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Intelligence Quotient and Iodine Intake: A Cross-Sectional Study in Children

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The association between iodine deficiency and poor mental and psychomotor development is known. However, most studies were undertaken in areas of very low iodine intake. We investigated whether a similar association is found in schoolchildren from southern Europe with a median urinary iodine output of 90 μg/liter. Urinary iodine levels were measured in 1221 children who also completed a questionnaire about their usual dietary habits. Intelligence quotient (IQ) was measured by Cattell's g factor test. IQ was significantly higher in children with urinary iodine levels above 100 μg/liter. The risk of having an IQ below the 25th percentile was significantly related to the intake of noniodized salt and drinking milk less than once a day. As expected, the risk of having an IQ below 70 was greater in children with urinary iodine levels less than 100 μg/liter. In conclusion, this study demonstrates that the IQ of schoolchildren in a developed country can be influenced by iodine intake. The results support the possibility of improving the IQ of many children from areas with mild iodine deficiency by ensuring an iodine intake sufficient to achieve a urinary iodine concentration greater than 100 μg/liter. (*J Clin Endocrinol Metab* 89: 3851–3857, 2004)

THE ASSOCIATION BETWEEN dietary iodine deficiency and poor mental and psychomotor development is known (1, 2). Cretinism and goiter represent just the tip of the iceberg, which has now been more clearly identified as the spectrum of iodine deficiency disorders (3). Although endemic goitrous cretinism has virtually disappeared in Europe (4), in many countries there are still areas of low iodine intake (5). Furthermore, studies of the effect of iodine administration on psychomotor development are not consistent. Some have shown iodine supplements to be beneficial in children aged 6–8 yr (6), whereas others have found no benefit in children aged 5–12 yr (7, 8). Differences in the type of psychometric test employed, the local severity of iodine deficiency, the study design, the inclusion of a control group, as well as difficulty in excluding other nutritional or educational factors related to iodine deficiency disorders could explain the discordant results of these studies (8–12). Most interventional studies have focused on evaluating the effect of iodine administration on intellectual capacity in socially depressed areas with low levels of iodine intake (6). Few studies, however, have been undertaken in European schoolchildren. Studies in the Hurdes region of eastern Spain, well known for its iodine deficiency (8, 10, 11), showed that school-age children from this area had a mean score on psychometric tests approximately 1 SD lower than children from areas with no iodine deficiency.

Our group recently reported an association between auditory threshold and urinary iodine levels in schoolchildren from the province of Malaga, southern Spain, with a median urinary iodine of 120 μg/liter (13). In a systematic review in the Cochrane database of the role of iodized salt intake in the prevention of iodine deficiency disorders, Wu *et al.* (12) found only six controlled prospective studies: three in children, two in children and adults, and one in pregnant women. The main conclusion was that methodological differences between the studies were so great that a meta-analysis was not feasible. Other conclusions were 1) iodized salt is an effective and harmless procedure for increasing iodine intake (increase in urinary iodine); 2) the prevalence of goiter tended to decrease (although not always significantly); 3) no clear conclusions can be derived about the long-term effect on intellectual or physical development of children or on mortality; and 4) further studies are needed of the relation between iodine intake and psychomotor activity.

We studied the possible relation between urinary iodine concentration (surrogate measure of iodine intake) and intellectual capacity in a group of schoolchildren from southern Europe with a median urinary iodine level of 90 μg/liter.

Subjects and Methods

The study was undertaken in schoolchildren from the province of Jaén, situated in southeast Spain. The sample size was based on previous calculations of the prevalence of goiter and urinary iodine levels in areas bordering the study zone (13), assuming an α error of 0.05 and a β error of 0.20. The total number of children studied was 1221, giving a sample size error less than 4% for the prevalence of both goiter and urinary iodine levels. Sampling was carried out in different stages to guarantee representativity of the whole geographic area; area (n = 5), village (n = 14), and children (n = 1221) were selected as the sampling units.

The study was carried out in state schools. Education in Spain is

Abbreviations: CI, Confidence interval; FT3, free T_3; FT4, free T_4; IQ, intelligence quotient; OR, odds ratio; TPO, antithyroperoxidase antibody.

universal, compulsory, and free for the age group studied, thereby ensuring that selection of a school unit was fully representative of the entire population. The following data were obtained from all children: 1) presence of goiter according to the recommendations of Pérez *et al.* (14, 15) (O, thyroid not palpable; IA, thyroid palpable and larger than the distal phalanx of the subject's thumb; IB, goiter palpable and visible only with full neck extension); 2) standardized weight and height (16) from which the body mass index was calculated [weight (kilograms)/height (meters)^2]; 3) evaluation of usual food consumption by means of a previously validated questionnaire (17) (the parents and teachers were informed of the characteristics of the survey, which, after completion at home, was sent by post to the investigators); and 4) intelligence quotient (IQ), by means of Cattell's g factor test (18, 19), but using the Spanish versions of the originals (20, 21). All psychometric evaluations were made by the same person. Cattell's test is a collective test, and both scale 1 (18) and scale 2 (19) were applied. The former is for children 4–8 yr old and was used in the first grade. The latter is for children 9–14 yr old and was used in the fifth and eighth grades. The instructions, the administration, and the correction of both forms were undertaken by the same person, although with the help of another psychologist for their administration to check that the children performed the tests correctly. These scales enable evaluation of intellectual function free of cultural influence and minimize the influence of accumulated knowledge and experience. All elements are composed of drawings; thus, children readily accept the task, and it is not difficult for them to maintain their attention. Scale 1 comprises the following subtests: classification (categorize a series of drawings with certain common features), orders (perform a series of tasks in response to commands given orally by the researcher), mistakes (detect the detail in the drawing which does not fit), riddles (answer a riddle from a list of alternatives), substitution (changing certain symbols for other key symbols), maze (find the way from one point to another), identification (test of vocabulary and pictures), and similarities (identification of perceptually identical objects among other different objects). All of these subtests are as free as possible from cultural influence, except for the identification task, in which the child's knowledge has an influence on the object shown. The tests were all administered collectively because of the large number of children involved. This necessitated elimination of the subtests concerning classification, orders, mistakes, and riddles, which are given individually. The subtests given, therefore, were substitution, maze, identification, and similarities. The tests given compose the abbreviated form (18). Scale 2 is composed of four subtests, all perceptive: series (identify the element that completes a series of elements resulting in a certain characteristic), classification (find the different element in a group), matrixes (complete the fourth element in a set of three with a common feature), and conditions (chose an alternative that fulfills the same conditions as the model given). In all cases the elements are presented graphically, with no cultural content.

The scores obtained in the different subtests of both scales are combined to give a single score, which is then transformed into a score out of 100 or in deviation IQ (normal distribution of the IQ, with an arithmetic mean of 100 and an SD of 15). These tests have already been validated for schoolchildren in Spain (22–24).

A blood sample obtained by venipuncture was taken from all children. After separating the serum, it was frozen at −20 C until later analysis. Measurements were made of TSH (reference value, 0.2–6.0 μU/ml), free T_3 [FT_3; reference value, 0.26–0.52 ng/dl (4–8 pmol/liter)], free T_4 [FT_4; reference value, 0.78–1.55 ng/dl (10–20 pmol/liter)], and thyroglobulin (reference value, 1.7–35 ng/ml) by time-resolved fluoroimmunoassay (PerkinElmer, Wallac Oy, Turku, Finland). Antithyroperoxidase antibodies (TPO) were measured by RIA (Biocode, Liege, Belgium), with a value above 30 IU/ml considered positive. Urinary iodine was measured by the technique described by Benotti and Benotti (25) from a casual urine sample frozen at −20 C until measurement.

Statistical study

Data are represented as percentages, percentiles, means, and SDs. Hypothesis contrast of continuous variables was made by *t* test for two comparisons or by one- or two-way ANOVA for multiple comparisons. In this case, significance between sample means was measured by Duncan's *post hoc* test. For qualitative variables, association was measured by χ^2 test. The strength of association between variables was measured by calculating the odds ratio (OR) from multivariate logistic regression models, and 95% confidence intervals were calculated according to Miettinen (26). Inclusion of variables in the regression models was made according to Kleimbaun's recommendations (27). In all cases the level of rejection of a null hypothesis was $\alpha = 0.05$. Analyses were made using SPSS software (version 10; SPSS, Inc., Chicago, IL).

Ethics

The study was authorized by the relevant health and education authorities, and the parents of all the children attending the school at the time gave written informed consent to the participation of their children in the study. The study was also approved by the ethics and investigation committee of one of the participating centers.

Results

The mean age of the children was 10.8 ± 2.9 yr (range, 6–16 yr), and they came from three academic years (first, fifth, and eighth grades). The prevalence of goiter was 19.4%, and both types IA and IB were more common in girls than boys ($P = 0.0004$). The mean urinary iodine level was 111.9 ± 77.5 μg/liter, and the median was 90 μg/liter. TSH levels above 5 μU/ml (range, 5.05–7.21 μU/ml) were present in 1.2% of children. Thyroglobulin levels were above 10 ng/ml in 36.7%, and TPO values were positive (TPO >30 IU/ml) in 3% of the children (Table 1). Urinary iodine levels correlated with TSH (r = 0.13; $P = 0.0003$) in both boys and girls and with thyroglobulin (r = −0.13; $P = 0.01$) in the boys. There was no significant correlation between urinary iodine levels and FT_3 or FT_4.

The mean IQ was 97.2 ± 17.1. The distribution of the IQ of the schoolchildren according to percentile was: 5th, 65.1;

TABLE 1. General characteristics of the schoolchildren

Age (yr)[a]	
Total	10.8 ± 2.9
Academic grade	
1st grade	6.7 ± 0.3
5th grade	10.7 ± 0.5
8th grade	13.9 ± 0.7
Sex (%), boys/girls[b]	51.5/48.5
BMI (kg/m^2)[a]	
Boys	19.9 ± 4.1
Girls	19.3 ± 3.5
Goiter[b]	
IA	
Total	16.9
Boys/girls	12.7/21.4
IB	
Total	2.5
Boys/girls	1.7/3.3
Urinary iodine	
Total (μg/liter)[a]	111.9 ± 77.5
<100 μg/liter[b]	54.7
<50 μg/liter[b]	26.2
TSH (μU/ml)	
Total[a]	1.80 ± 1.09
>5 μU/ml[b]	1.2
FT_4 [ng/dl (pmol/liter)][a]	1.03 ± 0.16 (13.26 ± 2.06)
FT_3 [ng/dl (pmol/liter)][a]	0.28 ± 0.04 (4.33 ± 0.70)
Thyroglobulin	
Total (ng/ml)[a]	9.86 ± 7.45
>10 ng/ml[b]	36.7
TPO positive (>30 IU/ml)[b]	3

BMI, Body mass index.

[a] Values are the mean ± SD.

[b] Values are presented as a percentage of the total.

10th, 74.0; 25th, 87.3; 50th, 99.0; 75th, 109.4; 90th, 117.0; and 95th, 121.0. There were no significant differences in IQ when the sex, level of education, and presence of goiter were considered (Table 2). The IQ was, however, significantly lower in children who had urinary iodine levels less than 100 μg/liter (96.40 ± 17.46 *vs.* 99.03 ± 15.81 μg/liter; $P = 0.01$). These differences in IQ according to urinary iodine level persisted in a three-way ANOVA model ($P = 0.02$) after correcting for sex, school grade, and the presence of goiter.

The IQ of the girls correlated positively with urinary iodine levels (r = 0.12; $\beta = 0.026$; $P = 0.005$) and negatively with thyroglobulin (r = −0.16; $\beta = -0.378$; $P = 0.006$). The correlations in the boys were not statistically significant. The IQ was not related to TSH, FT_4, or FT_3.

An IQ below the 25th percentile was significantly related to urinary iodine levels below 100 μg/liter (OR, 1.40; $P = 0.02$) and thyroglobulin values above 10 ng/ml (OR, 1.52; $P = 0.04$). These OR rose to 2.17 and 2.37, respectively, after introduction in the model of the interaction urinary iodine-thyroglobulin (Table 3). Introduction in the model of other variables, such as education level, presence of goiter, or sex, did not change the strength of the association between IQ and urinary iodine or thyroglobulin levels (data not shown).

Table 4 shows the risk gradient of having an IQ below the 25th percentile according to urinary iodine level. Considering children with urinary iodine levels of 150 μg/liter or greater as exempt from risk (OR, 1), the OR increased from 1.48 ($P = 0.16$) for children with urinary iodine levels greater than 100 μg/liter and 150 μg/liter or less to 2.31 ($P = 0.007$) in children with urinary iodine levels 25 μg/liter or less.

As expected, urinary iodine levels were significantly higher in the 32.6% of children who consumed iodized salt (118.22 ± 77.39 μg/liter; $P = 0.0004$; Table 5). IQ was significantly higher in children who consumed iodized salt (100.63 ± 15.44; $P = 0.001$) than in those who usually consumed common or marine salt (Table 5).

The 38% of children who consumed dairy products at least three times a day had higher urinary iodine levels (118.6 ± 79.8 μg/liter; $P = 0.0001$) and a higher IQ (98.01 ± 15.96; $P = 0.0008$; Table 5). None of the other food groups was related to urinary iodine level or IQ (data not shown).

Two-way ANOVA with intake of salt and intake of dairy products showed that the intake of iodized salt ($P = 0.001$) and dairy products ($P = 0.001$) accounted for the variation in IQ, with age as a covariable and sex as a control variable. There was no interaction among intake of dairy products, iodized salt, and sex (data not shown).

The risk of an IQ below the 25th percentile was significantly related to the intake of common *vs.* iodized salt (OR, 1.70; $P = 0.01$) and intake of milk less than once a day *vs.* three times a day (OR, 1.54; $P = 0.03$). Inclusion in the model of sex and age did not change this association (Table 6).

We found (data not shown) that 7.6% of the children had an IQ below 70, a clinically important threshold. Intake of iodized salt or a greater amount of milk reduced the probability of being below this threshold. Only 4.4% of children who consumed iodized salt had an IQ below 70 *vs.* 8.2% of those who did not consume it [OR, 1.92; 95% confidence interval (CI), 1.0–3.6; $P = 0.03$]. Some 5.5% of children who consumed milk more than three times a day had an IQ below 70 *vs.* 11.6% of the other children (OR, 2.25; 95% CI, 1.29–3.23; $P = 0.003$). As expected, the risk of having an IQ below 70

TABLE 2. IQ according to sex, school grade, goiter, and urinary iodine level

Variable	IQ	*P*
Sex		
Boys	96.34 ± 17.44	NS
Girls	98.17 ± 16.73	
Grade		
1st grade	97.73 ± 14.58	NS
5th grade	96.27 ± 19.34	
8th grade	97.78 ± 16.69	
Goiter		
No	97.36 ± 17.11	NS
IA	96.10 ± 17.10	
IB	100.48 ± 17.22	
Urinary iodine		
≤100 μg/liter	96.40 ± 17.46	0.01
>100 μg/liter	99.03 ± 15.81	

NS, Not significant.

TABLE 4. Prevalence (percentage) and risk (OR) of an IQ below the 25th percentile according to decreasing urinary iodine levels (micrograms per liter)

Urinary iodine[a]	% Children with IQ ≤ 25th percentile	β	SEβ	OR[b]	95% CI	*P*[c]
>150	16.5			1		
>100 and ≤150	22.5	0.39	0.28	1.48	0.85–2.56	0.16
>50 and ≤100	26.4	0.60	0.25	1.83	1.12–2.97	0.01
>25 and ≤50	26.7	0.63	0.31	1.89	1.02–3.45	0.04
≤25	30.1	0.83	0.31	2.31	1.25–4.21	0.007

β, Regression coefficient; SEβ, SE of β.

[a] Urinary iodine (dummy variable). Urinary iodine reference category, >150 μg/liter.

[b] Risk (OR) of an IQ below the 25th percentile according to urinary iodine level (exposure variable), calculated from a logistic regression model that included age and sex as confounding variables.

[c] *P* adjusted for age and sex.

TABLE 3. Logistic regression models

Models	Independent variables	β	SEβ	OR	95% CI	*P*
Model 1	Urinary iodine	0.33	0.14	1.40	1.04–1.86	0.02
Model 2	Thyroglobulin	0.41	0.20	1.52	1.01–2.27	0.04
Model 3	Urinary iodine	0.47	0.22	1.61	1.04–2.46	0.03
	Thyroglobulin	0.37	0.21	1.45	0.96–2.18	0.08
Model 4	Urinary iodine	0.77	0.29	2.17	1.22–3.81	0.008
	Thyroglobulin	0.85	0.36	2.35	1.15–4.74	0.01
	Urinary iodine-thyroglobulin interaction	0.72	0.45	2.17	0.85–4.96	0.10

Dependent variable: IQ = 0 (IQ > 25th percentile); IQ = 1 (IQ ≤ 25th percentile). Independent variables: urinary iodine (0 *vs.* 1, >100 *vs.* ≤ 100 μg/liter); thyroglobulin (0 *vs.* 1, ≤10 *vs.* > 10 ng/ml). β, Regression coefficient; SEβ, SE of β.

was greater in children who had urinary iodine levels less than 100 μg/liter (OR, 1.69; 95% CI, 1.03–2.75; $P = 0.03$). The strength and significance of this association were unchanged alter adjusting for age and sex.

Discussion

Numerous studies in populations with iodine deficiency have shown a reduction in the psychomotor ability of children (3, 8, 10). Our study confirms this association in a representative sample of schoolchildren from a developed country in southern Europe who were all similar from an ethnic and social viewpoint and who had no associated nutritional problems.

Even though moderate iodine deficiency was reported in the province of Jaén in 1980 (28), no institutional campaign of iodine prophylaxis has yet been undertaken. In the study reported herein, the study area would be classified as grade I or mild if the median urinary iodine level was considered (90 μg/liter) and nearer to moderate on the basis of goiter frequency (19.4%). The high proportion of children with thyroglobulin levels greater than 10 ng/ml (39.2%) confirms the persistence of mild to moderate iodine deficiency in the diet (6). Although the results suggest that the degree of iodine deficiency can be classified as mild, this does not mean that the consequences are mild, as indicated by decreases in IQ and hearing acuity (13). These disorders should not be considered merely mild handicaps in the current competitive environment found in developed nations. This is an observation appearing more and more frequently from studies in other European countries, where surveys in schoolchildren suggested that iodine deficiency was mild, but the children were affected by iodine deficiency disorders that are not really mild (6, 29).

Previous studies in the same area have shown the main nutritional determinants of urinary iodine in schoolchildren to be intake of iodized salt and amount of dairy products consumed (30). In the present study the highest urinary iodine levels were found in children who consumed iodized salt and those who consumed dairy products at least three times a day. The association between IQ and urinary iodine levels, on one hand, and between IQ and intake of iodized salt and dairy products, on the other, confirms the nutritional nature of this relation as well as the probable persistence over time of a deficient iodine intake. The possibility that other components of milk, such as amino acids or fatty acids, whose beneficial effect on brain development is known (31), may influence these results cannot be ruled out, but they are outside the scope of this study.

Most children were clinically and analytically euthyroid, according to the reference values and usual clinical criteria. In fact, no marked changes in TSH, FT_3, or FT_4 levels are usually found with moderate iodine deficiency, although thyroglobulin levels are increased (32). Just as we found an association between thyroglobulin and IQ in this study, we had previously found a relation between thyroglobulin and auditory threshold in schoolchildren who were socially and

TABLE 5. Urinary iodine level and IQ according to type of salt consumed and frequency of intake of milk

	Urinary iodine	IQ
Type of salt		
Common	99.48 ± 68.85[a]	96.64 ± 16.94[a]
Marine	94.44 ± 70.40[a]	95.50 ± 18.22[a]
Iodized	118.22 ± 77.39[b]	100.63 ± 15.44[b]
P	0.0004	0.001
Frequency of milk intake		
3 times/d	118.60 ± 79.80[b]	98.01 ± 15.96[b]
2 times/d	98.68 ± 68.70[a]	99.90 ± 16.23[b]
1 time/d	87.10 ± 58.40[a]	93.64 ± 19.41[a]
<1 time/d	80.82 ± 48.60[a]	93.75 ± 16.93[a]
P	0.0001	0.0008

[a] and [b] Different letters indicate significant differences between means.

TABLE 6. Logistic regression models

Models	Independent variables	β	SEβ	OR	95% CI	*P*
Model 1	Salt					
	2 *vs.* 3	0.33	0.18	1.39	0.98–1.98	0.07
	1 *vs.* 3	0.53	0.22	1.70	1.10–2.61	0.01
Model 2	Dairy					
	1 *vs.* 0	−0.12	0.18	0.88	0.62–1.26	0.50
	2 *vs.* 0	0.45	0.20	1.57	1.06–2.32	0.02
Model 3	Salt					
	2 *vs.* 3	0.32	0.18	1.38	0.97–1.96	0.08
	1 *vs.* 3	0.53	0.22	1.74	1.10–2.61	0.01
	Dairy					
	1 *vs.* 0	−0.10	0.18	0.89	0.63–1.29	0.55
	2 *vs.* 0	0.43	0.20	1.54	1.04–2.27	0.03
Model 4	Salt					
	2 *vs.* 3	0.31	0.18	1.36	0.96–1.94	0.09
	1 *vs.* 3	0.45	0.21	1.75	1.04–2.37	0.01
	Dairy					
	1 *vs.* 0	−0.09	0.18	0.91	0.64–1.30	0.61
	2 *vs.* 0	0.45	0.21	1.58	1.04–2.37	0.03
	Sex	0.30	0.16	1.35	0.99–1.85	0.06
	Age	0.0013	0.027	1.00	0.95–1.06	0.96

Dependent variable: IQ = 0 (IQ > 25th percentile); IQ = 1 (IQ ≤ 25th percentile). Independent variables: consumption of salt (dummy variable): 1 = common salt; 2 = marine salt; 3 = iodized salt (reference category = 3); consumption of dairy products (dummy variable): 0 = 3 times/d; 1 = 2 times/d; 2 = less than 1 time/d (reference category = 1); sex: 0 = boys; 1 = girls (reference category = girls); age (years) = continuous variable. β, Regression coefficient; SEβ, SE of β.

geographically very similar to those in the present study (13). This association suggests that the effect of iodine deficiency on IQ is produced by the persistence of thyroid dysfunction, presently subclinical, but which at some point during development (fetal or postnatal) must have caused damage to brain maturation (2, 29, 33–35). Numerous clinical and experimental studies have shown the importance of an adequate iodine supply for maturation of the fetal and newborn brain (2, 34).

This study demonstrates yet again the need to guarantee sufficient iodine intake even in developed areas with western lifestyles. The presence and grade of goiter were related to urinary iodine levels. The increased standard of living and nutritional improvements as well as chance contact with iodine-rich chemicals or nutrients favor silent iodine prophylaxis (36). This silent prophylaxis may skew the distribution of urinary iodine levels to the right (30), but it may not be sufficient to maintain adequate iodine intake throughout the child's life. Defects related to neuronal maturation may be the consequence of exposure to low iodine levels during the first half of pregnancy or the early period of life, which leave sequelae that are not wholly reversible (37–39). However, the literature is discordant regarding the influence of postnatal iodine administration on defects of cerebral maturation and function caused by exposure to iodine deficiency after birth (6–8, 12, 40, 41).

Increased intake of iodized salt has been shown to reduce the prevalence of goiter (12). Iodine deficiency in the region studied (Andalusia) has been known since at least the second half of the 20th century (28). Despite this, no iodine prophylaxis campaigns have been undertaken because other health markers in both adults and children were officially acceptable, even very satisfactory (42), and the health authorities did not consider these campaigns necessary. Although most of the palpated goiters in our study were grade IA, the prevalence of goiter was still high. This suggests that many of these children are growing up in an environment of mild iodine deficiency, including during fetal development. Studies in nearby areas (43, 44) have shown that urinary elimination of iodine by pregnant and nonpregnant women is below International Council for Control of Iodine Deficiency Disorders (ICCIDD)/World Health Organization/United Nations Children's Fund (UNICEF) recommendations (45).

Although the minimum required amount of iodine is not fully established, a population with a median urinary iodine of 100 μg/liter or more is generally considered to be free of risk of endemic goiter (46). In our study we found that the risk of an IQ below the 25th percentile, and even of having an IQ of 70 or less (a clinically relevant decrease in IQ), was greater in children with urinary iodine levels less than 100 μg/liter. We also found a biological slope between IQ and urinary iodine levels. This slope, besides satisfying one of Hill's criteria of causality (47), sheds doubt on a cutoff point of 100 μg/liter being sufficient to avoid those iodine deficiency disorders that are related to psychomotor maturation, as we have previously shown for the auditory threshold (13).

The children involved in this study were born between 1986 and 1996. The great social and economic changes in Spain occurred during the decades immediately preceding these dates, and it is unlikely that during the lives of these children there have been any important cultural, economic, or nutritional changes. There definitely do not seem to have been any changes in the consumption of iodized salt, because studies undertaken in the same area during the 1980s showed the frequency of consumption and urinary iodine levels to be very similar (28). The association between iodine intake and IQ suggests that the higher IQ in children with higher urinary iodine levels is the consequence of greater iodine intake during their life rather than increased intake shortly before the study or other social or nutritional confounders. Interestingly, goiter was twice as common in girls as in boys in our study, and a positive linear correlation between IQ and urinary iodine levels has been found in girls. This is especially important, because if these girls continue as they are from a nutritional viewpoint, they will be unable to fulfill their iodine requirements should they become pregnant. This might well have a negative effect on the neurodevelopment of the unborn child during the first half of gestation, leading to potentially irreversible damage, with persistence of iodine deficiency disorders in a population that is not appreciably iodine deficient on the basis of the mean urinary iodine level and currently accepted indicators of iodine deficiency.

Measuring intelligence by studying the g factor is not new in this type of research (48, 49). Most studies have compared psychomotor development in children from areas of severe iodine deficiency with that in children from iodine-sufficient areas. This study, however, did not attempt to compare intellectual development between the inhabitants of two different areas with regard to the presence or absence of iodine deficiency, but, rather, to verify the possible existence of intellectual differences related to the urinary iodine levels of subjects from the same area. When geographic areas are compared, it is assumed that most inhabitants of the iodine-deficient area have been subjected at some time in their development to this deficit, although the effect may currently be palliated. What is measured is the effect of long-term lack of iodine. Nonetheless, this procedure risks including in an iodine-deficient area an unknown number of subjects who have never suffered this deficit for reasons such as geographic mobility or healthy nutritional habits. It is also possible to consider some subjects as not iodine deficient who are in fact iodine deficient despite living in noniodine-deficient areas. By dividing the sample not by area of residence but by urinary iodine level, the problems mentioned above are avoided, although the risk exists of assuming iodine intake to be stable. If the main source of iodine is accepted to be the diet, then it is basically stable over time in societies not submitted to great socio-demographic changes. This is supported by the fact that urinary iodine levels in the children studied were very similar to those in a study conducted in the same area 20 yr ago (28).

The same test (Cattell's g factor in its different forms) was used for all children of each age group, which is not always the case. García *et al.* (11) and Bleichrodt *et al.* (8), for example, used different intelligence tests depending on the age of the subjects. The terminological confusion surrounding the concept of intelligence and its repercussions on designing tests to measure it from different perspectives is well known. The use of different tests for different age groups may introduce a variable in the data related to measurement errors rather than reflecting the existence of true intellectual differences between the various age groups. Finally, all of the children, whether they had high or low urinary iodine levels, lived in the same geographical and cultural area, thereby eliminating another type of error typical of the indiscriminate use of intelligence tests, *i.e.* the reference group upon which the scales are based. In general, areas with severe iodine deficiency are usually the most economically, socially, and culturally depressed areas, and a relation to some other nutritional problem is often common (6, 7, 45). Iodine-sufficient areas, on the other hand, are usually the most developed and coincide with the sample populations used for designing scales of intelligence tests. It is not surprising, therefore, that in isolated rural areas, IQ levels are lower than in prosperous urban areas, as also occurs when different races or cultures are compared (50).

In summary, this study suggests that IQ levels in schoolchildren in a developed country can be affected by iodine intake. Although this was not an interventional study, the results suggest that an increase in dietary iodine to raise median urinary iodine output above 150 μg/liter would enable the IQ to be increased several points in many of these children.

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