Diet inadequacies and neurobehavioural impairment in rural highland Ecuadoreans.

Peter R. Berti, Julia Krasevec, and Donald Cole.

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Author Information:

Peter Berti (Corresponding Author)
PATH Canada
One Nicholas St., Suite 1105
Ottawa, Ontario
K1N 7B7
tel: 613-241-3927 x.324
fax: 613-241-7988
pberti@pathcanada.org

Julia Krasevec
PATH Canada
One Nicholas St., Suite 1105
Ottawa, Ontario
K1N 7B7
tel: 613-241-3927 x.324
fax: 613-241-7988
pberti@pathcanada.org

Donald Cole
Department of Public Health Sciences,
Faculty of Medicine, University of Toronto
12 Queen's Park Crescent,
Toronto, Ontario,
Canada M5S 1A8
tel: (416) 946-7870
fax: (416) 978- 8299
donald.cole@utoronto.ca

ABSTRACT

Objectives: To examine the adequacy of the diet and neurobehavioural performance, and the relationship between diet and neurobevaiour in residents of a highland Ecuadorian community, who grow much of their own food, and uses high levels of neurotoxic agricultural pesticides.

Methods: Quantitative 24-hour recalls were conducted on at least two non-consecutive days for each household member (n=276). Adequacy of nutrient intake was assessed through comparison with FAO/WHO recommendations. Neurobehavioral tests focused on visual and motor domains. Mean age and education standardized Z-scores were calculated for each domain using data from a non-rural referent population.

Results: Dietary energy was mostly from carbohydrates (74%), with relatively low intakes of fat (16%) and protein (10%). The highest probabilities of inadequacy existed for vitamin A (30-59% in different age-gender strata) and vitamin B-12 (18-45%). Iodine intake was sufficient in all age groups. Among the 101 adults who had neurobehavioral assessments, mean Z-scores were below 0, particularly for motor function among women (mean –1.2, standard deviation 0.7).

Conclusions: Neurobehavioural performance was impaired in many individuals and the diet is in many ways inadequate, however no consistent relationship was observed between neurobehaviour and diet. Iodine dietary inadequacy has been virtually eradicated and riboflavin inadequacy has declined (80% in a 1994 study to 4% here) consistent with fortification programs. However, vitamin A, B12 and zinc inadequacies persisted, underscoring the continuing need for community level nutrition programs and national level efforts to promote sustainable livelihoods and dietary diversity.

INTRODUCTION

Previously published research of the nutritional adequacy of the highland Ecuadorian tuber and grain based diet has shown that inadequate intakes of various vitamins and minerals have been common (1,2). In particular, the diet has been shown to be inadequate for iron, zinc, calcium, vitamin A, vitamin B12, riboflavin, and perhaps other micronutrients as well. As a low-fat diet, the intakes of essential fatty acids are likely low. These observations have been supported through clinical/laboratory examinations that show a high prevalence of vitamin A, zinc, and iron deficiency (3-5). This malnutrition is further reflected in the high prevalence of underweight and stunting in the Ecuadorian Andes (2,6,7).

We conducted research in Ecuador on peripheral neurotoxicity and neurobehavioral impairment in potato farming families (8,9). Though we linked such impairments with exposure to agricultural chemicals, we were concerned that poor nutrition could also be affecting nervous system function. Deficiencies of a number of micronutrients are known to produce neurobehavioral problems similar to those suffered by persons exposed to carbamate and organophosphorus containing pesticides (8). These may be concomitant with peripheral nerve symptom effects which include but are not limited to, signs of poor coordination, memory and attention, abnormal deep tendon reflexes, reduced power, and elevated sensory thresholds (9,10). Deficiencies of specific nutrients which might produce nervous system effects include iodine, iron, zinc, vitamin A, vitamin B_{12}, folate, thiamin, vitamin E and essential fatty acids (11-27) most of which have been observed (1-6) or might logically be expected in highland Ecuador. Some nutritional deficiencies can directly affect neurobehavioural performance, e.g., iodine, iron, essential fatty acids, while others have indirect effects, e.g., folate deficiency can lead to muscular and mental fatigue (18). Indirect effects through other nutrients are also possible, e.g., vitamin A and riboflavin deficiencies impair iron absorption and utilization (28).

This article describes an updated assessment of dietary intake in a rural Ecuadorian population on all age groups. Among a sub-set of adults we also assessed neurobehavioural performance and tested for a relationship between neurobehavioural function and nutritional adequacy for those nutrients for which a relationship may be reasonably hypothesized. Finally, we reflect upon the implications of these results for population health and food and nutrition interventions in highland Andean regions.

METHODS

The investigation was based in three communities in the province of Carchi in northern Andean Ecuador, located between 2 800 and 3 400m above sea level near the equator. Communities are of mixed Spanish and indigenous ancestry. Compared to the rest of rural Ecuador, where subsistence farming is the norm, farmers in Carchi are wealthier, undertaking commercially oriented farming (29). The main crops in Carchi are potatoes and pasture for dairy cattle. Other crops grown in the study communities include barely, peas, fava beans, and wheat. The climate in the study area is consistent year round, having no distinct planting or harvesting seasons, resulting in no anticipated seasonalities in dietary intake. Hence, dietary intakes were recorded during a consecutive six month period, October 1999 through March 2000.

Sample Selection and Study Participants

From the larger pool of 67 households who volunteered to participate in an existing community development project, 54 households in three villages consented to take part in the nutritional assessment. Unfortunately, sufficient socioeconomic data for participating and nonparticipating households were not available to assess selection bias. The 291 residents from these households were split almost evenly between males and females and between adults and non-adults. Breast-fed infants were excluded from the study and the youngest individual was 1 year old. Missing age or weight data for nine individuals, and difficulties associated with estimating requirements for the six pregnant or lactating females left data on 276 individuals for analysis. For neurobehavioural testing, only those adults between the ages of 16 and 64 years and with at least three years of schooling were included (n=101) in order to have valid results (30). Ethics approval for this research was obtained through McMaster University and the Ecuadorean National Research Commission and was in accordance with the Helsinki Declaration of Human Rights.

Dietary Assessment Methods

A quantitative 24-hour dietary recall of the previous day's dietary intake was conducted, during two or three non-consecutive days, for each member of the participating families (method described in detail elsewhere (1)).

Food composition data were obtained from a database previously compiled (1), updated and completed with USDA food composition tables (31). Iodine levels of salt in the study communities were analyzed on five different occasions over the 6 month study period, employing a rapid test kit (32). Iodine intake was estimated using salt added to food while preparing meals (not additional salt added at the table, and therefore an underestimate of total intake) and average salt iodine level.

Adequacy of nutrient intake was assessed at the population level by comparing estimated nutrient intake to estimated requirement compiled from FAO/WHO publications (33,34). Iodine intakes were compared to recommended intakes, following the age grouping of the recommendations (35). Probability analysis (36) was employed for the assessment of intake adequacy for most nutrients. Probability analysis estimates the percentage of individuals in a group with inadequate intakes. The accuracy of probability analysis increases with larger sample sizes and increasing days of dietary data per subject. Therefore, data were analyzed in broad age groups, to increase group sample size, and only included subjects with ≥2 days of the dietary data. A minimum of 2 dietary surveys were available for 276 people, 37 with two days and 239 with three days.

Neurobehavioral Performance Methods

Neurobehavioural tests were selected from the Neurobehavioural Core Test Battery (NCTB), developed during a World Health Organization collaborative endeavour (37) and used in earlier work in Carchi (8). Tests chosen had been shown sensitive to the effects of known neurotoxins across a variety of exposed populations (38) or sensitive to prior organophosphate pesticide poisoning (39). Further, age and education based norms were available from a reference non-farm population without pesticide exposure (included students, housewives, labourers, skilled workers, small business persons and professionals) (30). Procedures used were the same as prior work, with tests conducted in community centres and schools using standard instructions in Spanish, adequate lighting, and limited distractions in order to optimize test conditions within the constraints posed by the rural, developing country setting. The nurse-tester was trained by the same supervising neuropsychologist, who also reviewed results and provided interpretative reports back to the consenting participants in each of the three communities.

Individual tests were grouped into two main functional domains: visuo-spatial (Block Design and Benton Visual Retention) and motor (Trails A & B, Visual and Auditory Reaction Times, Santa Anna in the dominant hand and Pursuit Aiming). For each test, a Z-score was calculated by subtracting the age and education based predicted value of the test from the participant's raw score for that test and dividing the difference by the standard deviation for the referent population. When a higher raw score indicated worse performance (e.g. reaction times) the sign of the Z-scores were reversed, so that for all transformed values, higher scores reflected better performance. The Z-scores were then averaged across those tests pertinent to the domain to obtain a summary Z-score for each functional domain for each participant.

Dietary Inadequacy – Neurobehavioural Performance Relationships

Estimates of prevalence of inadequacy are not amenable to conventional statistical tests (G.H. Beaton, personal communication, 1995). Hence, we examined the data for differences in inadequacy across groups with different neurobehavioural scores to see if meaningful patterns of relationships emerged.

RESULTS

Table 1 shows the intake of macronutrients. Across all sex and age groups, the source of energy was consistent at 10-11% from protein, 15-17% from fat, and 73-75% from carbohydrate.

** Table 1 about here**

Table 2 shows intakes of micronutrients. Intakes of calcium were very low with the average intake approximately half of the population recommended average of 400-500 mg/d for 1-10 year olds, 600-700 mg/d for 10-16 year olds, 500-600 mg/d for 16-19 year olds and 400-500 mg/d for adults (40). Intakes of vitamin C were very high with the minimum intake greater than the recommended intakes of 20mg/d for 0-13 year olds and 30 mg for subjects over 13 years of age (41), likely due to the high per capita consumption of potatoes (e.g., 294 grams per day for children 1-6 years, 943 grams per day for males16-40 yrs).

** Table 2 about here**

Table 3 lays out estimates of dietary inadequacy for protein and various micronutrients. Highest probabilities of inadequacy existed for vitamin A and vitamin B_{12}, followed by zinc, folate, protein and riboflavin, with some heterogeneity across age groups. Iodine intake, presented in **Table 4**, was sufficient in all age groups particularly given the underestimates of salt intake that likely occurred.

Tables 3 and 4 about here

Neurobehavioral performance among participants was generally poorer than the referent population, i.e., all mean Z-scores in **Table 5** were less than 0. Motor function tended to be worse than spatial function, particularly for women i.e., mean < -1 SD. Comparing groups with higher versus lower neurobehavioural test scores, no consistent patterns were observed for any micronutrient (see **Table 6**).

Tables 5 & 6 about here

DISCUSSION

The study population did not consume an adequate diet for many nutrients. Twenty percent of at least one sex-age group had inadequate intakes of zinc, vitamin A, vitamin B-12, and folate. The common denominator of these nutrient inadequacies was inadequate intake of animal-based foods. The diet in Carchi is dominated by staples of potatoes and grains, with adequate vegetables, but not enough meat, eggs or milk, or appropriately fortified foods. Wheat flour fortification with iron and B vitamins was initiated in 1996 in Ecuador, which increased the B vitamin intakes. This “profile” of dietary inadequacies is found elsewhere in the Ecuadorian Andes (1), but is only partly typical of developing country diets with low intakes of animal based foods and high intakes of starchy staples. In almost all other developing countries (and many developed countries) iron deficiency affects 30% or more of the population. However unlike the starchy staples consumed in most countries, potatoes are a source of dietary iron. The combination of potato iron, and iron from newly fortified wheat based products, accounts for the low prevalence of inadequacy of dietary iron. In fact, earlier work in Carchi among farm members found adequate hemoglobin levels among female housewives (mean, SD of 16.4 ,1.6 g/dl.) but lower hemoglobin levels among male pesticide applicators (14.7, 1.8 g/dl) (DC Cole, unpublished data).

Consistent with earlier findings, neurobehavioural performance among this developing country farm population was generally poor (8). Such poor performance has been found in other rural populations, particularly with lower educational attainment (30, 39). Hence the importance of both restricting the population to a minimum educational attainment and obtaining referent data matched on age and education as we did in this study. Although alcohol consumption is high among such populations, it is generally higher among men, inconsistent with our findings of greater relative impairment among women.

While the diet is inadequate and the neurobehavioural scores show widespread impairment, there does not appear to be any meaningful relationship between diet and neurobehavioural performance in this study. The level of error in dietary assessment may be too great to pick up subtle neurobehavioural affects of malnutrition. Perhaps the most likely nutrient to be related to neurobehaviour is vitamin $B_{12,}$ where 22% of adults have inadequate intakes. If 40% of these developed neuropsychiatric syndromes (16) there may be vitamin B_{12} deficiency-induced neurobehavioral impairment in 9% of adults, and the methods used in this study may not have been sensitive enough to detect such a small effect. More precise intake assessment or the use of biological markers of nutritional deficiency may be required, though the large neurotoxic effects of ongoing pesticide exposure may mask relatively smaller effects of malnutrition. The vast majority of the literature measuring neurobehavioural performance in rural populations has controlled for other exposures, though not nutritional status, and implicated pesticides (42), both past poisonings and ongoing exposure (43). Among our Carchi population we have found widespread evidence of rural household contamination with pesticides (44).

One continuing success story in Ecuador is the effectiveness of their salt iodization program. Ecuador used to have one of the highest rates of iodine deficiency in the world, and it was especially high in Carchi (45). Salt iodization legislation was enacted in Ecuador in 1968, and by the1980s, universal salt iodization was implemented in Ecuador. It continues with great success (46). The levels of iodine in salt from Carchi are adequate and now iodine deficiency is unlikely. However, today's adults were born and grew up in an iodine deficient environment (although, at least some of them reportedly purchased their salt in neighbouring Colombia which has had salt iodization since 1947). Iodine deficiency can cause irreversible neurobehavioural impairment that would be indistinguishable from that expected from past pesticide poisoning. However, acute pesticide poisonings are more common among men (47), inconsistent with our finding of greater neurobehavioural impairment among women.

It may be that the impaired neurobehavioural performance commonly observed in rural Carchi adults is a consequence of childhood iodine or other micronutrient deficiencies. Wheat flour fortification with iron, folate, riboflavin, thiamine and niacin began in the nineties. Such public health programs make the food more nutritious than it otherwise would have been in the fifties and sixties. We stratified the current neurobehavioural data set by birth cohorts. There was no difference in neurobehavioral performance between adults born in the 1950s, 1960s, 1970s or 1980s (results not shown). If in the future, pesticide use and exposure does not change, but neurobehavioural performance is better in new adults (e.g., individuals born 1985 or later), then it suggests that iodine, B vitamin or other deficiencies during the childhood of older adults may have contributed to poorer current neurobehavioural performance.

Our results on persistent nutritional inadequacies call for continued efforts to reduce malnutrition and poor health in Carchi and throughout the Andes. As elsewhere in the Americas, people do not suffer so much from abject poverty and starvation, but rather chronic inadequacies in the diet that collectively conspire to increase illness, shorten life, impair the quality of life, and prevent communities from reaching their full intellectual, physical, and economic potential. Focused "technical" efforts, such as increased food fortification, community level efforts, such as school lunch programs and health education, and broad social programmes aimed at poverty reduction and sustainable livelihoods would all work towards improving the health of Andean populations.

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Table 1. Daily intake of energy and macronutrients (mean ± SD), averaged over 2 (n=37) or 3 (n=239) 24 hour dietary recalls, by age and gender

Age/ gender	n	Energy (kcals)	Protein (g)	Fat (g)	CHO (g)
1-5.99 yrs					
Male	16	1410 ± 321	35.9 ± 9.6	24.3 ± 7.9	265.6 ± 65.5
Female	18	1469 ± 379	36.7 ± 8.1	28.5 ± 11.9	266.8 ± 72.4
6-15.99 yrs					
Male	45	1913 ± 545	50.2 ± 19.2	33.9 ± 16.2	354 ± 102.1
Female	48	1900 ± 483	51.1 ± 15.7	34.4 ± 13.3	347.7 ± 88.6
16-39.99 yrs					
Male	54	2838 ± 763	76.7 ± 20.8	46.9 ± 23.2	533.5 ± 147.8
Female	46	2201 ± 472	61.6 ± 16.4	37.5 ± 15.6	410.5 ± 90.9
40+ yrs					
Male	24	2576 ± 620	74.5 ± 22.7	42.8 ± 20.9	478.9 ± 116.3
Female	25	2073 ± 467	56.7 ± 15.7	35.1 ± 15	389.2 ± 90.9

Table 2. Daily intake of various micronutrients (mean ± SD), averaged over 2 (n=37) or 3 (n=239) 24 hour dietary recalls, by age and gender

Age/ Gender	N	Ca (mg)	Fe (mg)	Zn (mg)	Vit A (RE)	B-12 (µg)	Folate (mg)	Niacin (mg)	Riboflavin (mg)	Thiamin (mg)	Vit C (mg)
1-5.99 yrs											
Male	16	252±104	16.4±5.2	2.9±0.9	285±430	1.6±3.1	182±131	19.3±5.8	1.2±0.5	1.2±0.3	61±25
Female	18	281±125	16.1±5	3.6±1.5	401±574	2.4±4.0	160±79	18.1±6.1	1.3±0.7	1.3±0.5	58±19
6-15.99 yrs											
Male	45	370±201	23.3±7.8	4.7±2.3	351±421	1.1±0.9	241±166	27.5±9.5	1.4±0.6	1.8±0.7	89±40
Female	48	403±187	23.3±6.3	5.0±2.2	301±250	1.3±1.0	206±109	28.0±8.7	1.5±1.0	1.9±0.6	103±57
16-39.99 yrs											
Male	54	487±238	37.1±9.1	7.9±3.0	362±431	1.8±1.4	376±246	45.2±11.4	2.1±0.7	2.8±0.8	154±68
Female	46	417±202	28.7±6.7	6.3±2.7	295±325	1.6±1.2	287±200	35.7±8.7	1.7±0.6	2.1±0.5	113±48
40+ yrs											
Male	24	473±239	33.0±7.8	7.8±2.9	406±443	1.7±1.1	362±201	41.9±10.1	1.7±0.6	2.6±0.7	146±35
Female	25	418±225	25.2±4.7	6.0±2.0	272±350	1.5±0.9	278±178	31.1±7.4	1.4±0.4	1.9±0.5	112±37

Table 3. Prevalence of dietary inadequacy (%) of various nutrients by age and gender.

Age/gender	n	Fe_{PA}[1]	Zn_B[2]	Vit A_B[3]	B-12[4]	Folate[5]	Niacin[6]	Riboflavin[7]	Thiamin[8]	Prot[9]
1-5.99 yrs										
Male	16	0%	21%	51%	26%	0%	0%	0%	0%	0%
Female	18	0%	16%	30%	25%	0%	0%	6%	0%	0%
6-15.99 yrs										
Male	45	0%	19	43%	47%	5%	0%	9%	0%	6%
Female	48	0%	16	36%	36%	8%	0%	5%	0%	5%
16-39.99 yrs										
Male	54	0%	5%	47%	22%	4%	0%	1%	0%	2%
Female	46	0%	4%	55%	26%	10%	0%	4%	0%	4%
40+ yrs										
Male	24	0%	3%	35%	18%	10%	0%	9%	0%	6%
Female	25	0%	7%	59%	23%	24%	0%	8%	0%	10%

[1] Prevalence of iron dietary inadequacy (%) using "Prevent Anemia" requirement level and assuming 10% bioavailability of dietary iron.
[2] Prevalence of zinc dietary inadequacy (%) using "Basal" requirement level and assuming 35% bioavailability of dietary zinc.
[3] Prevalence of vitamin A dietary inadequacy (%)
[4] Prevalence of vitamin B-12 dietary inadequacy (%)
[5] Prevalence of folate dietary inadequacy (%)
[6] Prevalence of niacin dietary inadequacy (%)
[7] Prevalence of riboflavin dietary inadequacy (%)
[8] Prevalence of thiamin dietary inadequacy (%)
[9] Prevalence of protein dietary inadequacy (%)

Table 4. Calculation of iodine intake adequacy (using 21.0 µg I /g salt[1]) by age groups.

Age Group	RDA[2]	n	Salt Intake (mean ± SD g/day per capita)		Iodine intake (µg/day mean ± SD per capita, % of RDA)		Number (%) of individuals with mean intake:	
			Mean	Minimum[3]	Using Individuals Mean Salt Intake	Using Individuals Min. Salt Intake[3]	<50% RDA	<100% RDA
2-6 years	90	30	7.4±3.1	5.4±2.8	155±65 (173%)	113±59 (126%)	1 (3%)	6 (20%)
7-12 years	120	54	8.5±3.7	6.0±3.4	179±78 (149%)	120±69 (100%)	0 (0%)	14 (26%)
>12 years	150	179	14.0±5.6	9.7±4.7	294±118 (196%)	204±99 (136%)	1 (<1%)	14 (8%)

1. The average iodine content in salt samples tested at the household level.
2. RDA in µg/day (ICCIDD, 1997).
3. The minimum average was calculated using the day on which each individual consumed the least amount of salt from the 2-3 days of repeat 24-hour recalls.

Table 5. Neurobehavioral (NB) summary Z scores (mean ± standard deviation) for subset of adults meeting age and education criteria (n=101), by gender.

	n	Age	Overall NB	NB – Spatial	NB - Motor
Women	48	32.2 ± 10.8	-0.82 ± 0.70	-0.02 ± 1.45	-1.21 ± 0.73
Men	53	35.0 ± 13.0	-0.44 ± 0.65	-0.10 ± 1.27	-0.62 ± 0.68

Table 6. Prevalence of dietary inadequacy by gender and neurobehavioral score.

Gender	NB scores	N	Zn_B[1]	B-12[2]	Folate[3]	Riboflavin[4]	Vit A_B[5]
Females	**Z Spatial**						
	Z>0	26	3	27	8	2	76
	Z≤ 0	22	6	21	20	5	67
	Z Motor						
	Z> -1	18	5	24	9	6	50
	Z ≤ -1	30	6	16	4	0	39
Males	**Z Spatial**						
	Z>0	23	6	13	10	6	74
	Z≤ 0	30	5	24	5	2	63
	Z Motor						
	Z>-1	38	9	44	12	2	71
	Z ≤ -1	15	3	15	16	5	47

[1] Prevalence of zinc dietary inadequacy (%) using "Basal" requirement level
[2] Prevalence of vitamin B-12 dietary inadequacy (%)
[3] Prevalence of folate dietary inadequacy (%)
[4] Prevalence of riboflavin dietary inadequacy (%)
[5] Prevalence of vitamin A dietary inadequacy (%)