Original Article

Investigation of intelligence quotient and psychomotor development in schoolchildren in areas with different degrees of iodine deficiency

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This investigation aims to observe the intelligence and psychomotor development of the schoolchildren in iodine deficiency (ID) areas after the adoption of Universal Salt Iodization (USI), and evaluate the effect of the adoption of USI on their intelligence and psychomotor development. 564 schoolchildren (306 males and 258 females, age range from 8 to 13 yrs) from areas with severe, moderate, and mild ID were investigated. Intelligence quotient (IQ) was measured by Combined Raven's test, second edition. Psychomotor development was examined by Jinyi Psychomotor Test Battery (JPB). We found that the IQ scores of all subjects in the severe and moderate ID areas were 102±15.6 and 99.5±16.6 respectively, lower than those in the mild ID areas (108±12.4, $p<0.01$). The IQ scores correlated negatively with age (partial $r=-0.17$; $\beta=-1.95$; $p<0.0001$). The total T scores of JPB of all subjects in the severe and moderate ID areas were 316±42.3 and 330±47.7 respectively, lower than those in the mild ID areas (342±48.1, $p<0.05$). The total T scores of JPB correlated negatively with age (partial $r=-0.15$; $\beta=-4.94$; $p=0.0006$). We may conclude that after the adoption of USI in the ID areas investigated, USI has probably made a contribution to the partial recovery of intelligence and psychomotor development injured by ID in schoolchildren, and should be strengthened.

Key Words: iodine deficiency, schoolchildren, Universal Salt Iodization, intelligence, psychomotor development, Shenyang, Liaoning province, China

INTRODUCTION

Iodine deficiency (ID) is regarded by the WHO as the most common preventable cause of brain damage in the world.[1] The existence of a continuum from mild mental retardation to gross neurological impairment by ID has only been widely appreciated in the last several decades. Endemic cretinism, well known and controlled, is the extreme consequence caused by ID,[2,3] but of much greater public health importance are the more subtle degrees of brain damage and reduced cognitive capacity which affect the entire population. The mental ability of ostensibly normal children and adults living in areas of iodine deficiency is reduced compared to what it would otherwise be.[4]

Universal Salt Iodization (USI) was recommended by WHO and UNICEF in 1993 as the main strategy to achieve elimination of Iodine deficiency disorders (IDD).[4] In China, Iodized salt has been supplied universally to ID areas since 1960s, and USI was adopted in 1995 as national strategy. Endemic cretinism has been almost controlled and endemic goiter has declined to a low level now. In 2000, the stage goal of eliminating IDD has basically been reached, but of all 31 provinces, 7 provinces and 400 counties still suffered from ID.[5] There was still subclinical cretinism in ID areas although iodized salt has been supplied.[6]

In ID areas after the adoption of USI, the prevalence of the mild intelligence retardation and psychomotor abnormality need to be confirmed. This investigation was carried out in schoolchildren in ID areas after the adoption of USI to 1) observe the IQ and psychomotor development of the schoolchildren in ID areas after the adoption of USI, 2) evaluate the effect of the adoption of USI on the intelligence and psychomotor development of schoolchildren lived in ID areas.

METHODS

Study subjects and areas

The investigation was carried out in ID areas in rural region of Shenyang, Liaoning province, north eastern part of China. We randomly selected two villages in severe ID areas, two villages in moderate ID areas, and two villages in mild ID areas. The median urine iodine level of healthy adults investigated in 1990 was 23.6 and 24.2μg/g creatinine in the two severe ID villages, 40.7 and 45.2μg/g creatinine in the two moderate ID villages, 90.9 and

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80.7μg/g creatinine in the two mild ID villages, respectively. Iodized salt (the concentration of Potassium Iodide in salt is 1:50000) has been supplied to these investigated ID areas since 1980, and the adoption of USI began in 1995. The investigated villages were all in the same economic area of the Shenyang, and the educational levels and socio-economic levels in population of these areas were similar according to local governmental statistical records.

There was just one primary school in each investigated villages, and all children attended local primary schools. We investigated all 8-13 yrs old children in these 6 primary schools of 6 selected villages, who were born and have been living in these villages. No case of apparent cretinism was found in the investigated areas. Ethical approval for this investigation was obtained from the ethical committee of China Medical University.

Intelligence test

Combined Raven's Test, second edition (CRT-C2) [7] was used to test children's intelligence and to get raw scores. CRT-C_2 combined three groups (A AB B) of Raven's Colored Progressive Matrices Test[8] and three groups (C D E) of Raven's Standard Progressive Matrices Test[9] together. The sequence of 7 pages was adjusted according to the difficulty order which is from easiest to hardest. The size of pictures to be selected in some pages were adjusted the same as the cut section in cut pictures. CRT-C_2, testing general intellectual aptitude and reasoning by analogy, is culturally fair, non-linguistic. It reflects aspects of fluid intelligence, as opposed to crystallized intelligence.[10] CRT-C_2 is particularly suitable for intelligence screening of children in ID areas.

Chinese norm for rural children of CRT-C_2[7] was established from a sample of 2400 children in iodine sufficient areas of 20 provinces in China. With reference to CRT-RC_2, IQ scores were calculated according to the subject's raw scores, age, and sex. Mild intelligence retardation was then determined in subjects whose IQ is between 55 and 69.

Psychomotor development test

Psychomotor development was evaluated by Jinyi Psychomotor Test Battery (JPB). JPB was made with reference to WHO neurobehavioural core test battery and was validated in China to assess children's psychomotor development[11]. Four factors produced from factor analysis and seven subtests were included in JPB: exactitude factor, rapidity factor, wrist and finger flexible factor, and short-term memory factor (see Appendix I). [11]

Subtest raw scores were firstly calculated by JPB. Subsequently, Chinese normative values for rural children[11] were administered to get subtest T scores according to the subject's subtest raw scores, age, and sex. That is,

$$T=10(X-M)/S+50, \quad (1)$$

in which X was the subtest raw scores the subject get in the test, M and S is the mean and standard deviation, respectively, of subtest raw scores in Chinese norm with respect to age and sex. However, Reaction Time and Connect Number subtests T scores were calculated as follows,

$$T=10(M-X)/S+50, \quad (2)$$

because the mean of these subtests raw scores decrease as the subjects' age increase. At last, total T scores was obtained by summing up the subtest T scores. Psychomotor development status was ranked as three grades according to the total T scores: normality (>315), borderline (281～315), and abnormality (=<280).

Two claim examiners of intelligence or psychomotor development tests performed the testing. They were certified psychologists and have experienced psychology technical training. Assistant examiners scored these tests.

Statistical analysis

We used SAS, vision 6.12, to analyse the results, which were summarized by frequencies and percentages for categorical data and by mean and standard deviations for continuous data. Pearson chi-square and Kruskal-Wallis test were used to test the significance of differences among proportions. Difference of means was assessed by the one-way ANOVA test, and when significant difference was found, the means were compared by the Student-Newman-Keuls multiple comparison test. Multiple linear regression models were used to assess the relation between the children's age, sex, or areas and the score of Neurointellectual test. The strength of association between age and the score of Neurointellectual test was also measured by partial correlation coefficient. *p*<0.05 was regarded as the level of significance.

RESULTS

General characteristics

In the severe, moderate and mild ID areas, investigated subjects included 124, 94, and 88 boys, respectively, and 101, 87, and 70 girls, respectively. The boys in the severe, moderate, and mild ID areas were 9.69±1.29yrs, 10.1±1.35yrs, and 9.88±1.08yrs old, respectively. The girls were 9.93±1.5yrs, 9.87±1.41yrs, and 9.64±1.39yrs old, respectively. No significant difference existed among the age of boys or girls in the severe, moderate, and mild ID areas. The mean height of the boys in the severe, moderate, and mild ID areas were 132±8.61cm, 135±8.14cm, and 134±7.0cm, respectively, and those of the girls were

Table 1. Intelligence quotient (IQ) in the schoolchildren of different sex in areas with different degrees of ID

Sex	Severe ID areas		Moderate ID areas		Mild ID areas	
	N	Mean±SD	N	Mean±SD	N	Mean±SD
Boy	124	103±16.6*	94	99.7±16.2**	88	108±11.8
Girl	101	100±14.3**	87	99.3±17.1**	70	109±13.2
Total	225	102±15.6**	181	99.5±16.6**	158	108±12.4

compared with mild ID areas, $^{*}p<0.05$, $^{**}p<0.01$.

Table 2. Multiple linear regression analysis of IQ in schoolchildren

Variable	β	Standard β	t	*p*
Constant	127	0	26.5	<0.0001
Areas				
Severe ID areas	-6.20	-0.20	-4.00	<0.0001
Moderate ID areas	-8.25	-0.25	-5.06	<0.0001
Sex	1.09	0.03	0.86	0.390
Age	-1.95	-.017	-4.15	<0.0001

Dependent variable: IQ=continuous variable. Independent variables: the category of ID areas: dummy variable, reference ID areas are mild ID areas; Sex: 0=girls, 1=boys; Age(years)=continuous variable. *β*, Regression coefficient; Standard *β*, standard regression coefficient.; For this regression model, F=12.0, p<0.0001. Multiple correlation coefficient =0.281.

133±9.51cm, 132±9.0cm, and 135±7.51cm, respectively. There was no significant difference among the height of boys in the severe, moderate, and mild ID areas, and no significant difference among those of girls.

Intelligence performance

IQ scores are shown in Table 1. The IQ scores of boys in the severe or moderate ID areas were significantly lower than those in the mild ID areas (p<0.05). The IQ scores of girls in the severe or moderate ID areas were significantly lower, as compared to those in the mild ID areas (p<0.01). The IQ scores of all subjects in the severe and moderate ID areas were 102±15.6 and 99.5±16.6 respectively, lower than those in the mild ID areas (108±12.4, p<0.01). There was no significant difference between the IQ scores of all subjects in the severe ID areas and those in the Moderate ID areas.

We added the variable of IQ scores to a multiple linear regression model as dependent variable, and the category of ID areas, sex, age as independent variables (Table 2). In this regression model, the IQ scores of all subjects in the severe and moderate ID areas were still lower than those in the mild ID areas (p<0.0001). There are no significant differences when sex was considered. The IQ scores correlated negatively with age (partial r=-0.17; p<0.0001). There was an increase in IQ of 1.95 point for each 1-yr decrease in schoolchildren's age, after controlling for the impact of sex and the category of ID areas.

The frequency of distribution for the mild intelligence retardation (55≤IQ<70) in the severe, moderate or mild ID areas was 2.22%, 4.42%, and 0.63%, respectively, and no significant difference existed among them. The frequency of distribution for subjects whose IQ≥110 in the severe ID areas and moderate ID areas was 31.6% and 28.2% respectively, significantly lower than that in the mild ID areas (45.6%, p<0.01). The frequency of distribution for IQ<90 in the severe ID areas (20.9%) or moderate ID areas (23.2%) was significantly higher than that in the mild ID areas (5.06%, p<0.05).

Psychomotor development

The subtest T scores of Reaction Time, Digit Erase, Sign Register, and Digit Symbol were statistically lower in the severe ID areas than in the mild ID areas (p<0.05). The subtest T scores of Digit Erase, Digit Symbol, Connect Number in the moderate ID areas were statistically lower, as compared to those in the mild ID areas (p<0.05). The subtest scores of Reaction Time, Digit Erase, Sign Register, and Digit Symbol reflect exactitude factor, and were added to get the T scores of exactitude factor. We found that the T scores of exactitude factor in the severe ID areas (179±28.1) and moderate ID areas (185±33.2) were statistically lower, as compared to those in the mild ID areas (198±33.1, p<0.01).

The total T scores of JPB are shown in Table 3. The total T scores of boys in severe or moderate ID areas were significantly lower than those in mild ID areas (p<0.01). The total T scores of girls in severe ID areas were significantly lower than those in mild or moderate ID areas (p<0.01). The total T scores of all subjects in the severe and moderate ID areas were 316±42.3 and 330±47.7 respectively, lower than those in mild ID areas (342±48.1, p<0.05).

We added the variable of total T scores in a multiple linear regression model as dependent variable, and the category of ID areas, sex, age as independent variables (Table 4). In this model, the total T scores of all subjects in the severe and moderate ID areas were still lower than those in the mild ID areas (p<0.05). There were no significant differences when sex was considered. The total T scores correlated negatively with age (partial r=-0.15; p=0.0006). There was an increase in total T scores of JPB of 4.94 point for each 1-yr decrease in schoolchildren's age, after controlling for the impact of sex and the category of ID areas.

The differences among the frequency of distribution for different psychomotor development grades in different degrees of ID areas were statistical significant (by Wilcoxon rank sum test, H=10.3, p=0.0057).The frequency of distribution for normality in the severe ID areas was 55.1%, significantly lower than that in the mild ID areas

Table 3. Total T scores of JPB in the schoolchildren of different sex in areas with different degrees of ID

Sex	Severe ID areas		Moderate ID areas		Mild ID areas	
	N	Mean±SD	N	Mean±SD	N	Mean±SD
Boy	124	316± 45.9**	94	334±467**	88	338±48.0
Girl	101	317±37.5$^{**\#\#}$	87	327±48.7	70	347±48.1
Total	225	316±42.3$^{**\#\#}$	181	330±47.7*	158	342±48.1

Compared with mild ID areas: $^{*}p$<0.05, $^{**}p$<0.01; Compared with moderate ID areas, $^{\#}p$<0.05, $^{\#\#}p$<0.01.

Table 4. Multiple linear regression analysis of total T scores of JPB in schoolchildren

Variable	β	Standard β	t	*p*
Constant	390	0	26.9	<0.0001
Areas				
Severe ID areas	-25.4	-0.27	-5.41	<0.0001
Moderate ID areas	-10.3	-0.10	-2.07	0.039
Sex	-0.24	0.00	-0.06	0.95
Age	-4.94	-.015	-3.47	0.0006

Dependent variable: total T scores=continuous variable. Independent variables: the category of iodine deficiency (ID) areas: dummy variable, reference ID areas are mild ID areas; Sex: 0=girls, 1=boys; Age(years)=continuous variable. *β*, Regression coefficient; Standard *β*, standard regression coefficient.; For this regression model, F=10.6, p<0.0001. Multiple correlation coefficient=0.27.

(73.4%, p<0.01), but without significant difference from that in the moderate ID areas (64.1%). The frequency of distribution for abnormality in the severe, moderate and mild ID areas was 14.2%, 16%, and 12%, respectively, and no significant difference existed among them.

DISCUSSION

Iodine deficiency causes several important health consequences that together are called IDD. The adoption of this term emphasized that the problem extended far beyond simply goitre and cretinism.[4,12] USI is now being applied in almost all countries with an IDD problem recognized as being of public health significance. Remarkable improvement of iodine status has been received by the adoption of USI in ID areas, and was revealed by many investigations.[3,5,13-18] China has achieved great success in the control of IDD by the massive implementation of USI.[5,14] The data of the Fourth National Monitoring Activity in China in 2002 showed that the children's median urine iodine concentration was 241ug/l and goiter rate was 5.6%, 90% of total population had been supplied eligible iodized salt.[5]

Effective iodine supplementation plays a remarkable role in protecting brain development in ID areas, and can cause 11.5-12 IQ points increase for children born after iodine sufficient.[19,20] It is well established that iodine supplementation in iodine-deficiency mothers before pregnancy or during early pregnancy improves the motor and cognitive performance of their offspring.[21-23] A study in China showed that up to the end of the second trimester, iodine treatment protects the fetal brain from the effects of iodine deficiency. Treatment later in pregnancy or after delivery may improve brain growth and developmental achievement slightly.[23] The postnatal effects of iodine deficiency on cognitive function are less clear. Several trials have examined the effect of iodine supplementation on the cognitive performance of children, but their results are equivocal, and problems of method limit their interpretation.[24-28] However, one recent study conducted in Albania clear showed that the adverse effects of moderate iodine deficiency on aspects of cognitive and motor function in children aged 10-12 yrs were ameliorated and at least partially remedied with iodine repletion.[28] It also revealed that iodine repletion in children was associated with a small but significant increase in intelligence. The studies mentioned above may show that the earlier stage of life the adoption of iodine supplementation begin in, the greater the improvement of intelligence and motor performance will be.

This investigation was conducted in severe, moderate, and mild ID areas in rural areas of Shenyang, China in November 2003. USI began to be adopted in all investigated areas in 1995, when the investigated 8 yrs old children had just been born, the investigated 9 yrs old children were about 1 yrs old, the investigated 10, 11, 12, and 13 yrs old children were about 2, 3, 4, and 5 yrs old, respectively. Multiple linear regression models revealed that after controlling for the impact of areas and sex, there was an increase in IQ of 1.95 point and total T scores of JPB of 4.94 point for each 1-yr decrease in schoolchildren's age. The children who began to benefit from the adoption of USI at born (8 yrs old when investigated) scored 1.95 point higher in IQ and 4.94 point higher in total T scores of JPB than the children who began to benefit from the adoption of USI at 1 yrs old (9 yrs old when investigated). Or the children who began to benefit from the adoption of USI at 1, 2, 3, or 4 yrs old scored 1.95 point higher in IQ and 4.94 point higher in total T scores of JPB than the children who began to benefit from the adoption of USI at 2, 3, 4, or 5 yrs old, respectively. The younger the investigated children were, the better their intelligence and psychomotor development would be, for the protection of iodine will be more effective in earlier stages. USI has probably made contribution to the partial recovery of intelligence and psychomotor development injured by ID in schoolchildren, and should be strengthened.

The IQ scores in schoolchildren in the severe or moderate ID areas were significantly lower than those in the mild ID areas. The psychomotor performance, reflected by the total T scores of JPB and the prevalence of psychomotor abnormality, was still worse in the severe or moderate ID areas. The reasons may be as follows: non-iodized salt was still vended in severe or moderate ID areas before the adoption of USI, the improper ways of iodized salt storage led to iodine losses, and pregnant women had less salt in order to control the edemas. These reasons led to the low iodine status of pregnant women, and the injured intelligence and psychomotor development of their offspring. For prevention and control of IDD, the implementation of USI should be further strengthened in the investigated severe and moderate ID areas. In China, although the adoption of USI in ID areas has led to remarkable improvement of iodine status in 2004, eligible iodized salt was taken by 90% or more inhabitants in only 80.46% counties, and 14.91% counties hadn't developed iodized salt monitor.[29,30] The frequency of iodized salt monitor should be increased in county unit, as to know the effect of USI progress and then determine the adoption of corresponding feedback actions.

In these investigated areas, KI salt has been supplied since 1980, and the implementation of USI began in 1995, the children investigated were conceived and born after 1989 but before 1995. Our research was an elementary evaluation of USI effect on children's neurological development. It is significant to evaluate the effect of USI in the round on children's neurological development in the coming future. It is required to increase sample size to represent all economic sectors and larger area coverage.

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AUTHOR DISCLOSURES
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Appendix I: Subtests in Jinyi Psychomotor Test Battery (JPB)

Subtest name	*Subtest description*	*Factors of JPB*
Reaction Time	On an apparatus faceplate, four different colored indicator lights with corresponding push buttons are presented to the child, who is asked to press the corresponding push button as quickly as possible when the indicator light shines.	Rapidity factor[+]
Digit Erase	A lot of digits are shown in a big digits table. With a pencil, the child is asked to erase the specified digits in the table line by line quickly within a fixed time period (150 seconds).	Exactitude factor[§]
Sign Register	With a pencil, the child is asked to register the sigh "╫" in a specified sequence as quickly as possible.	Exactitude factor[§]
Benton Visual Retention	10 pairs of pictures in a specified order are shown to the child. In each pair of pictures, the first picture has just one geometry form, the second picture has four geometry forms including one which is the same as that in the first picture. After keeping on seeing the geometry form on the first picture for 10 seconds, the child is asked to choose the same one on the second and write down the corresponding number.	Short-term memory factor
Digit Symbol	Each digit and corresponding special sign are shown as examples in some quadrate blocks. There are just digits in the other quadrate blocks, and the child is asked to register the corresponding special signs as quickly as possible.	Exactitude factor[§]
Connect Number	The child is asked to use a pencil to link the circle of number 1 to number 25 orderly as quickly as possible.	Exactitude factor[§]
Bar Inversion	A lot of bars are inserted in a plate, the child is asked to pull out, invert, and then insert the bar in the same hole as quickly as possible.	Wrist and finger flexible factor

[+]Information process speed is reflected. [§]Visual motor efficiency, eye and hand concordant are reflected.

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中国辽宁省沈阳市不同碘缺乏病区学龄儿童智力和精神运动发育的调查

本研究目的是观察在实行全民食盐加碘后的碘缺乏病区学龄儿童智力、精神运动发育状况，并评价全民食盐加碘（USI）策略实施对病区儿童智力、精神运动发育的影响。重、中、轻度碘缺乏地区的 564 名学龄儿童（306 名男性和 258 名女性，年龄范围为 8-13 岁）接受了调查。用联合型瑞文测验（第二版）测验学龄儿童智商（IQ），津医精神运动成套测验（JPB）测验精神运动发育。我们发现重、中病区学龄儿童智商分别为 102±15.6 和 99.5±16.6，低于轻病区学龄儿童（108±12.4, p<0.01）。学龄儿童智商与年龄呈负相关（偏相关系数 r=-0.17; β=-1.95; p<0.0001）。重、中病区学龄儿童 JPB 总 T 分分别为 316±42.3 和 330±47.7，低于轻病区学龄儿童 (342±48.1, p<0.05)，学龄儿童 JPB 总 T 分与年龄呈负相关（偏相关系数 r=-0.15; β=-4.94; p=0.0006) 。我们可得出结论：在被研究的实施过 USI 的碘缺乏地区，USI 可能使学龄儿童因碘缺乏而受损的智力和精神运动发育得到了部分恢复，USI 应得到加强。

关键字：碘缺乏、学龄儿童、全民食盐加碘、智力、精神运动发育、沈阳、辽宁省、中国。