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Linkages of biomarkers of zinc with cognitive performance and taste acuity in adolescent girls

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Abstract

A cross-sectional study ($n = 403$) was conducted to examine the relationship of plasma zinc (PZ) and erythrocyte zinc (EZ) levels with cognitive performance and taste acuity for salt in Indian adolescent girls. PZ, EZ and hemoglobin were estimated in schoolgirls (10–16 years). Cognitive performance was assessed by simple-reaction-time (SRT), recognition-reaction-time (RRT), visual-memory, Raven's Progressive Matrices (RPM) test. Taste acuity was determined by recognition-thresholds-for-salt (RTS) using 10 different salt concentrations. Low PZ (<0.7 mg/l) and EZ (<8 μg/g of packed cells) were observed in 72% and 23.6% of girls, respectively. PZ and EZ were negatively associated with SRT ($r = -0.41, -0.34$), RRT ($r = -0.49, -0.4$), and positively with Memory ($r = 0.43$, 0.34) and RPM ($r = 0.39$, 0.31; $p < 0.05$) and remained significant after adjusting for socio-demographic factors and hemoglobin. RTS was impaired in 18.3% girls and significantly correlated with EZ ($r = -0.31$, $p < 0.05$). Zinc deficiency in adolescent girls was associated with poor cognition and taste function implying need for improving their dietary zinc intakes.

Keywords

Cognitive function, hemoglobin, Indian adolescent girls, reaction time, taste acuity, zinc status

History

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Introduction

Zinc plays a crucial role as a cofactor of a host of enzymes for optimal metabolism and body functions (International Zinc Nutrition Consultative Group, 2004). Zinc deficiency has serious health consequences, particularly in children, contributing to impairments in brain function and physical growth (Gibson, 2006). Mild to moderate zinc deficiency may induce a number of functional abnormalities, such as impaired cognitive performance, reduced taste acuity or loss of appetite in children (Benton, 2008; Black, 2003; Cavan et al., 1993). As zinc deficiency affects the health of children in developing and developed countries, it has become a veritable public health concern.

Based on the estimated prevalence of inadequate zinc intakes, the global prevalence of zinc deficiency is ranging from 4% to 73% in different countries (International Zinc Nutrition Consultative Group, 2004). Although severe zinc deficiency is rare, the incidence of mild to moderate deficiency is common throughout the world. Dietary intakes of Indian adolescents are inadequate in most of the micronutrients including zinc (Srihari et al., 2007; Tupe & Chiplonkar, 2010). Indians are lacto-vegetarians and animal source of zinc is meager in their diets causing low intakes of bioavailable zinc (Chakravarty & Sinha, 2002). However, its consequence on their health is scarcely documented (Vazir et al., 2006). Moreover, Indian girls, particularly from low or middle socio-economic class are vulnerable to nutritional deficiencies due to their secondary social status, early marriage and gender bias in familial food distribution (Puri et al., 2008). Recent studies have indicated low zinc and micronutrient status of adolescent girls from urban India; however, its association with functional indices of zinc are scarcely reported (Vazir et al., 2006; Tupe & Chiplonkar, 2009).

Although all nutrients are required for body functioning, the deficiency of some micro-nutrients like iron, zinc influence the cognition and behavior of children (Benton, 2008) with majority of such studies reported in infants and young children. Cognitive function was found to be associated with zinc status in pregnant women (Stoecker et al., 2009), and zinc supplementation improved memory in young and older adults (Maylor et al., 2006). As zinc is closely related to growth, examining the association of zinc status and cognitive development in adolescence is of vital importance.

Other than cognition, zinc deficiency can potentially lead to impaired taste acuity (Pluhator et al., 1996). Taste perception was found to be associated with the levels of serum zinc and erythrocytes zinc in older Europeans (Stewart-Knox et al., 2005) and adults (McDaid et al., 2007). Hypozincemic women with plasma Zn <700 ng/ml had decreased thresholds of electrical stimulation for gustatory nerves (Yokoi et al., 2003). Studies in young children and women have demonstrated the link of recognition for salt taste threshold with zinc status (Cavan et al., 1993; Ishida et al., 1985). However, suboptimal zinc status and its relation with taste acuity has been scarcely studied in adolescent girls (Gibson et al., 2002; Kawade, 2012).

Therefore, the aim of this study was to investigate the association of zinc status with cognition and taste perception in Indian adolescent girls. The objectives were to assess relationships between plasma and erythrocyte zinc (EZ) levels with (i) taste acuity for salt and (ii) cognitive performance using a battery of tests in apparently healthy Indian adolescent girls.

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Methods

Subjects

A cross-sectional study was carried out in school girls from Pune, India. Based on the SD of plasma zinc (PZ) in females (International Zinc Nutrition Consultative Group, 2004), a sample size of 330 was estimated for the power of the study to be 0.9. A physician conducted clinical examination to assess health status of the girls. Current health complaints if any were recorded.

Exclusion criteria

Girls who were currently suffering or those who had suffered in the previous fortnight from any illness such as fever, respiratory or gastro-intestinal infections or those under medical treatment, or taking multi-vitamin mineral supplements were excluded. Two schools were randomly selected from a list of 14 girls' secondary schools in Pune city, India. From the school attendance records of the selected schools, a random sample of 403 apparently healthy schoolgirls in the age of 10–16 years were recruited for the study using computer-generated random number sequence. The study protocol was reviewed and approved by the local ethics committee under the chairmanship of a retired professor of the International Institute of Population Sciences, Mumbai, for Zensar Foundation of India. All the parents gave their written informed consent and the girls gave their assent to voluntarily participate in the study.

Cognitive tests

A battery of four tests was used to assess cognitive performance of the girls. Simple Reaction Time (SRT) and Recognition Reaction Time (RRT) were measured using a visual reaction time apparatus (Anand Agencies, Pune, India). Raven's Standard Progressive Matrices (RPM), a non-verbal test of performance (Raven et al., 2004) was calculated as percentage score for each girl from her raw score using the reference percentile age norms for Indian adolescent girls (Deshpande & Ojha, 2002). A short-term visual Memory test was carried out adopted from the subtest of Post Graduate Institute (PGI) memory scale for Indian children and adolescents (Kohli et al., 1998). These tests were conducted under the supervision of a psychologist in a classroom on different days within a week's time of conducting the health examination. The nature and content of the test was explained to the girls and demonstrations were given before actually conducting the test.

Taste acuity

Taste acuity was assessed by determining recognition thresholds for salt (RTS) using the modified method of Gibson et al. (1989). Ten salt solutions were prepared using 0.75–25.0 mmol/l of analytical grade sodium chloride in distilled, de-ionized water. All solutions were prepared freshly and were at room temperature during administration. The test was performed in a separate room on each girl in the morning after an overnight fast. For the test, plain distilled water was given before any test solution was administered. Different salt concentrations were given to each girl in increasing order until, at a particular concentration; the girl could identify the taste. The reliability of this test was assessed on a subsample of 15 age-matched girls (intraclass correlation coefficient, $r = 0.72$, $p < 0.05$).

Biomarkers of zinc and iron

Venous blood samples were collected under fasting condition at 7.30 am in EDTA-coated sterile bulbs. PZ was estimated by the wet digestion method using three acid mixture ($HNO3:HClO4:H2SO4$ in 3:2:1 proportion) and deionised distilled water as per the manual of National Institute of Nutrition, India (Raghuramulu et al., 2003) using atomic absorption spectrometer (AAS) (Perkin Elmer Model 3110, Waltham, MA) with a specific cathode lamp. Erythrocyte (RBC) zinc was measured as per the method by Kenney et al. (1984). Weighed aliquots of red cells (0.5 to 1 g) were digested with the similar acid mixture and diluted with deionized water to estimate zinc by AAS. Hemoglobin was estimated using Automated Cell counter (ActDiff II, Beckman Coulter, Fullerton, CA). To ensure accuracy, reference serum sample (RANDOX Laboratories, Mumbai, India) was used as a standard for each batch of blood estimations.

Socio-demographic observations

Using standard questionnaire (International Institute for Population Sciences, 2006), demographic characteristics of the girls, such as family size, education and occupation of mother and father were recorded from their parents.

Statistical methods

All statistical analyses were carried out using SPSS 16.0 for Windows (SPSS Inc, Chicago, IL). The data were checked for normality by a one-sample Kolmogorov–Smirnov test. Pearson's or Spearman's correlation coefficients were computed between hemoglobin, plasma or RBC zinc status and four cognitive scores, i.e. simple and recognition reaction time, visual memory, RPM and also with recognition threshold of salt taste acuity considering the normality of continuous variables. Partial correlations were computed to explore the association of zinc status with functional indices after adjusting for socio-demographic factors and hemoglobin. Statistical level of significance was set at 0.05. For the type I probability between 0.05 and 0.1, the significance was considered as marginal.

Results

Mean age of the girls ($n = 403$) was 12.1 ± 1.0 years (Table 1). Around 72.9% girls had normal height for age (Z score >-1) and BMI for age ($-2<$ Z score $<+2$) as compared to Indian reference standards (Khadilkar et al., 2009). Majority of the mothers (91%) and fathers (86%) had education up to high school. Family size of 32% girls was ≤ 4 members and 68% girls had more than 5 members in the family. Among fathers, 86.9% were salaried employees and mothers of 37.8% girls were working in industry or as domestic servant.

Mean plasma levels of zinc were low (Table 1) and 72% girls were below the normal cutoff (<0.7 mg/l) (International Zinc Nutrition Consultative Group, 2004; Yokoi et al., 2003). Mean RBC zinc was low (<8 µg/g of packed cells) in 23.6% girls (Kenney et al., 1984). Prevalence of anemia (hemoglobin <12 g/dl) was 26.1%.

Cognitive performance of the girls

SRT of 60% girls was higher than 300 ms, which is the average SRT in normal children (Solso & Kimberly, 2001). Average RRT was found higher than SRT (Table 2) as RRT has complex stimulus (two stimuli in RRT versus one stimulus in SRT) eliciting a slower reaction time (Kosinski, 2010). Majority of the girls (71.5%) had their RPM percentile below 50th percentiles of Indian norms (Deshpande & Ojha, 2002). Visual memory score was low (<50) in 50% of the girls.

Table 2 describes mean (±SD) cognitive scores across quartiles of plasma and RBC zinc levels. There is a gradual decrease in mean SRT and RRT, and a gradual increase in mean RPM and Memory with increasing quartile of plasma (RBC) zinc levels. Pearson correlation coefficients of PZ with SRT and RRT

Table 1. Characteristics of the study population.

Parameter	Age group (year) 10–12 ($n = 137$)	12–14 ($n = 240$)	14–16 ($n = 26$)	All ($n = 403$)
Age (year)	11.2 ± 0.4	12.4 ± 0.5	14.6 ± 0.7	12.1 ± 1.0
Height (cm)	141.0 ± 8.0	144.5 ± 7.6	148.4 ± 8.5	143.2 ± 8.1
Weight (kg)	29.9 ± 6.6	32.7 ± 6.5	35.7 ± 6.2	31.9 ± 6.7
BMI (kg/m^2)	14.9 ± 2.5	15.7 ± 2.7	16.2 ± 2.5	15.5 ± 2.6
Hb (g/dl)	12.4 ± 1.2	12.5 ± 1.3	12.3 ± 1.3	12.4 ± 1.3
Plasma zinc (mg/l)	0.63 ± 0.18	0.64 ± 0.26	0.59 ± 0.19	0.63 ± 0.25
Erythrocyte zinc (μg/g of packed cells)[a]	10.5 ± 4.2	11.7 ± 3.7	10.5 ± 5.7	11.2 ± 4.1

Values are expressed as Mean ± SD.
[a]On a sub sample of 127 girls.

Table 2. Cognitive scores of the girls across quartiles of plasma zinc and RBC zinc level.

Parameter	Quartiles of plasma zinc (mg/l) Q1 (≤0.47)	Q2 (0.48–0.60)	Q3 (0.61–0.71)	Q4 (≥0.72)	r^a	r^b
SRT (ms)	357 ± 76	333 ± 81	315 ± 62	302 ± 50	−0.41*	−0.39*
RRT (ms)	440 ± 80	433 ± 87	391 ± 65	390 ± 52	−0.49*	−0.44*
RPM (percentile)†	23 (9)	30 (11)	35 (18)	37 (17)	0.43*	0.45*
Memory (%)†	48 (16)	53 (16)	55 (22)	58 (17)	0.39*	0.41*
	Quartile of RBC zinc (μg/g of packed cells) Q1 (≤ 8.2)	Q2 (8.2–10.7)	Q3 (10.7–13.4)	Q4 (≥ 13.4)		
SRT (millisecond)	346 ± 75	337 ± 65	332 ± 67	314 ± 51	−0.34*	−0.30*
RRT (millisecond)	419 ± 79	414 ± 54	408 ± 81	394 ± 68	−0.40*	−0.38*
RPM (percentile)†	24 (10)	29 (16)	33 (20)	38 (25)	0.34*	0.33*
Memory (%)†	48 (18)	52(16)	56 (20)	57 (15)	0.31*	0.29*

Values are expressed as mean ± SD. *$p < 0.05$.
SRT, simple reaction time; RRT, recognition reaction time; RPM, ravens progressive matrices; †, RPM, Memory and taste acuity threshold were not normally distributed. Hence median and interquartile range is given for them instead of mean and SD.
[a]Pearson's correlation coefficient between plasma zinc or RBC zinc level and other parameters.
[b]Partial correlations of plasma zinc or RBC zinc level after controlling for significant socio-demographic factors (i.e. age, family size, mother's education and occupation).

were negative and statistically significant ($p < 0.05$) (Table 2). Significant positive Spearman's rank correlations were observed for Memory and RPM with PZ ($p < 0.05$). Similarly, RBC zinc levels were negatively correlated with SRT and RRT ($p < 0.05$) and positively correlated with Memory and RPM ($p < 0.05$) (Table 2). Partial correlations of SRT, RRT, Memory and SPM with PZ also remained significant when adjusted for age, family size, parents' education and occupation ($p < 0.05$). Partial correlations of RBC zinc with cognitive parameters also persisted after controlling for the socio-demographic parameters.

Partial correlations of PZ, with SRT ($r = -0.24$), RRT ($r = -0.21$), Memory ($r = 0.19$), and RPM ($r = 0.19$) remained significant ($p < 0.05$) after adjusting for hemoglobin status. Similarly, partial correlations of RBC zinc with SRT ($r = -0.22$), RRT ($r = -0.18$), Memory ($r = 0.18$), and RPM ($r = 0.12$) were also significant ($p < 0.05$). Correlations of hemoglobin with SRT ($r = -0.12$), RRT ($r = -0.10$), Memory ($r = 0.17$) and RPM ($r = 0.08$) were not statistically significant ($p > 0.1$).

Taste acuity of girls

Figure 1 represents the percent distribution of girls for recognition threshold for salt (RTS) over 10 solutions of different salt concentrations. Median RTS was 5 mmol/l, and first and third quartiles were 5 and 7.5 mmol/l, respectively (Figure 1). No observation was reported for lowest (0.75 mmol/l) and highest (25.0 mmol/l) salt concentrations. Girls with lower RTS (≤2.5 mmol/l) were 18.3%; those with high RTS (≥7.50 mmol/l) were 45.2%.

Mean (±SE) plasma and RBC zinc levels showed a decreasing trend with increasing salt concentrations (Figure 2). The differences in mean plasma and RBC levels between the lowest and highest salt concentration were significant ($p < 0.05$). Correlation of RTS with PZ was marginally significant ($r = -0.12$, $p < 0.1$) but RTS was significantly correlated with RBC zinc ($r = -0.31$, $p < 0.05$).

Discussion

Our study demonstrated significant association of plasma and RBC zinc status with the cognitive measures, i.e. reaction time, visual memory and RPM in Indian adolescent girls. Though not zinc status, early life under nutrition is reported to affect audiovisual reaction time to a visual stimulus in Indian adolescents (Agarwal et al., 1998). Our results indicated that higher the zinc status better will be visual memory scores. A higher average memory score (99) was observed in hostel-resident Indian children (6–15 year) (Vazir et al., 2006) as compared to the present study group which might be because of the zinc adequacy in their diet. These hostel children when supplemented with a multiple micronutrient beverage showed better attention-concentration but no improvement in memory. This might be the result of high memory score and zinc adequacy at baseline. In adults zinc supplementation resulted in beneficial effect on spatial working memory but a detrimental effect was seen on attention

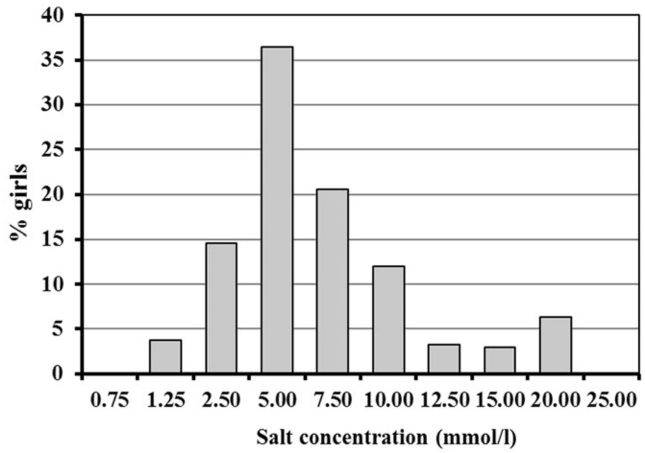

Figure 1. Percent distribution of the girls for recognition threshold for salt.

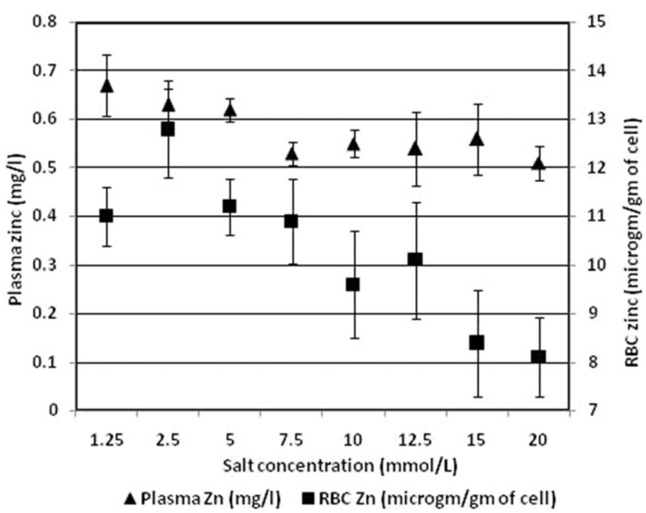

Figure 2. Average plasma and erythrocyte zinc levels at different taste acuity thresholds in girls.

(Maylor et al., 2006). Similarly, zinc deficiency was found to affect cognition in pregnant women (Stoecker et al., 2009).

Certain other micronutrients like iron, iodine, vitamin B12 have been identified as important for brain function in various life stages like infancy or preschool years (Benton, 2008). Multiple micronutrient supplementation with or without zinc in healthy schoolchildren (5–16 years) have shown marginal increase in fluid intelligence but not with crystallized intelligence, and improvement in visual recall and Raven's colored Progressive Matrices test scores (Eilander et al., 2010; Manger et al., 2008; Nga et al., 2011). These results indicate that the interactions among different micronutrients may have variable effect on the cognition. However, the risk of interactions varies with dose and duration of supplementation and baseline micronutrient status of participants (Hettiarachchi et al., 2008; Sandstrom, 2001). Thus, it is necessary to understand the role of specific nutrients like zinc and interactive effects among multiple micronutrients especially in growing age.

Mechanisms linking zinc to cognitive development and function are still unclear. However, certain neurons of the hippocampus are rich in zinc (Frederickson & Danscher, 1990), and fluid cognitive deficits and impaired working memory have been associated with the hippocampus (Blair, 2006) that has a role in spatial memory and has been suggested to be sensitive to zinc deficiency (Takeda, 2001). Our results support the role of zinc in memory and cognition.

Our study girls exhibited median threshold for salt taste recognition to be 5 mmol/l. The median RTS reported in 7-year-old periurban Guatemalan children (Cavan et al., 1993) was (7.5 mmol/l) higher than the study group. This may be because of low zinc status of the study girls. Less sensitivity for salt taste has been reported in Nigerian children (9–17 years) (Okoro et al., 1998). Taste acuity for salt in our girls was significantly correlated with EZ but weakly correlated with PZ. Similar finding has been reported in older Europeans (Stewart-Knox et al., 2005) where in higher serum zinc was found to be associated with sour but not salt, sweet or bitter tastes and EZ was associated with salt taste. Further association of low zinc status with higher median RTS for salt has been reported by studies in 7-year-old children (Cavan et al., 1993). Negative association of PZ with rate of correct discrimination of salt concentration was found in college-aged women (Ishida et al., 1985) and higher dietary zinc intake was associated with better taste acuity for salt in females (McDaid et al., 2007; Noh et al., 2012).

In conclusion, studies showing putative biological mechanism linking poor zinc status with lower cognitive performance and higher threshold for salt taste especially in childhood are scarce. Present study demonstrated the adverse effects of zinc deficiency on cognition and taste perception. The study population of adolescent girls with low zinc status showed lower cognitive performance and higher threshold for salt taste. Therefore, measures need to be taken to improve the micronutrient status especially zinc nutrition of Indian adolescent girls.

The present study was carried out in girls; however, similar study needs to be undertaken in boys since sex differences (McDaid et al., 2007) in taste acuity have been observed. Secondly responses for different tastes such as bitter, sweet may vary with zinc status which was not examined in the present study. Further we used plasma and EZ as biomarkers of zinc status. Several indices of zinc status such as erythrocyte membrane zinc, zinc metalloenzymes, zinc binding proteins such as metallothionine and other genetic markers are reported (Gibson et al., 2008). However, no unique biomarker of zinc status is recommended so far, especially in community settings (Gibson et al., 2008). For the simplicity of the expression, plasma and EZ are used in the present study. Another limitation of the study is that we did not measure other micronutrient status except iron for their role in cognition. Interactions of other micronutrients with zinc and in turn on the cognition may be examined by further research.

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Declaration of interest

This study was partially funded by Zensar Foundation, Pune, India. The authors declare that there is no potential conflict of interest or disclosures regarding the research work in the article.

References

Agarwal KN, Agarwal DK, Kumar A, Upadhyay SK. 1998. Sequel of early undernutrition on reaction time of rural children at 11–14 years. Ind J Med Res 107:98–102.

Benton D. 2008. Micronutrient status, cognition and behavioral problems in childhood. Eur J Clin Nutr 47:38–50.

Black MM. 2003. The evidence linking zinc deficiency with children's cognitive and motor functioning. J Nutr 133:1473S–1476S.

Blair C. 2006. How similar are fluid cognition and general intelligence? A developmental neuroscience perspective on fluid cognition as an aspect of human cognitive ability. Behav Brain Sci 29:109–125.

Cavan KR, Gibson RS, Grazioso CF, Isalgue AM, Ruz M, Solomons NW. 1993. Growth and body composition of periurban Guatemalan children in relation to zinc status: a cross-sectional study. Am J Clin Nutr 57: 334–343.

Chakravarty I, Sinha RK. 2002. Prevalence of micronutrient deficiency based on results obtained from the national pilot program on control of micronutrient malnutrition. Nutr Rev 60:S53–S58.

Deshpande CG, Ojha JM. 2002. Indian Norms for Raven's Standard Progressive Matrices. New Delhi: Manasayan.

Eilander A, Gera T, Sachdev HS, Transler C, van der Knaap HCM, Kok FJ, Saskia JM, Osendarp SJM. 2010. Multiple micronutrient supplementation for improving cognitive performance in children: systematic review of randomized controlled trials. Am J Clin Nutr 91:115–130.

Frederickson C, Danscher G. 1990. Zinc-containing neurons in hippocampus and related CNS structure. Prog Brain Res 83:71–84.

Gibson RS. 2006. Zinc: the missing link in combating micronutrient malnutrition in developing countries. Proc Nutri Soc 65:51–60.

Gibson RS, Heath ALM, Ferguson EL. 2002. Risk of suboptimal iron and zinc nutriture among adolescent girls in Australia and New Zealand: causes, consequences, and solutions. Asia Pac J Clin Nutr 11: S543–S551.

Gibson RS, Hess SY, Hotz C, Brown KH. 2008. Indicators of zinc status at the population level: a review of the evidence. Brit J Nutr 99: S14–S23.

Gibson RS, Vanderkooy PDS, MacDonald AC, Goldman A, Ryan BA, Berry M. 1989. A growth-limiting, mild zinc-deficiency syndrome in some Southern Ontario boys with low height percentiles. Am J Clin Nutr 49:1266–1273.

Hettiarachchi M, Liyanage C, Wickremasinghe R, Hilmers DC, Abrams SA. 2008. The efficacy of micronutrient supplementation in reducing the prevalence of anaemia and deficiencies of zinc and iron among adolescents in Sri Lanka. Eur J Clin Nutr 62:856–865.

International Institute for Population Sciences. 2006. National Family Health Survey, Government of India. Household Questionnaire. Mumbai, India, 2005–2006. Available at: http://www.nfhsindia.org/pdf/Household. http://www.nfhsindia.org/NFHS-3 Data/VOL-2/Household Questionnaire.pdf. Accessed on 2 September 2006.

International Zinc Nutrition Consultative Group (IZiNCG). 2004. Technical Document #1C. Hotz and K. H. Brown, guest editors: assessment of the risk of zinc deficiency in populations and options for its control. Food Nutr Bull 25:S99–S199.

Ishida H, Takahashi H, Suzuki H, Hongo T, Suzuki T, Shidoji Y, Yoon KH. 1985. Interrelationship of some selected nutritional parameters relevant to taste for salt in a group of college-aged women. J Nutr Sci Vit 31:585–598.

Kawade R. 2012. Zinc status and its association with the health of adolescents: a review of studies in India. Glob Health Action 5:7353. DOI: 10.3402/gha.v5i0.7353.

Kenney MA, Ritchey S, Culley P, ApplStat M, Sandoval W, Moak S, Schiiin P. 1984. Erythrocyte and dietary zinc in adolescent females. Am J Clin Nutr 39:446–451.

Khadilkar VV, Khadilkar AV, Cole TJ, Sayyad MG. 2009. Cross-sectional growth curves for height, weight and body mass index for affluent Indian children, 2007. Indian Pediatr 46:477–489.

Kohli A, Mohanty M, Malhotra R, Verma SK. 1998. Measurement of memory in children: construction of a simple clinical tool in Hindi. Behav Med J 1:34–42.

Kosinski RJ. 2010. A literature review on reaction time. Updated on September 2010; Available at: http://biae.clemson.edu/bpc/bp/Lab/110/reaction.htm. Accessed on 10 December 2010.

Manger MS, McKenzie JE, Winichagoon P, Gray A, Chavasit V, Pongcharoen T, Gowachirapant S, et al. 2008. A micronutrient-fortified seasoning powder reduces morbidity and improves short-term cognitive function, but has no effect on anthropometric measures in primary school children in northeast Thailand: a randomized controlled trial. Am J Clin Nutr 87:1715–1722.

Maylor EA, Simpson Ellen EA, Secker DL, Meunier N, Andriollo-Sanchez M, Polito A, Stewart-Knox B, et al. 2006. Effects of zinc supplementation on cognitive function in healthy middle-aged and older adults: the ZENITH study. Brit J Nutr 96:752–760.

McDaid OB, Stewart-Knox B, Parr H, Simpson E. 2007. Dietary zinc intake and sex differences in taste acuity in healthy young adults. J Human Nutr Dietet 20:103–110.

Nga TT, Winichagoon P, Dijkhuizen MA, Khan NC, Wasantwisut E, Wieringa FT. 2011. Decreased parasite load and improved cognitive outcomes caused by deworming and consumption of multi-micronutrient fortified biscuits in rural Vietnamese schoolchildren. Am J Trop Med Hyg 85:333–340.

Noh HY, Paik HY, Chung J. 2012. Salty taste acuity in relation to zinc nutritional status and αENaC A663T gene polymorphism among Korean young adults. FASEB J 26:647–648.

Okoro OE, Uroghide GE, Jolayemi TE, Georged OO, Enobakhared CO. 1998. Studies on taste thresholds in a group of adolescent children in rural Nigeria. Food Qual Pref 9:205–210.

Pluhator MM, Thomson ABR, Fedorak RN. 1996. Clinical aspects of trace elements: zinc in human nutrition-assessment of zinc status. Can J Gastroenterol 10:37–42.

Puri S, Marwaha RK, Agarwal N, Tandon N, Agarwal R, Grewal K, Reddy DHK, et al. 2008. Vitamin D status of apparently healthy schoolgirls from two different socioeconomic strata in Delhi: relation to nutrition and lifestyle. Br J Nutr 99:876–882.

Raghuramulu N, Nair MK, Kalayansundaram S. 2003. Manual of laboratory techniques. Hyderabad, India: National Institute of Nutrition; p 26–27, 160–167.

Raven J, Raven CJ, Court JH. 2004. Manual for Raven's progressive matrices and vocabulary scales. Section 3. Oxford: OPP Ltd.

Sandstrom B. 2001. Micronutrient interactions: effects on absorption and bioavailability. Brit J Nutr 85:S181–S185.

Solso RL, Kimberly MM. 2001. Experimental psychology: a case approach, 7th ed. Boston: Allyn & Bacon.

Srihari G, Eilander A, Muthayya S, Kurpad AV, Seshadri S. 2007. Nutritional status of affluent Indian school children:what and how much do we know? Ind Pediatr 44:199–203.

Stewart-Knox BJ, Simpson EEA, Parr H, Rae G, Polito A, Intorre F, Meunier N, et al. 2005. Zinc status and taste acuity in older Europeans: the ZENITH study. Eur J Clin Nutr 59:S31–S36.

Stoecker B, Abebe Y, Hubbs-Tait L, Kennedy T, Gibson R, Arbide I, Teshome A, et al. 2009. Zinc status and cognitive function of pregnant women in Southern Ethiopia. Eur J Clin Nutr 63:916–918.

Takeda A. 2001. Zinc homeostasis and functions of zinc in the brain. Biometals 14:343–351.

Tupe R, Chiplonkar SA. 2009. Zinc supplementation improved cognitive performance and taste acuity in Indian adolescent girls. J Am College Nutr 28:388–396.

Tupe R, Chiplonkar SA. 2010. Diet patterns of lacto-vegetarian adolescent girls: need for devising recipes with high zinc bioavailability. Nutrition 26:390–398.

Vazir S, Nagalla B, Thangiah V, Kamasamudram V, Bhattiprolu S. 2006. Effect of micronutrient supplement on health and nutritional status of schoolchildren: mental function. Nutrition 22:S26–S32.

Yokoi K, Egger NG, Ramanujam VMS, Alcock NW, Dayal HH, Penland JG, Sandstead HH. 2003. Association between plasma zinc and zinc kinetic parameters in premenopausal women. Am J Endocr Metab 285: E1010–E1020.