Kannass et al., 2004). An iron supplementation trial in Chile found no differences in scores on the Bayley Scales of Infant Development between supplemented and non-supplemented infants. However, infants who were supplemented tended to have shorter visual fixations toward the stimuli (Lozoff et al., 2003). Finally, a study carried out in India found that infants aged 5 to 12 months with weight for age *z* scores less than -1 failed to show evidence of visual recognition memory, i.e., neither novelty nor familiarity preference (Rose, 1994).

1.1. Aims of the current research

Our objective was to develop and evaluate a modified VIP procedure to be administered in rural Ethiopian villages and to determine if VIP was associated with growth measurements in infants aged 6 to 8 months from these villages. Although there are several techniques to measure VIP (Colombo, 1993; Fagan & Shepherd, 1991; Rose, Feldman, & Jankowski, 2001), all have been developed for use in a laboratory setting. Links between malnutrition or poor growth and deviations from normal cognitive development in infancy are needed in order to determine when and how to intervene. With 52% of children under 5 years in Ethiopia suffering from moderate to severe stunting (UNICEF, 2004), identifying links in infancy between cognitive functioning and growth is essential. We evaluated three measures of growth that reflect subtle differences in nutritional status. Decreased length for age is associated with longer term energy deficits and/or specific nutrient deficiencies (e.g., zinc or iron (Gibson, 2006; Bougle, Laroche, & Bureau, 2000), while lower weight for age reflects recent deficits in energy intake. Head circumference is less susceptible to nutritional insult and more directly reflects brain growth (Black, 2003; World Health Organization, 1986). Of interest was whether weight, length, or head circumference was more predictive of three aspects of VIP: novelty preference, look duration during familiarization (i.e., encoding) and look duration during test phases (i.e., recognition). In order to access this rural population, we developed a simplified version of the standard VIP paradigm that was portable and required minimal equipment. Because all the infants were African, we also chose to use graphic stimuli (see Rose et al., 2001) instead of the more commonly used stimuli, which consist of Caucasian faces (Fagan & Shepherd, 1991). This decision is supported by recent research that finds infants are able to differentiate between same and different race faces by as early as three months (Kelly et al., 2005).

Based on results obtained by Rose (1994) in India, we first hypothesized that infants with delayed growth would have altered development of VIP in general and NP in particular. Specifically, we predicted that novelty quotients (time looking at novel stimuli divided by time looking at novel + familiar stimuli) of Ethiopian infants would be equal to or lower than chance (i.e., no preference or a familiarity preference that is associated with very young infants) and

that other VIP measures would be consistent with those for infants younger than 6–8 months. Slower information processing in infants is thought to be characterized by long looks at stimuli and relatively few gaze shifts between stimuli (Colombo, 2001b; Colombo, Shaddy et al., 2004; Kavšek, 2004; Rose et al., 2002). Secondly, we hypothesized that look duration would be inversely correlated with growth measures and that shift rates would be directly correlated with growth. Finally, we hypothesized that malnourished infants (z scores < -2) would have significantly worse performance on measures of VIP than better nourished infants.

2. Method

2.1. Participants

One hundred infants, 6 to 8 months of age (mean 7.3 ± 0.9 SD) were recruited from four impoverished rural communities (93% of inhabitants of the region live in rural communities) in the Sidama region in the Kolla or hot Rift Valley lowlands of Southern Ethiopia. Residents' primary occupations are subsistence farming and petty trading. Our preliminary studies in the area found that 89% of adult women had received two years or less of formal education (Abebe et al., 2006). Villages have limited access to electricity or safe water (Central Statistical Authority, 1999). Infants in the area are routinely breastfed past their first birthdays. The major food staples for complementary feeding of infants and young children are maize and kocho, a fermented starch processed from a root crop called enset (Ashenafi & Abebe, 1996). The current project was one of a series conducted in 2003 and 2004 to prepare for a larger clinical trial. Sites were chosen because they were part of the outpatient network of one of our project partners, Bushelo Health Clinic. The study procedures were approved by the Institutional Review Boards at Hawassa University, Awassa; Oklahoma State University, Stillwater; and University of Colorado Health Sciences Center, Denver.

2.2. Procedure

Infants were recruited at regularly scheduled visits of the outpatient care team. Informed consent was obtained from the mother, and infants were screened for age and health status. Clinic record cards were used to verify age. Infants were excluded if their mothers reported vomiting, diarrhea or coughing in the three days prior to testing. To be included in the final sample infants needed to complete at least three VIP trials (each consisting of one familiarization and two test phases).

2.2.1. Anthropometry—Infants were weighed to the nearest 2 g using a Seca 345 infant scale while wearing a tee shirt of known weight distributed by study personnel. The weight of the tee shirt was deducted before performing analyses. Infant length was assessed to the nearest 0.1 cm using a length board. Head circumference was measured to the nearest 0.1 cm using a non-elastic measuring tape. Length and head circumference were measured in duplicate unless the measurements differed by more than 0.5 cm. In that case, a third measurement was taken. The discrepant value was discarded and an average was used in analysis. Measurements were taken by a pair of trained research assistants under the direct supervision of a senior member of the research team.

2.2.2. Visual information processing—Testing was conducted outdoors, in the common area of each village, to assure adequate lighting for videotaping. Each infant was tested while seated on the mother's lap in front of a three-sided booth that was moved to assure that the sun did not shine in the infant's eyes. The booth was locally made and could be disassembled for transport. It was 110 cm high with the doors for displaying stimuli placed 59.5 cm from the ground. The infant was positioned approximately 50 cm from the stimuli and was gazing slightly upward. The centers of the stimuli were 30 cm apart and were attached to two revolving doors 21 cm square that were manually turned by the research team. Presentation of the stimuli

was timed with a stop watch. The team practiced turning the doors until an adult observer determined that the doors were moved simultaneously. A video camera was positioned between the door openings to record the infant's gaze. A softly spoken word recorded on the videotape indicated when the stimuli were presented and removed. Researchers checked the videotapes in the field for accuracy in timing of stimulus presentation by reviewing the recording and monitoring the timing encoded on the videotapes by the camera.

In the familiarization phase of each trial, the infant was presented with two identical, colorful 2-dimensional geometric stimuli modeled after those developed by Rose et al. (2001; Rose, Feldman, & Wallace, 1988) for 60 s. The doors were then turned and, out of the infant's view, one of the familiar stimuli was replaced by a new (novel) picture. This initial placement of the novel stimulus was randomly determined with the constraint that on two of the four trials the initial placement would be on the left. After 5 s, the doors were rotated out of the infant's view and the placement of novel and familiar stimuli was switched; the two stimuli were presented again for 5 s. Infants were given a total of four trials, each consisting of a 60 s familiarization phase, followed by two 5 s test phases. As noted above, data from infants with fewer than three complete trials were excluded from the data analyses and for infants with three complete trials, all data from the incomplete trial were excluded. Analyses of variance revealed no differences in VIP variables between infants who completed 3 or 4 trials (all $ps > .23$).

Our VIP protocol differed from that which has become the standard procedure. First, we chose not to use pictures of faces as stimuli as is typically done (Colombo, Kannass et al., 2004; Fagan & Shepherd, 1991) because these standard sets contain a high percentage of Caucasian faces. Recent research by Kelly et al. (2005) found that by as early as 3 months infants prefer looking at faces of their own race. This supports our decision to use graphic stimuli. Second, an "infant control" procedure is usually used such that, once the infant has looked at the familiar stimulus for a set period of time (e.g., 20 s), the familiarization period is ended. Our "low-tech" field apparatus did not allow us to accurately measure accrued looking time. Therefore, we decided to maximize the likelihood that infants would accrue the necessary familiarization by providing a long window of 60 seconds.

Looking behavior was coded in the laboratory at Oklahoma State University from videotapes by two teams of three students who did not take part in the data collection and were blind to placement of stimuli. Teams were trained to observe the direction and duration of looks by first viewing videotapes of adults and older children looking in specific directions. In the second phase of training, teams jointly coded trials that were not included in the final data set to determine look direction and duration. In the next phase of training, each team independently coded trials and then met to resolve discrepancies. After training, one team was chosen to code all the infants and the other independently coded 20 infants, 10 initially and 10 half-way through the coding, to determine reliability as described in a subsequent section.

The following criteria were used as the basis for coding. *Position*: A baby was judged to be looking at a stimulus if the reflection of that stimulus was seen in the pupil of one of the eyes, or a look was determined from the angle of the gaze consistent with the known angles of fixation based on training tapes. *Duration*: A fixation on a stimulus (a "look") must have been at least 1 s in duration. A look away must also have been at least 1 s in duration. All durations were measured at least twice with stopwatches to the nearest .01 s. *Shifts*: A shift occurred when an infant's gaze moved from one stimulus to the other with less than 1 s between fixations.

The reliability of videotape coding was established by the second team of three students who independently scored the data from 20 of the infants. The correlations between the coding of the two teams were generally high and only slightly lower than those of laboratory studies where considerably better experimental control is possible (e.g., Rose et al., 2002). The mean

correlation coefficient for familiarization phases for the number of looks was .86; for duration of looks .88; and for shifts between stimuli .85. For test phases, the mean correlation for number of looks was .87, and for duration of looks .86. Reliabilities obtained for the number of shifts during test phases were lower with a mean correlation of .57.

Coding established the number of looks per trial, the duration of these looks, and the number of shifts for both the familiarization phase and for the test phase of each trial. Additional variables were then derived: mean familiarization time; the duration of the longest look during familiarization; the mean duration of each look during familiarization; the shift rate (shifts per second) during familiarization; the mean duration of each look during test phases; the shift rate during test phases; and the novelty quotient, which was the amount of time the infant looked at the novel stimulus in all test phases divided by the amount of time spent looking at both novel and familiar stimuli during all test phases.

2.3. Data analysis plan

Descriptive data were analyzed using SPSS version 12 (SPSS, Inc., Chicago, IL) and are expressed as means $\pm$ *SD*. *Z* scores for anthropometric measures were calculated by EPI Info version 3.3 (Centers for Disease Control, Atlanta, GA) using norms recommended by the World Health Organization (1986). Prior to hypothesis testing, we used independent sample *t*-tests to determine whether differences existed between participants who completed the requisite number of trials and those who were excluded from the analyses for not doing so. The first hypothesis was evaluated by comparing the sample mean novelty quotient score to chance using a one sample *t*-test.

The second hypothesis was evaluated with zero-order and partial correlation analysis between all growth parameters, age and all VIP measures: novelty quotient, familiarization time, longest look to stimulus during familiarization, mean duration of looks during familiarization and test phases, and shift rate during familiarization and test phases. Three regression analyses were also conducted to evaluate the three growth parameters as predictors of three aspects of VIP: novelty quotient, length of longest look during familiarization, and mean look duration during test phases. These predictors were chosen because novelty quotient had previously been shown to be associated with growth (Rose, 1994) and because slower information processing in infants is thought to be characterized by longer looks at stimuli and relatively few gaze shifts between stimuli (Colombo, 2001b; Colombo, Shaddy et al., 2004; Kavšek, 2004; Rose et al., 2002). To test the third hypothesis, infants were first grouped by malnutrition (growth parameter *z* score < -2 , see World Health Organization, 1986) and then analyses of variance were conducted for all measures of VIP.

3. Results

The final sample consisted of 69 infants (34 males, 35 females) who had completed at least three of the four possible VIP trials (familiarization and two test phases). Of the original 100 infants, 26 failed to complete the minimum three trials because of excessive crying, fussing, or maternal interference (e.g., holding the infant's head in the direction of the stimuli). In addition, the data from five participants were discarded from analyses because they failed to accumulate at least 5 s of looking time during familiarization on three or more trials (Rose et al., 1982; Rose et al., 1995). We tested for differences between the infants included (3–4 trials) versus excluded (0–2 trials) by age ($p = .40$), sex ($p = .42$), head circumference ($p = .64$), weight ($p = .42$), or length ($p = .09$). As the excluded infants had incomplete or compromised VIP trials, it was not possible to compare included versus excluded infants using VIP variables.

3.1. Anthropometric measures

The mean age and z scores for infant growth parameters are reported in Table 1. Mean z scores may be a better indication of the general growth of the sample than mean weights and lengths as z scores are derived using both age and the growth parameters. A z score of -2 or less on either weight-for-age or length-for-age is considered an indicator of malnutrition (World Health Organization, 1986). Of the 69 infants in the final sample, eight infants had z scores below -2 on both weight and length measures. An additional eight infants had weight-for-age z scores below -2 , and nine more infants had length-for-age z scores below -2 . Analyses of variance revealed no significant differences in any growth parameter (all $ps > .49$) when infants were grouped by three versus four novelty preference trials completed.

3.2. Visual information processing measures

Means and standard deviations of infant VIP measures are reported in Table 1. The mean duration of looks to stimulus during all familiarization phases (21.8 ± 6.3 s) was sufficient to allow for, if not a strong novelty preference, at least equal preferences (i.e., a novelty quotient of .50) for novel and familiar stimuli during the test phases (Rose, 1994; Rose et al., 1988; Rose et al., 2002). However, the mean novelty quotient in the present study was only .39 ($SD = .13$), which was significantly less than chance, $t(68) = 6.88, p < .001$, with only 12 of the 69 infants (17.4%) attaining .50 or greater. Thirty-nine infants had a mean duration ≥ 20 s of looking during familiarization, an amount found to be more than sufficient to produce a strong novelty preference for these stimuli with this age group (Rose et al., 1988). The mean for this subgroup of 39 was 26.2 s ($SD = 4.5$). However, even when only these infants that had ample familiarization (relative to American infants; Rose et al., 1988) were examined, there was still a robust familiarity preference, mean NQ = .41, $t(38) = 3.97, p < .001$.

The strong preference for the familiar stimulus exhibited by most of the infants is more typical of very young infants (Rose et al., 1982), not 6–8 month olds. The shift rates of visual fixations (.11 per second during familiarization, .12 during test phases) were also low relative to those reported by Rose et al. (2002). However, this measure is relatively new and norms have yet to be established.

3.3. Relations between anthropometric and visual information processing measures

Table 2 presents correlations for all measures. Coefficients below the diagonal have age partialled out of the correlation. These tests of hypothesis 2 revealed the novelty quotient was not correlated with any anthropometric measure (Table 2). However, in support of hypothesis 2, other measures of VIP were correlated with anthropometric measures.

There was a modest correlation between total amount of familiarization and novelty quotient ($r = .26, p < .05$), indicating that those infants who looked longer at the stimuli during familiarization had greater visual preference for the novel stimuli during test phases. When the familiarization time data were divided into tertiles, the top 23 infants looked at the stimulus during familiarization for a mean of 29.0 s, the middle third for 21.4 s, and the bottom third for 15.1 s. When the novelty quotients of these three groups were examined, the top third, who were familiarized for 29.0 seconds, showed a mean novelty quotient of 40.5%; the middle third 41.6%; and the bottom third 36.0%. Clearly, none of these groups showed a novelty preference, nor was there a significant difference among these novelty quotients, $F(2, 66) = 1.2, p = .295$, although the amount of familiarization was significantly different among groups, $F(2, 66) = 138.5, p < .001$. Thus, the correlation between total familiarization and novelty quotient is best expressed by saying that greater familiarity preference was modestly associated with less overall looking during the familiarization phase.

Table 3 presents the results of three multiple regression analyses: longest look during familiarization, mean look duration during test phases, and novelty quotient. Predictors were *z* scores for weight, length, and head circumference and infant age was controlled in the first block of each regression. Whereas none of the growth parameters explained novelty quotient, weight for age *z* score alone explained significant variance in longest look during familiarization and head circumference alone explained significant variance in mean look duration during test phases.

3.4. Malnutrition and novelty preference

In support of hypothesis 3, infants with weight-for-age *z* scores lower than -2 (15 out of 69) had significantly extended longest looks at stimuli during familiarization than the better nourished group (15.1 ± 9.2 vs. 10.2 ± 5.4 , $F(1, 67) = 7.173$, $p = .009$). Infants with length-for-age *z* scores below -2 (14 out of 69) had significantly slower mean shift rates during familiarization ($.07$ shifts/second $\pm .05$ versus $.12$ shifts/second $\pm .06$, $F(1, 67) = 8.006$, $p = .006$), and during the test phases ($.08$ shifts/second $\pm .03$ versus $.13$ shifts/second $\pm .08$, $F(1, 67) = 4.246$, $p = .043$). Other visual information processing variables did not differ significantly among infants grouped by *z* scores.

4. Discussion

The primary objective of the study was to develop and test a modified VIP procedure suitable for administration in remote communities. The secondary objective was to test three hypotheses. We implemented the VIP protocol in the open air in Ethiopian villages, analyzed data and demonstrated high reliabilities in coding. Furthermore, we found evidence in support of hypothesis 1 that Ethiopian infants would fail to show novelty preference; instead a strong familiarity preference was found. We also found evidence to support hypothesis 2, that VIP measures would be significantly associated with growth parameters. Finally, we demonstrated significant VIP differences between malnourished infants and their better nourished peers.

One way to assess the validity of our field version of the VIP paradigm was to examine well-replicated, age-related findings. Thus, we expected visual information processing measures to improve with age (Colombo, Shaddy et al., 2004; Rose & Feldman, 1995). Associations between familiarization time and novelty preference, and between age and test phase measures were as expected, supporting the use of this field-adapted version of the VIP paradigm.

The association between total familiarization time and novelty quotient ($r = .26$) needs to be considered within the context of the overall familiarity preference shown by the infants. Since faster processing speed is associated with better cognitive performance (Colombo, Shaddy et al., 2004), one could argue that less familiarization (faster processing) should be associated with greater NP. That is, a negative correlation between familiarization time and novelty quotient would be predicted because novelty quotient is also associated with better cognitive performance (Rose et al., 2003). However, this assumes that there is adequate time for most, if not all, infants to fully encode the stimulus. This does not appear to have occurred in the present study because only 17.4% of the infants showed a novelty quotient $> .50$. Clearly our Ethiopian infants – because of age, nutrition, and/or other factors – did not appear to have had sufficient familiarization time for stimulus encoding. Thus, greater familiarization time allowed for more encoding and improved novelty quotient, although NP *per se* was rarely achieved, resulting in the positive correlation.

Although only 16 infants were classified as malnourished (weight for age < -2.00), the group mean for weight was more than one standard deviation below the mean for typically developing children (World Health Organization, 1986). As hypothesized, development of NP for the whole sample was significantly delayed, with infants showing a strong preference for the

familiar stimuli instead of the age-appropriate preference for the novel stimuli. However, the novelty quotient was not correlated with any of the anthropometric measures. This suggests that aspects of the sample other than growth were responsible for the unusually low novelty quotient. One alternative hypothesis is that these infants may have failed to sufficiently encode the familiar stimulus. The mean time that the infants looked at the familiar stimulus was 21.8 s, far greater than the 5 s typically allowed with American infants for the stimuli used (Rose & Feldman, 1995). However, Rose (1994) found that even 30 s was not long enough to establish NP in underweight infants in India when 3-dimensional objects were used. Indeed, even the 23 infants in the study who had a mean familiarization looking time of 29.0 s had a mean novelty quotient of only 40.5%. Thus, even though it is possible that the strong familiarity preference was tied to delayed growth, the lack of a correlation between the novelty quotient and anthropometric measures, along with the failure to establish a minimum amount of familiarization needed to achieve novelty preference, suggests further research is necessary before this conclusion is warranted. Studies using the standard protocol -- which relies on infant-controlled familiarization and human faces as stimuli -- need to be done in order to confirm the robust familiarity preference found in this study. It is possible that the geometric stimuli utilized did not adequately engage the infants' attention and consequently sufficient familiarization was not achieved.

Measures more closely associated with processing speed support the second hypothesis that there would be an association between VIP measures and growth. Length of longest look showed the expected association with weight for age, while mean look duration during test phases was associated with head circumference. These two associations were confirmed in the hierarchical regression analyses. Weight is an indicator of short-term nutritional deficiencies, whereas length is an indicator of longer-term nutritional deprivation (World Health Organization, 1986). The current findings suggest that encoding of the stimulus materials was affected more by current nutritional status. In contrast, mean length of look was most closely related to head circumference, a measure of longer-term brain development. Finally, when comparing infants by degree of malnutrition, novelty quotient did not differ between groups, although the expected difference was seen in length of longest look when separated by weight for age and in shift rates when separated by length for age. This latter finding and others involving shift rate during test trials (i.e., correlations with anthropometric measures) should be taken as tentative due to the fact that the inter-coder reliability was low (mean correlation = .57) for this particular VIP measure.

In comparing the three growth parameters as predictors of the three measures of VIP, we carefully considered the influence of collinearity [see variance inflation factors (VIF) in Table 3]. The magnitude of each VIF is considerably less than 10, the level of concern for collinearity (Stevens, 2002, pp. 92–93). Although collinearity is not an issue in the current data set, suppression is. Suppression occurs in regression when the inclusion of one variable partials out the criterion-irrelevant part of another predictor's variance (Stevens, p. 124; Tzelgov & Henik, 1991), resulting in an increase in the standardized regression coefficient for the predictor. When the magnitude of the beta weight is larger than the zero-order correlation coefficient, suppression exists. A comparison of the correlation coefficients in Table 2 with the beta weights in Table 3 reveals that, relative to the correlation coefficients, the magnitude of the beta weights increases for both length and weight in relation to longest look during familiarization, whereas the magnitude of the beta weight for head circumference is unaffected. Removing head circumference from the regression equation has no impact on the beta weights for length and weight, so we do not consider head circumference in this discussion. Tzelgov and Henik caution that the real contribution of each variable is best evaluated when the criterion-irrelevant portion is removed, that is, based on the regression coefficients rather than the correlation coefficients. In the current data set, this means that the best measure of the association between weight and length of longest look is the semipartial r^2 (16%) in Table 3,

which partials out the effects of length, rather than the squared correlation coefficient (i.e., 10%) in Table 2. The association between length and duration of longest look is similarly suppressed by weight, but not to the same degree. Thus, the greater importance of weight for stimulus encoding is clear. The importance of adequate weight gain for speed of encoding and processing in infancy emphasizes to developmental psychologists and nutritionists the importance of early adequate energy intake.

Delays in infant growth are commonly used as markers for malnutrition and are associated with increased morbidity and mortality in infancy and early childhood (R. E. Black et al., 2003; Wachs et al., 1993). However, research demonstrating the relation of growth retardation to specific cognitive processes is limited. In a study in India, Rose (1994) found that growth-delayed infants exhibited no preference for novel or familiar stimuli as opposed to the familiarity preference observed in this study. Although growth parameters in Rose's study and ours were generally similar, differences in micronutrient deficiencies associated with the growth delay between the two countries could explain the discrepancy in VIP findings (Grantham-McGregor & Ani, 1999; Wachs et al., 1993). Dykman, Ackerman, Loizou, and Casey (2000) found that children diagnosed with failure to thrive during infancy had slower response times on word recognition tasks using visual event-related potentials when tested during early adolescence. Their results are consistent with the present finding that infants with poorer growth had longer looking times. While the current study does not address the direct impact of individual components of infants' diet or the diets of their breastfeeding mothers on VIP, studies have found look duration to differentiate infants with varying concentrations of docosahexaenoic acid (DHA; Colombo, Kannass et al., 2004; Werkman & Carlson, 1996). Additionally, associations between general cognitive development and energy, protein and fat intake (Wachs et al., 1993), iron and infant temperament (Wachs, Pollitt, Cueto, Jacoby, & Creed-Kanashiro, 2005), and zinc and preschool verbal scores (Hubbs-Tait, Kennedy, Droke, Belanger, & Parker, 2007) suggest that dietary constituents other than energy may affect VIP.

4.1. Limitations and implications

While it may be difficult to link specific behaviors during infancy directly with long-term consequences, those behaviors may change the way the child interacts with the environment and thus affect the child's development (Colombo, 2001a; Institute of Medicine, 2004). For example, improvements in motor development are commonly seen in nutritional supplementation studies (Grantham-McGregor & Ani, 1999; Institute of Medicine, 2004). These behaviors may not appear to be directly associated with cognition. However, locomotor experience in infancy is associated with changes in perception, cognition and social-emotional development (see review by Campos et al., 2000). The decreased information processing abilities observed in the infants with poorer growth can be expected to impact a variety of other developmental processes, and imply that small disadvantages in early development may impact higher-order function during a later developmental stage (Colombo, 2001a). However, it must be noted that various VIP measures have been designed to explore processes underlying basic cognitive development. Thus, the laboratory tests we based our design upon are not standardized in administration, leading to possible difficulties in interpretation across studies (Colombo, 2001a). Finally, although maternal education influences both choice of diet (Wachs, Creed-Kanashiro, Cueto, & Jacoby, 2005) and infant stimulation (Wachs et al., 1993; Walker, Chang, Powell, & Grantham-McGregor, 2005), we did not control for this factor.

The development of cognition is a process being explored by both nutritionists and developmental psychologists. There has been an increasing call for assessments that evaluate specific cognitive processes which may be more sensitive to environmental variation (e.g., nutrients), better predict later intellectual status (M.M. Black, 2003; Colombo, 2001a; Grantham-McGregor, & Ani, 1999; Hubbs-Tait, Nation, Krebs, & Bellinger, 2005) and can

be compared across cultures. The results of the present investigation support the use of VIP measures as one such assessment tool. Understanding the interrelated effects of various nutrients on developmental processes will require longitudinal studies designed to examine both a wide range of nutritional factors and of developmental domains to develop an integrated model of nutrient effects on cognitive development.

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Table 1
Mean (*SD*) growth parameters and visual information processing variables of infants completing 3 or more novelty preference trials ($N = 69$)

	Mean	SD
Growth parameters:		
Age in months (m)	7.2	.90
Weight (kg)	7.06	1.34
Weight/age z score	-1.12	1.19
Length (cm)	66.0	4.30
Length/age z score	-1.05	1.31
Weight/length z score	-.35	1.30
Head circumference ^a (cm)	43.9	2.20
Head circumference z score	.06	1.52
Visual information processing variables:		
Total time looking at stimulus during familiarization (s)	21.76	6.33
Longest look to stimulus during familiarization (s)	11.19	6.62
Mean duration of looks during familiarization (s)	3.05	1.21
Shift rate during familiarization (shifts/s)	.11	.06
Mean duration of looks during test phases (s)	2.59	.52
Shift rate during test phases (shifts/s)	.12	.074

^a $N = 68$. One child refused head circumference measurement.

Table 2
Correlations of infant VIP variables and age with anthropometric measures (above diagonal) and partial correlations of infant VIP variables with anthropometric measures while controlling for age (below diagonal). ($N = 69$)

	Wt. z score	Length z score	HC z score	NQ all trials	Famil. (s)	Longest look to stimulus during famil. (s)	Mean duration of looks during famil. (s)	Shift rate during (shift/s)	Mean duration of looks during test phase (s)	Shift rate during test phases (shifts/s)	Age
Wt. z score	<i>r</i>	-.581	.387	-.010	.104	-.320	-.091	.153	.038	-.028	.160
	<i>p</i>	.000*	.001*	.937	.395	.007*	.455	.209	.759	.819	.190
Length z score	<i>r</i>		.474	-.004	.068	.001	.039	.197	-.092	.240	.345
	<i>p</i>		.000*	.974	.582	.992	.753	.105	.451	.047*	.004*
HC z score	<i>r</i>	.359		-.105	-.231	-.052	-.227	.170	-.322	.306	.375
	<i>p</i>	.003*		.396	.058	.675	.062	.167	.007*	.011*	.002*
NQ all trials	<i>r</i>	-.014	-.120		.255	.137	.384	-.260	-.120	.140	.021
	<i>p</i>	.911	.332		.035*	.263	.001*	.031*	.327	.252	.865
Famil. (s)	<i>r</i>	.103	-.263	.256		.093	.366	.227	.298	.048	.028
	<i>p</i>	.408	.032*	.037*		.448	.002*	.060	.013*	.697	.821
Longest look to stimulus during famil. (s)	<i>r</i>	-.328	-.036	.135	.103		.283	-.124	.215	-.114	-.033
	<i>p</i>	.007*	.773	.274	.407		.018*	.309	.076	.352	.789
Mean duration of looks during famil. (s)	<i>r</i>	-.095	-.251	.384	.367	.287		-.478	.272	-.102	.014
	<i>p</i>	.444	.041*	.001*	.002*	.019*		.000*	.024*	.405	.909
Shift rate during famil. (shift/s)	<i>r</i>	.132	.101	-.269	.222	-.101	-.434		-.120	.290	.193
	<i>p</i>	.288	.414	.028*	.071	.414	.000*		.327	.016*	.112

		Wt. z score	Length z score	HC z score	NQ all trials	Famil. (s)	Longest look to stimulus during famil. (s)	Mean duration of looks during famil. (s)	Shift rate during famil. (shift/s)	Mean duration of looks during test phase (s)	Shift rate during test phases (shift/s)	Age
Mean duration of looks during test phase (s)	<i>r</i>	.091	.012	-.241	-.118	.318	.226	.289	-.075	--	-.709	-.294
	<i>p</i>	.462	.924	.050*	.342	.009*	.066	.018*	.546		.000*	.014*
Shift rate during test phases (shift/s)	<i>r</i>	-.093	.132	.195	.143	.038	-.102	-.115	-.236	-.681	--	
	<i>p</i>	.456	.285	.114	.247	.762	.409	.355	.055	.000*		.002*

Note: HC: head circumference, *N* = 68 one child refused; NQ: novelty quotient; Famil: familiarization

* *p* < .05.

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Table 3
Summary of hierarchical regression analyses predicting three VIP variables from weight, length and head circumference z scores

Outcome	Change statistics ^a			Coefficients ^b			
Block and Predictors	ΔR^2	df	p	β	SE	sr^2	VIF
Longest Look - Familiarization							
1 – Infant age in months	.00	1, 66	.690	-.05	.89	.00	1.00
2 – Weight, Length, Head Circum	.16	3, 63	.010				
Weight				-.50	.80	.16	1.56
Length				.30	.77	.05	1.78
Head Circumference				.03	.60	.00	1.43
Total R^2 for Model = .16, p = .020							
Mean Look Duration – Test Phase							
1 – Infant age in months	.08	1, 66	.017	-.29	.07	.08	1.00
2 – Weight, Length, Head Circum	.09	3, 63	.097				
Weight				.18	.06	.02	1.56
Length				.03	.06	.00	1.78
Head Circumference				-.33	.05	.08	1.43
Total R^2 for Model = .17, p = .018							
Novelty Quotient							
1 – Infant age in months	.00	1, 66	.882	.02	.02	.00	1.00
2 – Weight, Length, Head Circum	.02	3, 63	.793				
Weight				.02	.02	.00	1.56
Length				.04	.02	.00	1.78
Head				-.15	.01	.02	1.43
Total R^2 for Model = .02, p = .900							

^a ΔR^2 is the unique variance explained by each block in the regression;

^b β is the standardized and B is the non-standardized regression coefficient. SE is the standard error of B ; sr^2 is the squared semipartial correlation coefficient, the unique variance explained by each variable. VIF is the variance inflation factor, an indicator of multicollinearity.