J Autism Dev Disord (2015) 45:203–212
DOI 10.1007/s10803-014-2205-8

ORIGINAL PAPER

Nutritional Status of Children with Autism Spectrum Disorders (ASDs): A Case–Control Study

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Published online: 7 September 2014

Abstract Children with autism spectrum disorder (ASD) have problems of food selectivity, implying risks of nutritional deficiencies. The aim was to compare intakes of macro and micronutrients and body mass index in ASD and typically developing (TD) children. In a case–control study, 3-day food diaries and anthropometric measurements were completed for ASD (n = 40) and TD (n = 113) children (aged 6–10 years) living in the same area. Body mass indices were below the 5th percentile in 20 % of ASD versus 8.85 % of TD children. We found intakes were lower for fluoride ($p = 0.017$) and higher for vitamin E ($p = 0.001$). There was limited food variety and inadequacy of some intakes suggests that routine monitoring of ASD children should include assessment of their dietary habits, as well as anthropometric measurements.

Keywords Feeding assessment · Selective eating · Autism · ASD (autism spectrum disorder) · Feeding disorders · Mealtime problems

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Introduction

Autism spectrum disorder (ASD) is a neurodevelopment disability characterized by lack of social and emotional reciprocity, limited verbal and non-verbal language skills and the presence of stereotyped and repetitive behaviors. The prevalence of autism has been increasing in recent decades and is now regarded as a relatively common neurodevelopmental disorder. Estimates based on data for 2008 suggest that the rate has increased to 11.3 per 1,000 people (CDC 2012) (1 in 88), with a male to female ratio of 4:1. On the other hand, no differences have been detected as a function of socioeconomic or cultural background (Baghdadli 2005). Parents of children with ASD commonly report feeding problems including food refusal, limited dietary intake, and behavior problems at mealtimes, with many studies over the years backing these parental concerns (Raiten and Massaro 1986; Clark et al. 1993; Cornish 1998; Klein and Nowak 1999; Whiteley et al. 2000; Ahearn et al. 2001; Ahearn 2003; Najdowsky et al. 2003; Buckley et al. 2005; Luiselli et al. 2005; Martins et al. 2008; Johnson et al. 2008; Cermak et al. 2010; Emond et al. 2010; Bandini et al. 2010; Evans et al. 2012; Maskey et al. 2012; Zimmer et al. 2012).

While in some cases there is an identifiable organic etiology such as abnormal sensory processing (Twachman-Reilly et al. 2008); oromotor difficulties (Matson et al. 2011); or gastrointestinal problems including constipation, diarrhea, stomach bloating or gastroesophageal reflux (Coury et al. 2012); in others, it seems reasonable to accept that food selectivity is a manifestation of the restricted interests and behavioral rigidity (Ledford and Gast 2006) that are characteristic of ASD. In particular, this applies to aversions or preferences for certain foods over others on the basis of texture, color, taste, shape, temperature and even the type of utensils, shape and color of packaging, layout and presentation of dishes (Schmitt et al. 2008). The combination of organic problems and problematic eating behaviors might be associated with a greater risk of nutritional inadequacy among children with ASD (Schreck et al. 2004; Twachman-Reilly et al. 2008). In turn, this may lead to overweight/obesity or underweight. What is more, interventions related to food intake may exacerbate eating problems (Francis 2005): that is, there may be a contradiction between efforts to encourage social integration and the imposition of special diets (Sponheim 1991).

In a classic study, the nutritional assessment of children with ASD found the overall adequacy of intake to be similar to that in controls (Raiten and Massaro 1986). Since then, many authors have reached similar conclusions (Levy et al. 2007; Lockner et al. 2008; Schmitt el al. 2008; Zimmer et al. 2012). These findings suggest that children's energy and macronutrient requirements tend to be satisfied despite food selectivity. Other authors, however, refer to inadequate intakes of certain nutrients. For instance, Ho et al. (1997), Cornish (2002), Johnson et al. (2008), Herndon et al. (2009), Xia et al. (2010), Bandini et al. (2010), Emond et al. (2010), and Hyman et al. (2012) have reported insufficient intake of at least one of the following: fiber, calcium, zinc, phosphorous, iron, or vitamins A, C, E, K, B_6, B_{12}, D or folate. Overall, results so far are very mixed.

Therefore, the specific aims of this study were to investigate the nutritional status of children diagnosed with ASD, using three-day food diaries (including one non-working day). We compared children with ASD with typically developing (TD) children and data for each group with the Acceptable Macronutrient Distribution Ranges (AMDRs), and Estimated Average Requirements (EARs) proposed for the Spanish population by the Spanish Society for Community Nutrition (SENC 2011) and the Spanish Federation of Nutrition, Food and Dietetics Societies (FESNAD 2010). We hypothesized that children with ASD would have: (1) different anthropometric measures to those of TD children; (2) intakes that differed from the nutritional recommendations for the Spanish population; and (3) Healthy Eating Index scores that were significantly different to those of TD children.

Methods

Participants

This was an observational case–control study of nutritional factors in ASD and TD children. The children's diagnoses of an ASD were based on: the Autism Diagnostic Observation Schedule-Generic (ADOS-G) (Le Couteur et al. 2008); the Autism Diagnostic Interview-Revised (ADI-R) (Lord et al. 1994); and the clinical opinion of an experienced clinical psychologist. We considered only the diagnosis, not the severity of the disorder. The ASD children (cases) were recruited from a special school for disabled children in Valencia, Spain (run by the Autism Project Association and the Mirám Foundation). Invitations to participate in the study were sent by mail to candidate families, and responders were screened for eligibility by telephone and appointments scheduled for an assessment for the study. Those who did not respond to the mailing were invited to participate by telephone and then, if they agreed and met the eligibility criteria, were given an appointment. A total of 40 children (35 boys and 5 girls) agreed to enroll on the study. Notably, as the prevalence of ASD is higher in boys than in girls, there are fewer girls with these disorders at the school.

The results are compared to a matched group of 113 TD children (63 boys and 50 girls) that were identified as eligible controls for this study. These were recruited in Colegio San Cristobal de Picassent (Valencia, Spain), an elementary school in the same area as the special school attended by those in the case group. This school was recommended by the staff of the local education board as having children with similar socioeconomic backgrounds to those attending the special school for ASD children. Among the local education board staff there are clinical psychologists who routinely assess all children attending the school, not ruling out, but reducing the risk of the control group including children with high-functioning ASD.

Before we started the study, we explained the tests that would be carried out to the parents of all the children involved, including that data collected would be kept confidential in line with Spanish data protection regulations, and obtained their informed consent. This was obtained from the parents of each participant (or whichever parent accompanied the child) at the time of the visit. In addition, the study was approved by the Ethics Committee of Dr Peset Hospital in Valencia. The study was carried out during the second half of 2012.

Inclusion and Exclusion Criteria

In both groups, the following inclusion criteria were applied: the child had to be between 6 and 9 years old, and parents or legal guardians had to agree to the participation of the child and give written informed consent. Exclusion criteria included use of dietary supplements or application of dietary restrictions including the gluten-free, casein-free diet (GFCF); the diagnosis of a genetic syndrome known to be associated with ASD (e.g., Fragile X syndrome) or of any conditions (endocrine or metabolic diseases, among others) that might affect the child's intake or use of nutrients; and the taking of any drugs that could modify food intake, use or requirements, or in other ways interfere in the study results; as well as failure to attend the appointments made in the center to conduct the interviews and not properly completing the nutritional record.

Data Collection

Examination Protocol and Measurements

At the visit, parents of both groups were interviewed using a questionnaire to elicit information on their child's age, birth history, medical history, use of over-the-counter and prescription medications, use of vitamin and mineral supplements, and any special dietary restrictions, food allergies, or food selectivity (including food refusal, a limited repertoire of accepted foods, and high-frequency single food intake). At the same time, we explained to the parents/main caregivers in detail how to assess food and drinks consumed by the child and they were asked to record estimated portion sizes for each item ingested. A visual guide was provided to improve the accuracy of portion size estimates. Parents were asked to submit food labels with ingredients, brands, added ingredients and the recipes for homemade dishes where possible. In addition, they were given a telephone number for information and support, which they could call to help resolve any issues that arose while completing the diary. In the event of missing or incomplete data, researchers contacted the parents.

Body Mass Index (BMI)

At time of the visit, height and weight of each of the participants (both ASD and TD children) were recorded by the principal investigator himself, a registered dietitian. Height (in centimeters) and weight (in kilograms) were measured using standard anthropometric techniques (World Health Organization 1996) with a Seca 213® stadiometer (height) and Seca 813® scales (weight). All anthropometric measurements were obtained in duplicate and averaged. BMI (kg/m2) values were calculated from height and weight measurements. Based on the percentile ranking obtained, BMI was used to classify children into one of the following four categories (CDC 2000): underweight ($\leq$5th percentile), healthy (>5th to <85th percentiles), overweight ($\geq$85th to <95th percentiles), or obese ($\geq$95th percentile).

Dietary Intake

To carry out the dietary survey, parents were given a form on which they had to record all the foods and drinks consumed by their child over a three-day period, including one non-working day. This type of three-day food diary is currently considered the *gold standard* among methods for assessing diet (Barret-Connors 1991; Institute of Medicine 2000). The records of foods consumed were then used to calculate intakes of calories, and of macro and micronutrients, using a computer program (DIAL®) for the assessment of diets and management of nutritional data, developed by the Department of Nutrition and Dietetics, Complutense University of Madrid. This open software includes a list of some of the enriched/fortified foods commonly available in Spain. It is possible for foods to be added to the database and, in this way, we were able to include the nutritional composition of packaged foods taken from food labels. Nutritional data obtained were compared with Spanish food composition tables (Mataix Verdú2003; Moreiras 2011). The DIAL program also facilitates the calculation of the Health Eating Index (HEI) (Kennedy et al. 1995). This instrument is composed of ten items: five concern intakes of key foods, cereals, fruit, vegetables, dairy products and meat-fish-eggs; and five concern adherence to nutritional recommendations (intake of total fats, saturated fats, cholesterol and salt, and food variety).

Estimate of Nutrient Adequacy/Deficiency

The DRIs include values for the Recommended Dietary Allowance (RDA), the Estimated Average Requirement (EAR), the Adequate Intake (AI), and the Tolerable Upper Intake Level (UL), as well as the Estimated Energy Requirement (EER) for energy, and AMDR for macronutrients (IOM 2000; Murphy and Barr 2011).

For each nutrient, the children were categorized as at risk of inadequate intake based on whether (or not) they met the corresponding nutritional targets (SENC 2011) and RDIs (FESNAD 2010) proposed for the Spanish population. In addition, comparisons were made with the RDIs in use in the USA to explore possible differences. Specifically, we used EARs for micronutrients when available, adopting AI values for nutrients for which EARs have not be determined (fiber, fluoride, manganese, sodium, potassium vitamin K and pantothenic acid). The percentage of energy provided by protein, fat and carbohydrate was also calculated and compared with the AMDRs.

Using the data on the food consumed, we made nutritional assessments of the following intakes: total energy (calories); carbohydrates; lipids; proteins; fiber; vitamins A, $B_{6,}$ B_{12}, C, D, E and K, folate, niacin, thiamin, riboflavin, biotin, and pantothenic acid; and minerals, calcium, iron, zinc, iodine, phosphorus and fluoride.

Statistical Analysis

Measures of central tendency (mean), dispersion (SD) and range were calculated for the demographic data. We compared ASD and TD children in four categories, underweight, healthy, overweight, and obese, applying Bonferroni corrections to control for multiple comparisons.

Using the Student́s *t* test, we made comparisons of nutritional intake (continuous variables) with an independent categorical variable (ASD/TD status). The normality of the data was confirmed with a non-parametric statistical test (Shapiro–Wilk). Further, for dichotomous categorical variables, we compared the adequacy of the diet of the children in the two groups with respect to the recommended intakes (recommendations met, not at risk vs. not met, at risk) by constructing contingency tables, calculating odds ratios and using the χ^2 test (or Fisher exact test, as appropriate) to assess statistical significance. The intake distributions of nutrients were adjusted for day-to-day variation by statistical modeling (the National Research Council method as extended by researchers at Iowa State University). This procedure was employed to ensure that the data reflected the usual intake. In addition, the EAR cut-off point method was used to assess the prevalence of the inadequacy in the intake of nutrients for which requirements are symmetrically distributed around the mean (IOM 2003; Lauzon et al. 2004). All statistical tests were two-tailed and alpha was set at 0.05. The analysis was not stratified by sex, the sub-group of girls being too small to have statistical power; on the other hand, the dietary recommendations are the same for boys and girls in this age group.

Data were entered into an Excel spreadsheet, using double-data entry to minimize the risk of errors, and then transferred to SPSS® (Statistical Package for Social Sciences) v19 for the statistical analysis.

Results

Anthropometric Measurements

Table 1 summarizes the baseline characteristics (age, weight, height, BMI) of the two groups, ASD and TD children. We found statistically significant differences ($p < 0.01$) in BMI, but not in age ($p = 0.19$).

Table 2 reports percentiles BMI for each group, using the values for the controls as a point of reference. We found that the BMI distribution was shifted to the left among children with ASD compared to TD children, that is, the cases had lower BMI than the controls, and the difference was statistically significant ($p = 0.02$).

Analysis of Nutrients

Mean Healthy Eating Index scores were similar in ASD and TD children (mean ± SD: 65.34 ± 10.75 vs. 66.10 ± 10.58; $p = 0.70$), classifying the children's diets as "needs to be improved" in both cases. On the other hand, individual scores indicated that 4 (10 %) ASD and 7 (6 %) TD children had poor diets [$\chi^2 = 0.64$; $p = 0.42$]. For food variety, scores were 3.38 ± 2.34 and 3.40 ± 2.19 ($p = 0.96$), respectively.

Table 3 summarizes the results of the nutrient analysis. As compared to TD children, children with ASD had consumed significantly less fluoride ($p = 0.02$) and more vitamin E (p = 0.001), results which are compatible with a low intake of fish, a source of fluoride, and high intake of sunflower and corn oil, both rich in Vitamin E (data not shown).

Table 4 presents the intakes of the two groups of children compared to the RDIs. The ORs show that the children with ASD had a 5.55-fold higher risk of failing to meet recommendations for calcium than TD children, their risk being 3.28–fold higher for proteins, 3.28-fold higher for vitamin C, and 5.24–fold higher iron. In addition, we can observe that: (a) inadequately low intakes of carbohydrates and fiber, with excessive intakes of lipids and cholesterol were common in both groups, the proportion failing to meet recommendations being higher among TD children; (b) most TD children consumed less than the recommended amount of vitamin E; and (c) inadequate intakes of calcium, vitamins C and D, and iron was more frequent in ASD than TD children. With respect to the other nutrients considered, no statistically significant differences were found between the groups comparing RDIs, and the distribution of intakes was similar. When these comparisons were made considering the RDIs for the USA (Institute of Medicine IOM 2010), and we found similar levels of inadequate intake, except for carbohydrates (AMDR in Spain 50–55 vs. 45–65 % in USA) and iodine (EAR: 120 mcg vs. 65 mcg, respectively) (data not shown).

Table 5 summarizes the number of nutrients for which intake was inadequate in the two groups of children according to the DRIs. None of the differences between the groups were statistically significant.

Table 1 Baseline characteristics for the ASD and TD children

	ASD children, sex (%) mean ± SD (n = 40)	Range	TD children, sex (%) mean ± SD (n = 113)	Range	p^a
Girls	5 (13 %)		50 (44 %)		0.01
Boys	35 (87 %)		63 (56 %)		
Age (years)	7.01 ± 1.01	6.01–9.75	8.34 ± 1.19	6.08–9.99	0.19
BMI (kg/m^2)	15.85 ± 2.07	13.00–22.00	18.46 ± 3.40	13.00–28.00	<0.01

ASD autism spectrum disorder, *TD* typically developing

[a] Statistically significant differences at $p < 0.05$

Table 2 Distribution of BMI percentiles in ASD and TD children

Diagnosis	Body mass and index percentile			
	Underweight (≤5th)	Healthy weight (>5th–85th)	Overweight (≥85th–<95th)	Obese (≥95th)
Total, n (BMI, kg/m2)[a]				
ASD children (cases)	8 (20 %)	28 (70 %)	4 (10 %)	0 (0 %)
TD children (controls)	10 (9 %)	55 (49 %)	31 (27 %)	17 (15 %)

BMI body mass index, *ASD* autism spectrum disorder, *TD* typically developing

[a] Overall Chi square p value = 0.024, df = 3

Discussion

The results should be viewed in the context of the fact that, given the pathophysiological and clinical characteristics of ASD, the two study groups (ASD and TD children) have similar nutritional requirements in terms of what can be considered a suitable diet (Schreck et al. 2004; Kranz et al. 2006; Alpert 2007; Keen 2008).

Our first hypothesis was that the anthropometric parameters would be statistically different in the two groups. We found that the BMI values were lower in ASD than TD children. Previous research has found very mixed results concerning height, weight and BMI in children with ASD (Zimmer et al. 2012; Ho et al. 1997; Emond et al. 2010; Hyman et al. 2012; Evans et al. 2012; Souza et al. 2012; Levy et al. 2007 Hediger et al. 2008; Moore et al. 2004).

We started with the second hypothesis that children with ASD would have significantly different intakes of macro and micronutrients to TD children. However, their intakes were only found to be lower for fluoride and higher for vitamin E. Most children in both groups (ASD and TD children) failed to meet recommendations for carbohydrates and fiber, with intakes lower than the RDIs, and for lipids and cholesterol, intakes these types of nutrients being excessive, particularly among TD children. On the other hand, inadequate intakes of vitamin D, calcium and iron were more frequent among ASD children than controls.

Research papers discussing nutrition among children with ASD have reported conflicting results on the extent of nutritional deficiencies in this population, but it has often been found that there are no or only small differences in macronutrient intake between ASD and TD children. In a classic study, Raiten and Massaro (1986) noted that their ASD group had significantly higher intakes of total energy, carbohydrates, and proteins, though not of fat. However, given that their study dates from more than 30 years ago and eating patterns have changed considerably over that time, caution should be exercised in making comparisons with new data. In contrast, some other studies (Hyman et al. 2012; Shearer et al. 1982) have found significantly lower intakes of total energy in ASD children. More recently, several studies (Emond et al. 2010; Johnson et al. 2008; Lockner et al. 2008) did not find any significant differences in nutritional intake (for instance, in total energy, proteins, carbohydrates and fats) compared to TD children, despite ASD children being reported to have more behavioral problems at meal times (Johnson et al. 2008).

Regarding vitamins, some early research suggested significantly higher intakes niacin, thiamin, and riboflavin in ASD children (Raiten and Massaro 1986). However, several studies have described lower intakes of vitamin A (Raiten and Massaro 1986; Hyman et al. 2012; Shearer et al. 1982), vitamin C (Emond et al. 2010; Hyman et al. 2012; Raiten and Massaro 1986; Shearer et al. 1982), vitamin D (Emond et al. 2010), and riboflavin (Hyman et al. 2012; Shearer et al. 1982). Raiten and Massaro's early study also found significantly higher intakes of calcium, phosphorus and iron (1986). However, other authors (Hyman et al. 2012; Shearer et al. 1982) found significantly lower intakes of calcium, zinc and phosphorus, but nevertheless concluded that ASD children consume similar amount of nutrients to controls.

With regards to recommendations, some previous studies (Zimmer et al. 2012) have observed low intakes of

Table 3 Comparison of actual average nutrient intake in ASD and TD children

Daily nutrient intake	ASD children (n = 40) Mean (DS)	TD children(n = 113) Mean (DS)	*p* value[a]
Macronutrients			
Energy (Kcal/d) EER	1938.70 (426.26)	1925.11 (369.96)	0.86
Carbohydrates (% TEV)	46.53 (6.64)	44.76 (4.51)	0.13
Total fats (% TEV)	37.19 (5.59)	38.62 (4.32)	0.15
Proteins (% TEV)	16.29 (4.54)	16.58 (2.35)	0.70
Cholesterol (mg/d)	263.93 (103.84)	296.65 (84.32)	0.05
Fiber (g/d)	17.64 (8.43)	15.08 (4.09)	0.07
Vitamins			
Folic acid (mcg/d)	214.68 (79.55)	195.84 (55.31)	0.17
Niacin (mg/d)	28.79 (8.26)	31.31 (7.38)	0.09
Vit. A (mcg/d)	889.53 (620.59)	792.27 (396.06)	0.36
Vit. B6 (mg/d)	1.81 (0.60)	1.88 (0.74)	0.55
Vit. C (mg/d)	86.49 (52.64)	81.44 (38.88)	0.58
Vit. D (mcg/d)	1.97 (1.51)	2.59 (2.42)	0.06
Vit. E (mg/d)	8.34 (4.35)	5.74 (1.79)	<0.01
Biotin (mcg/d)	26.74 (18.75)	23.14 (6.66)	0.24
Thiamin (mg/d)	1.20 (0.40)	1.28 (0.40)	0.27
Riboflavin(mg/d)	1.75 (0.64)	1.75 (0.49)	0.95
Vit B12 (mcg/d)	4.81 (3.74)	5.43 (3.26)	0.36
Vit K (mcg/d)	104.23 (51.69)	93.45 (45.39)	0.30
Panthothenic acid (mg/d)	4.63 (1.16)	4.78 (1.04)	0.47
Minerals			
Calcium (mg/d)	783.23 (359.30)	863.43 (244.90)	0.19
Iron (mg/d)	11.92 (4.38)	12.29 (3.35)	0.62
Zinc (mg/d)	8.57 (2.56)	8.98 (1.95)	0.35
Iodine (mcg/d)	77.43 (22.91)	84.67 (27.56)	0.11
Phosphorus (mg/d)	1,222.31 (316.34)	1,294.36 (262.35)	0.20
Fluoride (mcg/d)	186.13 (87.37)	224.77 (83.13)	0.02

ASD autism spectrum disorder, *TD* typically developing, *Vit* vitamin, *TEV* total energy value, *EER* estimated energy requirement

[a] Wilcoxon rank sum test, two-tailed alpha, $p < 0.05$

proteins, and others an imbalance of macronutrients with high lipid (Cornish 1998; Sousa et al. 2012) and protein (Cornish 1998; Sadowska and Cierebiej 2011) intakes. Nevertheless, some authors have noted adequate intakes for energy, fats, and proteins in most ASD children (Levy et al.2007; Xia et al. 2010). Further, several researchers (Herndon et al. 2009; Hyman et al. 2012; Kranz et al. 2006; Sadowska and Cierebiej 2011) have reported similar results to ours with low intakes of fiber, compared to the DRIs.

Our finding of vitamin D intakes being lower than nutritional recommendations is consistent with the findings of several studies over the last 15 years concerning vitamins (Cornish 1998; Hediger et al. 2008; Herndon et al. 2009; Hyman et al. 2012; Lindsay et al. 2006, Moore et al. 2004; Sadowska and Cierebiej 2011; Zimmer et al. 2012). We found a small proportion of children with ASD failing to meet recommendations on vitamin E intake, while previous studies (Herndon et al. 2009; Suitor and Gleason 2002) have found lower than recommended intakes of vitamin E. Some authors have observed that niacin, vitamin B_1 and B_2 were adequate in most ASD children (Xia et al. 2010). However, other studies have found a high proportion of ASD children had lower than recommended intakes of riboflavin (Shearer et al. 1982), niacin (Cornish 1998), or panthothenic acid, and vitamin K (Lindsay et al. 2006, and have found low intakes of vitamin B_{12} (Zimmer et al. 2012), $B_{6,}$ and C (Cornish 1998; Xia et al. 2010) and of folate (Cornish 1998). Further, intakes have been observed to be lower than the DRIs for vitamin A (Sadowska and Cierebiej 2011; Xia et al. 2010).

Latif et al. (2002) alerted us to a high prevalence of iron deficiency among ASD children. This was consistent with the results of Ho et al. (1997) and Cornish (1998), and has subsequently been found by Johnson et al. (2008), Herndon et al. (2009) and Xia et al. (2010), among others. Specifically, Dosman et al. (2007) reported that 35 % of school-age children with ASD did not have a high enough dietary intake of iron, and Bilgiç et al. (2010) also found that iron levels were significantly lower in a ASD than TD preschoolers. On the other hand, the recent results of Reynolds et al. (2012), and those of our study are not consistent with these earlier findings. It is possible the fortification of foods has increased children's intakes of iron in recent years.

Regarding other minerals, previous studies have found low intakes of calcium (Bandini et al. 2010; Briefel and Johnson 2004; Cornish 1998; Herndon et al. 2009; Ho et al. 1997; Johnson et al. 2008; Suitor and Gleason 2002). Several authors observed mixed results of for magnesium, namely a high (Sadowska and Cierebiej 2011; Zimmer et al. 2012) adequate intakes in most ASD children (Xia et al. 2010) or but also a low daily intake (Levy et al. 2007). Intakes have been found to be low for zinc (Raiten and Massaro 1986; Xia et al. 2010) and also for sodium and phosphorus, although these values were not significantly different from those of the reference population (Sadowska and Cierebiej 2011). Overall, there continues to be a lack of consensus: for instance, though Lindsay et al. (2006) concluded that, in general, the mean intakes for macronutrients, vitamins and minerals exceeded DRIs, another

Table 4 Nutrient inadequacy in ASD and TD children

Daily nutrient intake	DRIs (6–9 Y)	ASD children (n = 40) Number (%) not meeting	TD children (n = 113) RDIs for nutrients	OR	IC 95 %	*p* value[a]
Carbohydrates (% TEV)	50–60	30 (75 %)	102 (90 %)	0.32	0.13 –0.84	0.03
Total fats (% TEV)[b]	30–35	27 (68 %)	96 (85 %)	0.37	0.16 –0.85	0.03
Proteins (% TEV)	10–15	8 (20 %)	8 (7 %)	3.28	1.14 –9.44	0.03
Cholesterol[b] (mg/1,000 kcal)[c]	NA	38 (95 %)	113 (100 %)	0.00	–	0.07
Fiber (g/d)	25	33 (83 %)	113 (100 %)	0	–	<0.01
Vitamins						
Folic acid (mcg/d)	200	10 (25 %)	24 (21 %)	1.24	0.53 –2.88	0.79
Niacin (mg/d)	12	0 (0 %)	0 (0 %)	–	–	1
Vit. A (mcg/d)	400	4 (10 %)	5 (4 %)	2.40	0.61 –9.42	0.24
Vit. B6 (mg/d)	1.4	1 (3 %)	1 (1 %)	2.84	0.18 –47.02	0.46
Vit. C (mg/d)	55	8 (20 %)	8 (7 %)	3.28	1.14 –9.44	0.03
Vit. D (mcg/d)	5	35 (88 %)	85 (75 %)	2.31	0.82 –6.46	0.16
Vit. E (mg/d)	8	13 (33 %)	55 (49 %)	0.51	0.24 –1.08	0.11
Biotin (mcg/d)	12	1 (3 %)	2 (2 %)	1.42	0.13 –16.13	1.00
Thiamin (mg/d)	0.8	1 (3 %)	0 (0 %)	–	–	0.26
Riboflavin(mg/d)	1.2	1 (3 %)	0 (0 %)	–	–	0.26
Vit B12 (mcg/d)	1.5	0 (0 %)	0 (0 %)	–	–	1
Vit K (mcg/d)	55	7 (18 %)	13 (12 %)	1.63	0.60 –4.43	0.49
Panthothenic acid (mg/d)	3	0 (0 %)	0 (0 %)	–	–	1
Minerals						
Calcium (mg/d)	800	14 (35 %)	10 (9 %)	5.55	2.21 –13.9	<0.01
Iron (mg/d)	9	5 (13 %)	3 (3 %)	5.24	1.19 –23.04	0.03
Zinc (mg/d)	10	2 (5 %)	1 (1 %)	5.89	0.52 –66.86	0.17
Iodine (mcg/d)	90	28 (70 %)	73 (65 %)	1.28	0.59 –2.78	0.67
Phosphorus (mg/d)	700	0 (0 %)	0 (0 %)	–	–	1
Fluoride (mcg/d)	1,000	40 (100 %)	113 (100 %)	–	–	1

ASD autism spectrum disorder, *TD* typically developing, *Vit* vitamin, *TEV* total energy value, *Y* years

Fisher's exact test $p < 0.05$

[a] Mantel-Haenzel tests were used to test the significance of differences between ASD and TD children ($p < 0.05$)

[b] Intakes failed to meet recommendations if they were less than DRIs, except in the cases of total fats and cholesterol for which inadequate intakes were those over the DRI or nutritional target for Spanish people, respectively

[c] DRI for cholesterol is not determinable. Instead, the target for the Spanish population of 100 mg/1000 kcal was considered

study found that the majority of children with ASD did not in general meet recommended nutrient intakes (Ho et al. 1997).

Regarding our third hypothesis, despite the inadequacy of intake of one or more macro and micronutrients in our sample, the difference in HEI between the groups was not significant, scores classifying the children's diets as "need to improved" in both cases. This quantitative result is comparable to findings of Shearer et al. (1982), Raiten and Massaro (1986), Johnson et al. (2008), Lockner et al. (2008), Hyman et al. (2012), though these authors did not report specifically HEI scores.

The contrasting results reported in the papers cited should be interpreted with caution. The lack of standard criteria with respect to nutritional tables across the different countries where the research has been conducted could well lead to mixed results when comparing intakes. In addition, the age groups for which recommendations are defined vary between sets of tables, e.g., those of the USA (4–8, 9–13 years); FAO/WHO (4–6, 7–9 years); European Union (4–6, 7–10 years); and Spain (4–5, 6–9 years). Similarly, the availability and consumption of fortified foods was not detailed in the papers reviewed. Finally, authors use different cut-off values to define "adherence" to the recommended levels. In some cases (Herndon et al. 2009), 100 % of the RDIs is set as the threshold, while in others (Johnson et al. 2008) just 80 % is accepted. All this may result in the studies producing results which are not directly comparable and is likely to underlie the seemingly contradictory results.

Table 5 Number (%) of nutrients for which intake was inadequate

No of nutrients	Group	
	ASD (n = 40) (%)	TD (n = 113) (%)
0	0 (0 %)	0 (0 %)
1–5	4 (10 %)	15 (13 %)
6–10	33 (83 %)	91 (81 %)
+10	3 (8 %)	7 (6. %)

Overall Chi square. p value = 0.61, df = 5

Limitations of the Study

The relatively small sample size affects the statistical power to identify differences between groups. Further, there may be errors in intake data associated with the quantities recorded that were in principle determined by weighing on kitchen scales or using other household measuring devices, in recording of the three-day diaries or in the database, despite efforts to check data. Lastly, there could have been incorrect information on the labels of packaged foods or errors in the nutritional assessment of certain nutrients in the computer program used for processing the data. Further, it could be that RDIs should be different for children with ADS, though for the moment no alternative recommendations have been proposed.

It might also be considered a limitation that we excluded children taking dietary supplements or with dietary restrictions. To date, there is insufficient evidence to support the view that such interventions are beneficial in autistic children, in general. Children on these types of diets could well have very well different nutritional profiles, though in fact previous studies indicate that the exclusion of children on restriction diets did not substantially alter the nutritional patterns observed (Hyman et al. 2012).

In our sample of ASD children, there were considerably more boys than girls; a reflection of the characteristic sex ratio in ASD. Though this imbalance was not present in the TD sample, we note that Spanish dietary recommendations for the age group studied (6–9 years) are the same for boys and girls. We should also underline that the cases and controls compared, though not matched for sex, were matched not just for age but also for area of residence and socioeconomic status, as well as being followed over the same period of time.

Overall, we consider that our study has a strong internal validity given the low attrition rate, high quality of the self-reported information and exclusion of children on restriction diets. We consider that these factors compensate for the limitations on generalizability and external validity associated with participant selection.

Recommendations and Implications for Practice

In our study, food selectivity did not seem to result in children's intake failing to satisfy their energy or macronutrient needs, which can be attributed to efforts of their parents. Although many children with ASD did not consume the recommended intakes of certain nutrients, this is also the case for the Spanish child population in general. On the other hand, our data on food intakes, HEI, and foot variety scores suggest the need for increased vitamin and mineral intake, from food and/or supplements. Overall, the data suggest that dietary assessment and recommendations should be made on a case-by-case basis, supported by anthropometric and laboratory data.

Further, it should be recognized that while a varied diet is typically associated with better nutrition, the consumption of fortified foods may enable a less varied diet to satisfy nutritional requirements. Nevertheless, in children with a limited range of accepted foods, interventions involving dieticians and other specialists may be indicated to encourage them to eat a greater variety of foods.

Future studies should extend the data by exploring food intakes of children on restricted diets. Overall, there are insufficient data so far for there to be a clear consensus on whether nutritional intake is generally impaired in children with ASD and the potential consequences of this for their development. Further research is required to clarify the relationship between the symptomatology of ASD, eating patterns and health status; this would require characterization of the various different behavioral phenotypes of ASD, considering more detailed diagnoses, as well the standardization of the protocols for assessing nutritional problems. In addition, more data are needed to validate food variety as an indicator of risk for deficient or excessive intakes of nutrients. Given evidence that some children with ASD do not eat a balanced diet, the range and severity of risk of deficiencies or excesses needs to be further investigated in order to guide the management of their diet to minimize the risk of them developing chronic or degenerative conditions.

Acknowledgments The authors would like to acknowledge the contributions of the Autism Project Association (ASPAU), Fundació Mirám in Valencia, and Colegio San Cristóbal de Picassent (Valencia), as well as the children who participated in the study and their parents. We are also grateful for support from colleagues at the Dr. Peset University Hospital (Valencia, Spain). No external funding was received for this study. We gratefully acknowledge the assistance of editors of Ideas Need Communicating Language Services with the preparation of this manuscript.

Conflict of Interest The authors have no conflicts of interest to disclose.

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