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ORIGINAL PAPER

Does Nutritional Intake Differ Between Children with Autism Spectrum Disorders and Children with Typical Development?

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Abstract Consumption of macro- and micronutrients and food group servings by children with autism spectrum disorders (ASDs; $n = 46$) and typical development ($n = 31$) were compared using 3-day diet records. Children with ASDs consumed significantly more vitamin B6 and E and non-dairy protein servings, less calcium, and fewer dairy servings ($p < .05$). The significantly lower dairy serving intake persisted after controlling for child age and sex and parental dietary restrictions, and excluding children on the gluten-free casein-free (GFCF) diet. Large proportions of children in both groups did not meet national recommendations for daily intake of fiber, calcium, iron, vitamin E, and vitamin D.

Keywords Autism · Dietary intake · Children

Numerous case studies have reported dietary selectivity among children with autism (e.g., Ahearn 2003; Ahearn et al. 2001; Buckley et al. 2005; Clark et al. 1993; Luiselli et al. 2005; Najdowski et al. 2003). Repetitive behaviors and restricted interests, a core feature of autism, may play a role in dietary selectivity. Children with autism spectrum disorders (ASDs) often resist novel experiences, which may include tasting new foods. In addition, many children with ASDs have sensory hypersensitivities and may reject foods due to an aversion to texture, temperature or other characteristics of the foods.

Despite case reports of food selectivity, relatively few studies have examined the adequacy of dietary intake among children with ASDs or compared their intake to that of control children (Cornish 1998; Ho and Eaves 1997; Raiten and Massaro 1986; Schreck et al. 2004; Shearer et al. 1982; Levy et al. 2007). These studies have produced conflicting results.

Macro- and micronutrient intakes, and consumption of foods from different food groups, have been compared in children with autism and children with typical development. Using 3-day diet records, Shearer et al. (1982) found that children with autism had significantly lower intakes of calcium and riboflavin, and ate fewer foods from the dairy food group, than did children with typical development. After analyzing 7-day diet records, Raiten and Massaro (1986) found no difference between diagnostic groups with regard to nutrient intake. Schreck et al. (2004) used a food preference inventory to examine parents' perception of nutritional intake in children with autism and typical development. Children with autism reportedly consumed less fruit, dairy products, vegetables, proteins and starches than did controls.

Levy et al. (2007) evaluated 3-day diet records from 52 children with autism enrolled in a Secretin treatment trial. Nutritional intake was compared to published RDA norms for calories, protein, carbohydrates and fats. Mean values for calories, carbohydrates and fats were average (95–101%), but the mean value for proteins was much

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higher than the RDA (211%, range = 67–436%). Ho and Eaves (1997) collected 3-day diet diaries among children with autism and found that 33% had low calcium intake and only 7.4% met Canadian recommendations for nutritional intake values. Using a 3-day diet history, Cornish (1998) found that 53% of children with autism had intakes below the reference nutrient intake (RNI) for at least one of vitamin C, iron, vitamin D, niacin, riboflavin, vitamin B_6, calcium or zinc, though 13 of the 17 children drank more milk than the RNI. None of these studies compared children with autism to typically developing children.

The gluten-free and casein-free (GFCF) diet is currently a popular form of complimentary and alternative treatment among parents of children with ASDs. The concept of gluten sensitivity in children with autism was first introduced in 1979 (McCarthy and Coleman 1979 as reported by Erickson et al. 2005 in a critical review). The efficacy of the GFCF diet in children with ASDs has not been established. Two randomized controlled trials have evaluated the GFCF diet as a form of treatment (Knivsberg et al. 2002; Elder et al. 2006). Knivsberg et al. (2002) found that autistic behaviors improved in ten children with ASD on the diet as compared to ten control subjects over the course of a year in a single blind, randomized trial. The improvement was small and its clinical relevance is unclear. The second trial found no change in symptoms of 15 children with autism in a double-blind, placebo-controlled crossover trial of the GFCF diet, though a few parents reported improvement (Elder et al. 2006). Despite the dietary restrictions imposed by the GFCF diet, Cornish (2002) found similar intakes of energy, protein and micronutrients among children with ASDs on the GFCF diet and those who were not on the diet.

While these studies have provided insight into the nutritional intake of children with autism, methodological issues such as small sample size and lack of controls compromise the power and validity of the results. Furthermore, we found no studies examining whether children with ASDs eat foods from each of the main food groups as outlined by the United States Department of Agriculture (USDA 2007) Food Pyramid. Studies focusing solely on micro- and macronutrient intake may not identify effects of dietary restrictions among children with ASDs, since the majority of foods on the market today are fortified with vitamins and minerals. Further study is needed to identify whether children with ASDs meet the nationally recommended nutritional intake as well as typically developing children, and whether children with ASDs have more restrictive diets than children with typical development.

The specific aims of this study were to compare the dietary intake of children with ASDs to that of children with typical development, and to compare the nutritional status of children with ASDs and children with typical development to the national dietary intake recommendations. Our primary hypothesis was that children with ASDs would have lower macro- and micronutrient intake compared to children with typical development. Additionally, we predicted that children with ASDs would eat fewer servings of different food groups than children with typical development. Our secondary hypothesis was that children with ASDs would meet national daily recommended intake less often than children with typical development.

Methods

Participants

Between 2002 and 2006, following approval by the Colorado Multiple Institutional Review Board, subjects were recruited for a cross-sectional study of medical issues in children with and without ASDs through hospitals, clinics, schools and treatment facilities in Denver. Children with ASDs met criteria for their diagnosis through: (1) The Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord et al. 1999); (2) The Social Communication Questionnaire (SCQ; Berument et al. 1999) or the Autism Diagnostic Interview-Revised (ADI-R; Lord et al. 1994), and (3) the clinical opinion of an experienced licensed clinical psychologist. All measures were administered by a licensed clinical psychologist or experienced research assistant who was research reliable on the measures (i.e., received at least 85% consensus on items over three successive administrations).

Of 121 children consenting to the larger study, 32 failed to return required study materials (e.g., diet diaries): 14 with autism (12 male, 2 female), eight with typical development (7 male, 1 female), and ten with developmental disabilities. Twelve children with unrelated developmental delays were excluded from this analysis. The study sample comprised the remaining 77 children, of whom 46 met criteria for ASDs and 31 had typical development.

Data Collection

Parents were asked to record all food ingested by the child, and to provide estimated portion sizes for each item ingested, using sequential diet diaries. Because dietary nutrient intake from foods and beverages was the focus of the study, data were not analyzed on type or amount of vitamin and mineral supplement intake. Parents received standardized training for diet diaries and could request information or assistance at any time during participation. A measurement guide was provided to parents to improve the accuracy of reported portion sizes. Parents were asked to submit food wrappers with ingredients and copies of homemade recipes where possible. Parents were also encouraged to complete the diaries during a typical week, and were told to discontinue the diaries if the child became ill, although no parent discontinued the diary for this reason.

Initially, we requested 7-day diaries in order to obtain adequate reports on fiber intake (Bingham 1987; Nelson et al. 1989). After 26 subjects completed 7-day records, there was no significant difference in average daily fiber intake for 3 days compared to 7 days as shown by a paired *t*-test ($t = 1.15$, 95% CI: -0.4 to 1). Parents of subsequently enrolled subjects were asked to complete 3-day diaries, which is consistent with standard practice (Barrett-Connor 1991; Institute of Medicine 2001). To make data consistent between individuals and to reduce variance, only the first 3 days of intake recorded in the diaries were used for children who had diaries longer than 3 days. To assess whether this decision affected our results, we compared the averages including all days to averages from the first three and last three days for each nutrient. These averages were found to differ by no more than 5% (data not shown). Parents were also asked whether the child's diet had been restricted, and if so, by whom and why. Height and weight were collected by physical exam on 26 children with ASD and by parent report for the remaining 51 children. Although studies have shown that mothers may over- or underestimate their child's height and weight, differences between self-report and physical examination tend to be small (e.g., Dubois and Girard 2007; Huybrechts et al. 2006; Scholtens et al. 2006).

Certified bionutritionists analyzed each child's nutritional intake using the computerized Nutrition Data Systems for Research (NDS-R, University of Minnesota Nutrition Coordinating Center, Minneapolis, MN, USA). Three bionutritionists analyzed diets over the 4-year study. Mean values for micro- and macronutrients were calculated. NDS-R software provides some information regarding the categorization of food groups by food eaten, but it does not include serving sizes for children. One author (AH) collaborated with a registered dietician, both of whom were blinded to case and control status, to categorize foods into the six food groups. Standardized serving sizes for children were estimated by comparing mean food quantities eaten to previously published estimates of mean food quantities that children eat per sitting (Smiciklas-Wright et al. 2002).

Outcomes of Interest

Mean dietary intakes of carbohydrates, energy, fat, fiber, protein, calcium, folate, iron, niacin, tryptophan, tyrosine, vitamin A, vitamin B_6, vitamin C, vitamin D, vitamin E, and zinc were examined as well as servings of the following food groups: dairy, fruits, grains, non-dairy protein, vegetables, fats and oils, and sweets.

The adequacy of dietary intake was assessed by comparing the mean dietary intake for each nutrient to the *Dietary Reference Intakes (DRI): Recommended Intakes for Individuals, Vitamins* (Institute of Medicine 2001), which breaks down recommendations by ages 1–3 and 4–8. Mean intakes of nutrients for which DRIs and tolerable upper levels are published were examined individually. Micronutrients were assessed as above the tolerable upper level, adequate (i.e., at least 100% of the DRI but below the tolerable upper level), or inadequate (i.e., falling below 100% of the DRI). Tolerable upper levels are not available for macronutrients, thus consumption of 100% or more of the DRI was considered adequate.

Statistical Analyses

The distributions of some dependent variables (i.e., calcium, folate, iron, tryptophan, tyrosine, vitamin A, vitamin C, vitamin D, vitamin E, and zinc, and servings of food groups) were positively skewed. These variables were logarithmically transformed to normalize their distributions. For food groups where servings included values of zero (i.e., all except grains and proteins), a constant was added to all values prior to log transformation. For servings of fruit and dairy, a constant of 1.0 was added, which anchored the minimum values of the distributions at 1.0, as has been recommended (Osborne 2002). However, the majority of children in both groups had less than one mean serving of vegetables, fats and sweets per day; hence a constant of 0.5 was added to these values (Yamamura 1999).

We compared demographic and anthropometric characteristics, dietary restrictions, intake of micronutrients, macronutrients, and servings of food groups between children with ASD and typical development using a student's t-test for continuous variables and a chi-square test (or Fisher's Exact test if appropriate) for binomial variables, with a two-sided alpha of 0.05. As sensitivity analyses, we compared food group servings after adding constants ranging from 0.1 to 10.0 prior to log transformation. Conclusions regarding the statistical significance of test results were not affected by changes in the constant (data not shown). We used chi-square tests to examine the adequacy of dietary intake in relation to DRIs between diagnostic groups.

We conducted a one-way analysis of covariance (ANCOVA) to evaluate the effect of parental dietary restrictions overall on between-group differences for each of the nutrients and food groups, including diagnosis as the independent variable and parent-restricted diet as the covariate. We evaluated the potentially confounding effects of age and sex using similar models.

In planned subgroup analyses, we investigated potential differences resulting from GFCF diet restrictions. We excluded children on the GFCF diet and compared intake of micronutrients, macronutrients, and servings of food groups between children with ASD and children with typical development using a student's *t*-test. Within the ASD group, we compared children on and off the GFCF diet. A student's *t*-test was conducted to identify differences in mean intake between groups.

Although multiple comparisons were employed, we chose not to adjust alpha values. As described by Perneger (1998), adjustments to alpha values increase the possibility of type II errors.

Results

Participants

Table 1 describes study participants. Subjects were comparable with regard to chronological age, ethnicity, and BMI. There were significantly more males and more children with dietary restrictions in the ASD group than in the typically developing group. In all but six cases with dietary restrictions, parents had restricted the children's diets. Among children with ASDs, two children (9.1%) in the 1–3 year age group were on the GFCF diet, while 12 children (37.5%) in the 4–8 year age group were on the GFCF diet. Within the ASD group, all children were diagnosed with autism except for one child with Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS).

Nutrient Analysis

Children with ASDs consumed significantly less calcium and more vitamin B_6 and vitamin E than did children with typical development (Table 2). The range in intake was wider among children with ASD than those with typical development for every nutrient except folate, tryptophan, and tyrosine.

Overall, children with ASDs ate significantly more servings of non-dairy proteins and significantly fewer servings of dairy than did children with typical development (Table 3). For every food group, the range in number of servings was wider for those with ASD than those with typical development. Subgroup analysis by age group demonstrated that the overall differences were largely due to group differences among 4–8 year olds. Children with ASDs in this age group ate significantly more servings of non-dairy proteins and fruit and significantly fewer servings of dairy than did children with typical development. Among the 22 children aged 1–3 years old, children with ASDs similarly ate more non-dairy protein servings and fewer dairy servings than did typically developing children, but differences were smaller and not statistically significant.

Adjustment for age and sex did not substantively affect the significant mean differences between groups in intake of calcium, vitamin E, servings of non-dairy protein, or servings of dairy (data not shown). However, the difference between groups in vitamin B_6 intake was smaller and no longer statistically significant after taking into account group differences in age or sex.

Adjustment for parental dietary restrictions did not substantively affect the significant mean differences

Table 1 Description of participants

	ASD ($n = 46$)	Typical ($n = 31$)
Male sex, *n* (%)	44 (95.7)	23 (74.2)*
Mean age (months) (*SD*)	55.9 (13.9)	59.9 (16.5)
Range	33.0–96.0	30.0–93.0
Race/ethnicity, *n* (%)		
Caucasian	33 (71.7)	26 (83.9)
Hispanic	6 (13.0)	2 (6.5)
African American	2 (4.3)	0 (0.0)
Asian	1 (2.2)	0 (0.0)
Bi-racial	1 (2.2)	2 (6.5)
Unknown	3 (6.5)	1 (3.2)
Mean full IQ (*SD*)[a]	67.1 (29.6)	–
Range	24.0–145.0	–
Mean BMI (*SD*)	16.4 (2.0)	15.8 (1.5)
Range	13.2–23.6	13.1–21.0
Mean BMI *Z*-Score (*SD*)	0.42 (1.23)	0.11 (1.14)
Range	−2.71–3.46	−2.90–3.24
BMI Percentile		
<5th	2 (4.7)	3 (9.7)
5th–85th	30 (69.8)	24 (77.4)
85th–95th	7 (16.3)	3 (9.7)
>95th	4 (8.7)	1 (3.2)
Diet restriction, *n* (%)	27 (64.3)	4 (12.9)**
Reason for restriction, *n* (%)[b]		
Allergy	8 (19.0)	3 (75.0)
Behavioral	9 (21.4)	0 (0.0)
Bowel problems	6 (14.3)	0 (0.0)
Child preference	6 (14.3)	1 (25.0)
Other	7 (16.7)	0 (0.0)
Unspecified	4 (9.5)	0 (0.0)
Gluten/Casein free diet, *n* (%)	14 (31.1)	0 (0.0)**

* Diagnostic groups significantly different at $p = 0.012$

** Diagnostic groups significantly different at $p < 0.001$

[a] Children with ASD: $n = 26$ for mean IQ, $n = 43$ for BMI and BMI percentile, $n = 42$ for diet restriction and $n = 44$ for gluten/casein free diet

[b] Among children with a diet restriction. Some children had more than one restriction

Table 2 Nutrient analysis for ASD and typical groups and dietary reference intakes (DRI)

Nutrients	DRI (1–3 years/4–8 years)	ASD ($n = 46$) Mean (*SD*) Range	Typical ($n = 31$) Mean (*SD*) Range	Mean difference (95% CI)
Carbohydrate (g)	130 g/130 g	200.23 (60.17)	213.15 (51.76)	−12.92 (−39.29 to 13.44)
		86.23–367.57	108.53–351.70	
Energy (kcal)	800–1300 kcal/900–2500 kcal	1459.70 (391.37)	1508.74 (336.07)	−49.04 (−220.43 to 122.35)
		555.88–2651.82	974.38–2332.33	
Fat (g)	33–54 g/39–62 g	54.63 (21.58)	52.39 (15.72)	2.24 (−6.77 to 11.24)
		14.28–133.02	25.33–82.84	
Fiber (g)	19 g/25 g	11.66 (5.32)	10.75 (3.34)	0.91 (−1.23 to 3.06)
		3.44–28.77	5.04–17.74	
Protein (g)	13 g/19 g	49.60 (17.05)	52.83 (15.93)	−3.23 (−10.92 to 4.46)
		20.27–94.38	29.54–107.98	
Niacin (mg)	6 mg/8 mg	16.61 (7.56)	14.75 (5.14)	1.86 (−1.24 to 4.96)
		6.63–40.36	8.90–28.26	
Vitamin B_6 (mg)	0.5 mg/0.6 mg	1.53 (0.78)	1.23 (0.40)	0.30 (0.03–0.57)*
		0.53–3.81	0.72–2.50	
				Geometric mean ratio (95% CI)**
Calcium (mg)	500 mg/800 mg	746.52 (444.31)	894.08 (292.55)	0.72 (0.56–0.91)*
		110.79–2504.16	373.10–1583.57	
Folate (μg)	150 μg/200 μg	321.67 (163.25)	309.08 (174.95)	1.02 (0.83–1.26)
		127.28–771.99	107.61–1154.24	
Iron (mg)	7 mg/10 mg	11.38 (6.60)	10.90 (4.13)	1.00 (0.83–1.20)
		5.80–39.16	4.74–26.50	
Tryptophan (g)	–	0.59 (0.22)	0.66 (0.21)	0.89 (0.76–1.02)
		0.23–1.14	0.37–1.34	
Tyrosine (g)	–	1.77 (0.67)	2.04 (0.66)	0.85 (0.72–1.00)
		0.63–3.80	1.10–4.27	
Vitamin A (IU)	693 IU/907.5 IU	5049.80 (5762.21)	4679.41 (3371.85)	0.88 (0.59–1.29)
		298.20–27745.92	1013.77–16967.20	
Vitamin C (mg)	15 mg/25 mg	74.01 (49.79)	58.24 (32.33)	1.12 (0.85–1.49)
		11.44–200.65	24.69–187.16	
Vitamin D (μg)	5 μg/5 μg	4.85 (4.58)	4.89 (2.45)	0.73 (0.50–1.07)
		0.23–23.06	0.96–11.34	
Vitamin E (mg)	6 mg/7 mg	7.95 (6.37)	4.44 (1.83)	1.48 (1.17–1.91)*
		0.95–31.22	1.87–9.93	
Zinc (mg)	3 mg/5 mg	7.93 (4.97)	7.71 (2.92)	0.97 (0.80–1.17)
		1.69–29.89	3.00–15.44	

* Difference significant *at* $p < .05$

** Geometric ratios and 95% confidence intervals are shown for all log transformed nutrients. A ratio of 1.0 indicates no difference between groups. A ratio <1.0 indicates reduced intake in children with ASD relative to typical children and a ratio greater than 1.0 indicates greater intake in children with ASD relative to typical children

between groups in intake of vitamin B_6, servings of non-dairy protein, and servings of dairy (data not shown). However, the differences between groups in intake of calcium and vitamin E were smaller and no longer statistically significant after taking into account group differences in parental dietary restrictions.

As shown in Table 4, both groups had similar distributions of intakes above and below the DRI cutoff for each

Table 3 Food group analysis for ASD and typical development groups overall and by age group

	ASD Number servings Mean (*SD*) Range	Typical development Number servings Mean (*SD*) Range	Geometric mean ratio (95% CI)[a]
Overall	$n = 46$	$n = 31$	
Fruits	2.30 (1.36)	1.82 (1.18)	1.15 (0.94–1.40)
	0.00–5.80	0.30–4.77	
Grains	3.39 (1.68)	3.55 (1.23)	0.89 (0.73–1.08)
	0.71–8.57	1.61–7.09	
Proteins	2.60 (1.63)	1.72 (0.90)	1.46 (1.03–2.06)*
	0.18–6.36	0.13–3.36	
Dairy	2.18 (2.12)	3.42 (1.84)	0.63 (0.50–0.80)*
	0.00–10.50	1.08–9.77	
Fats and oils	0.92 (1.02)	0.92 (0.82)	0.91 (0.69–1.18)
	0.00–4.41	0.00–4.11	
Vegetables	1.35 (2.13)	1.10 (0.75)	0.87 (0.65–1.17)
	0.00–9.56	0.00–3.36	
Sweets	1.60 (1.68)	1.74 (1.69)	0.92 (0.69–1.23)
	0.00–9.51	0.00–8.82	
Age group 4–8	$n = 32$	$n = 23$	
Fruits	2.49 (1.27)	1.55 (0.79)	1.34 (1.11–1.62)*
	0.87–5.80	0.32–3.11	
Grains	3.61 (1.80)	3.55 (1.27)	0.93 (0.73–1.20)
	0.71–8.57	1.61–7.09	
Proteins	2.97 (1.56)	1.84 (0.81)	1.57 (1.12–2.18)*
	0.42–6.08	0.28–3.10	
Dairy	2.09 (1.82)	3.35 (1.78)	0.63 (0.48–0.82)*
	0.00–5.83	1.37–9.77	
Fats and oils	1.14 (1.10)	0.91 (0.62)	1.04 (0.76–1.41)
	0.00–4.41	0.00–2.12	
Vegetables	1.43 (2.12)	1.16 (0.76)	0.87 (0.62–1.23)
	0.00–9.56	0.21–3.36	
Sweets	1.56 (1.32)	1.86 (1.87)	0.90 (0.64–1.27)
	0.00–4.99	0.00–8.82	
Age group 1–3	$n = 14$	$n = 8$	
Fruits	1.86 (1.48)	2.61 (1.73)	0.77 (0.46–1.31)
	0.00–5.02	0.30–4.77	
Grains	2.91 (1.29)	3.56 (1.18)	0.79 (0.56–1.12)
	1.58–6.21	2.10–5.82	
Proteins	1.75 (1.49)	1.39 (1.09)	1.34 (0.57–3.13)
	0.18–6.36	0.13–3.36	
Dairy	2.40 (2.75)	3.61 (2.14)	0.63 (0.34–1.16)
	0.00–10.50	1.08–7.69	
Fats and oils	0.43 (0.57)	0.95 (1.30)	0.67 (0.40–1.14)
	0.00–1.78	0.19–4.11	
Vegetables	1.17 (2.23)	0.90 (0.73)	0.89 (0.44–1.79)
	0.00–8.37	0.00–1.79	
Sweets	1.71 (2.38)	1.38 (1.07)	0.99 (0.55–1.79)
	0.20–9.51	0.39–3.51	

[a] No constant was added to all values for Grains and Proteins. For Dairy and Fruit a constant of 1.0 was added to all values, and for Fats, Vegetables, and Sweets a constant of 0.5 was added to all values

* Difference significant at $p < .01$

Table 4 Dietary intakes for ASD and typical development groups in relation to dietary reference intake (DRI) recommendations and tolerable upper (TOL U) levels

	ASD ($n = 46$) *n* (%)	Typical ($n = 31$) *n* (%)
Carbohydrates		
Meets DRI[a]	41 (89.1)	30 (96.8)
<100% DRI	5 (10.9)	1 (3.2)
Energy		
Meets DRI	45 (97.8)	31 (100.0)
<100% DRI	1 (2.2)	0 (0.0)
Fat		
Meets DRI	39 (84.8)	25 (80.6)
<100% DRI	7 (15.2)	6 (19.4)
Fiber		
Meets DRI	3 (6.5)	0 (0.0)
<100% DRI	43 (93.5)	31 (100.0)
Protein		
Meets DRI	46 (100.0)	31 (100.0)
<100% DRI	0 (0.0)	0 (0.0)
Calcium		
>TOL U Level	0 (0.0)	0 (0.0)
Meets DRI	26 (56.5)	22 (71.0)
<100% DRI	20 (43.5)	9 (29.0)
Folate		
>TOL U Level	0 (0.0)	0 (0.0)
Meets DRI	40 (87.0)	28 (90.3)
<100% DRI	6 (13.0)	3 (9.7)
Iron		
>TOL U Level	0 (0.0)	0 (0.0)
Meets DRI	24 (52.2)	19 (61.3)
<100% DRI	22 (47.8)	12 (38.7)
Niacin		
>TOL U Level	18 (39.1)	7 (22.6)
Meets DRI	27 (58.7)	24 (77.4)
<100% DRI	1 (2.2)	0 (0.0)
Vitamin A		
>TOL U Level	25 (54.3)	20 (64.5)
Meets DRI	19 (41.3)	11 (35.5)
<100% DRI	2 (4.3)	0 (0.0)
Vitamin B_6		
>TOL U Level	0 (0.0)	0 (0.0)
Meets DRI	46 (100.0)	31 (100.0)
<100% DRI	0 (0.0)	0 (0.0)
Vitamin C		
>TOL U Level	0 (0.0)	0 (0.0)
Meets DRI	41 (89.1)	30 (96.8)
<100% DRI	5 (10.9)	1 (3.2)
Vitamin D		
>TOL U Level	0 (0.0)	0 (0.0)
Meets DRI	15 (32.6)	14 (45.2)
<100% DRI	31 (67.4)	17 (54.8)
Vitamin E*		
>TOL U Level	0 (0.0)	0 (0.0)
Meets DRI	19 (41.3)	3 (9.7)*
<100% DRI	27 (58.7)	28 (90.3)
Zinc		
>TOL U Level	4 (8.7)	3 (9.7)
Meets DRI	36 (78.3)	26 (83.9)
<100% DRI	6 (13.0)	2 (6.5)

[a] "Meets DRI" refers to average intakes of at least 100% of the dietary reference intake and less than the tolerable upper level. Tolerable upper levels were not available for macronutrients

* Difference significant at $p = 0.004$

nutrient except for vitamin E. Children with ASD were significantly more likely to consume the recommended intake of vitamin E than were children with typical development. In both diagnostic groups, substantial proportions of children consumed less than the DRI of fiber, calcium, iron, vitamin D and vitamin E. A large percentage of children from both diagnostic groups consumed more than the tolerable upper level for vitamin A. About 10% of the total vitamin A intake was preformed vitamin A.

Subgroup Analyses

After excluding children on the GFCF diet, children with ASD consumed fewer servings of dairy (geometric mean ratio [GMR]: 0.69; 95% CI: 0.52–0.92) and more servings of non-diary protein (GMR: 1.41; 95% CI: 0.99–2.02) than did typical children, although the latter difference was no longer statistically significant. Significantly higher vitamin B_6 intake persisted (mean difference: +0.39; 95% CI: 0.02–0.76), while differences in intake of vitamin E (GMR: 1.24; 95% CI: 0.92–1.67) and calcium (GMR: 0.79; 95% CI: 0.59–1.05), were smaller and no longer significantly different.

Among children with ASDs, those on the GFCF diet consumed significantly more vitamin E than did those not on the diet (GMR: 1.90; 95% CI: 1.24–2.93). No other statistically significant differences between these two groups were identified.

Discussion

Nutrient Analysis

Although we hypothesized that children with ASDs would consume fewer macro- and micronutrients than would children with typical development, we found this to be true only for calcium. In contrast to our hypothesis, the ASD group consumed significantly more vitamin B_6 and vitamin E than did the typically developing group. The difference in vitamin B_6 intake between groups was independent of group differences in parental dietary restrictions, age, and sex. However, the differences between groups in vitamin E and calcium intake appeared to be driven by group differences in parental dietary restrictions, primarily from GFCF dietary restrictions among children with ASD. The diagnostic groups did not differ with regard to any other micronutrients or any macronutrients. Although children with ASDs and typical development had similar mean intakes of most macro- and micro-nutrients regardless of parental dietary restrictions, it is notable that the range of intakes was wider among children with ASDs, more of whom had intakes on the extreme ends of the range.

We also predicted that children with ASDs would consume fewer servings from some food groups than children with typical development. We did find that children with ASDs consumed fewer servings from the dairy food group, and more from the non-dairy protein food group, than did children with typical development. Differences in servings of dairy and non-dairy protein remained after excluding children on the GFCF diet, although the difference in servings of non-dairy protein was no longer statistically significant due to a smaller sample size. The difference in servings of non-dairy protein might seem unexpected given that the groups were not statistically different with regard to their mean intake of protein. The inconsistency may be due to the method of food group categorization, where foods were placed into their primary food group (e.g., milk and cheese constituted the dairy and not the protein food group). Children with typical development may have consumed more protein from dairy products, making up for their lower protein intake from foods in the non-dairy protein food group.

Differences between the study groups in the intake of food group servings were greater among children aged 4–8 than those aged 1–3. Children aged 4–8 may be more selective about foods they eat, and parents may have less control over eating habits as their child ages. The 4–8 year age group also contained a higher percentage of children on the GFCF diet. Symptoms in children with ASDs typically become more noticeable as they become older (e.g., Newschaffer et al. 2007), and one such symptom, the need for sameness, might play a role in the food intake differences seen in the older age group. In contrast, children aged 1–3 may be more apt to eat foods presented to them or parents may choose to present less varied foods to younger children. Younger children in general may be less willing to accept a varied diet, and maturational changes that produce more willingness to vary one's diet may occur less often or later among children with ASDs.

Two previous studies compared nutritional intake in children with ASDs versus children with typical development. Both studies are more than 20 years old. Because ASD diagnoses have shifted over time, comparisons to our results should be made judiciously. Shearer et al. (1982) found that children with autism consumed significantly less calcium than children with typical development, a trend that was mirrored in our sample. Raiten and Massaro (1986) found that sex and age differences between groups accounted for significant differences between children with autism and children with typical development for intake of energy, protein, carbohydrates, niacin, and iron (as well as other nutrients we did not examine). We did not find differences in these nutrients, whether or not we adjusted for group differences in age or sex.

Like us, Shearer et al. (1982) found that children with autism consumed fewer servings from the dairy food group, though this difference was smaller and not statistically significant in their study. At the time of Shearer's study, the GFCF diet was not widely used and enrolled children were unlikely to have been on the diet. It is likely that the greater difference in dairy consumption that we saw was due in part to the greater proportion of children with ASDs on the GFCF diet. Excluding children on the GFCF diet did not eliminate this difference, however, indicating that the GFCF diet did not account entirely for the difference between groups in dairy consumption. In addition, the children included in Shearer et al. were aged 7–9 years; hence our results among a much younger sample may not be directly comparable.

As described previously, Schreck et al. (2004) used a food preference inventory to determine whether parents of autistic or typical children believed their child would eat servings of foods from specific food groups. The authors found that children with autism ate significantly fewer servings from each of five food groups (fruits, dairy, vegetables, non-dairy proteins, and starches), a pattern not reflected by our participants. In contrast, children with ASDs in our study consumed more fruits and non-dairy proteins than typically developing children. Although they did consume fewer servings of grains and vegetables, the differences were small and not statistically significant. The only similarity between studies was the dairy food group, where children with ASDs consumed significantly fewer servings of dairy in both studies.

Our secondary hypothesis was that children with ASDs would meet national daily recommended intake less often than children with typical development. Interestingly, both groups met recommendations similarly across nutrients, except for vitamin E. Children with ASDs met vitamin E recommendations more often, though a large proportion of both groups still failed to meet the DRI. Both diagnostic groups had adequate intakes for all nutrients except for fiber, calcium, iron, vitamin E, and vitamin D, where large proportions of both groups fell below the DRI cutoff. This trend in deficiencies in both groups has been mirrored in previous research looking nationally at dietary intakes by children. Children in the United States tend to have intakes below recommendations for fiber (Kranz et al. 2006), calcium (Briefel and Johnson 2004; Suitor and Gleason 2002), vitamin E (Suitor and Gleason 2002), and vitamin D (Moore et al. 2004). A large percentage of our sample fell below the DRI for iron, however, which was not reflected by previous national studies of dietary intake (Briefel and Johnson 2004; Suitor and Gleason 2002), although inadequate dietary iron intake has been reported in children with autism (Dosman et al. 2007). While a large number of children fell above the tolerable upper level for vitamin A intake, only a small percentage of the vitamin A consumed was preformed and thus the quantity of vitamin A consumed was not likely to be toxic.

The USDA publishes recommendations for servings from each food group by age group. Daily recommendations are similar for age groups 1–3 and 4–8 years, where it is recommended that children consume 5–12 servings of grains, 5–10 servings of fruits and vegetables, 2–3 servings of non-dairy proteins, and 4 servings of milk products for 1–3 year olds and 2–4 servings for 4–8 year olds. Our sample of 1–3 year olds on average consumed fewer servings than is recommended for each of the food groups. Children aged 4–8 years met recommendations only for dairy and non-dairy protein, where both diagnostic groups consumed adequate amounts of dairy, and the ASD group consumed adequate amounts of non-dairy proteins. Despite this, both groups generally met requirements for energy intake.

Ho and Eaves (1997) and Cornish (1998) compared nutritional intake in children with autism to nationally recommended intake values. The majority of children included in Ho and Eaves' study did not meet guidelines for at least one of their specified nutrients. Approximately half of the children included in Cornish's study had lower calcium, iron, niacin, vitamin B6, vitamin C, vitamin D and zinc, which was not reflected in our sample except in the case of vitamin D. While our sample of children with ASDs had more children with parent-imposed dietary restrictions than without, it is possible that such parents are more aware of the foods their children consume and make efforts to assure that their children meet dietary recommendations.

Limitations of the Study

Our study was limited by small sample size, which reduced our power to identify differences between groups. For example, to detect the two-fold differences observed between groups in meeting recommended dietary intake of calcium, niacin, and vitamin D, we would have required a sample 3–4 times larger. On the other hand, our study was sufficiently powered to detect significant differences in the intake of a number of other micronutrients and food groups.

There are limitations inherent to use of diet diaries for food intake assessment, such as misreporting the foods consumed. There are also limitations inherent to using a nutrient database, for example, some of the nutrients in food are estimated due to inadequate manufacturer's information. It is also possible that three-day diaries were not adequate to represent overall intake in the present sample, especially for nutrients with large day-to-day variability, such as vitamin A. However, diet diaries are standard practice and, while less accurate than methods involving direct observation, are used often in nutritional research and are more accurate than historical recall and food frequency questionnaires (e.g., Barrett-Connor 1991).

The long time-span of the study may have introduced issues of seasonality, where certain foods are more likely to be consumed at certain times of the year. In addition, examining mean nutritional intake may obscure variation. The range in intake was much wider for children with ASDs than children with typical development, though this variation was hidden when means were compared.

We excluded children whose parents did not complete the diet diary, which limits the generalizability of our results. The children of the more motivated parents who completed the diet diary may differ in the types and amounts of foods they eat compared to children whose parents failed to complete the diary. However, this bias is unlikely to have affected our analysis of group differences, since both groups were comprised of those with completed diaries.

Conclusions

Overall we found few differences in average nutrient intake between children with ASDs and children with typical development, although the range of intake was generally wider in children with ASDs. We did find important differences between groups in intake of vitamin B_6, and servings of non-dairy protein and dairy foods that could not be explained by differences in parental dietary restrictions, age, or sex, and differences in vitamin E and calcium intake that were attributable to parental restrictions on dietary intake. Differences between groups appeared to be at least partially attributable to parent implementation of the GFCF diet, since all differences were smaller and in most cases no longer statistically significant, when children on the GFCF diet were excluded. The small sample size may have prevented our detection of other differences and future research is needed to determine whether more differences exist. Using 3-day diet records at several time points with a larger sample would help with day-to-day variability in nutrients and issues with seasonality. In addition, a comparison group of children with developmental disabilities would provide useful information. Pediatricians and parents of children with ASDs, especially children with dietary restrictions, need to be aware of the potential for nutritional deficiencies.

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