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Interrelation of food selectivity, oral sensory sensitivity, and nutrient intake in children with autism spectrum disorder: A scoping review

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ABSTRACT

Background: Food selectivity is an emerging health concern among children with autism spectrum disorder (ASD). Food selectivity is used to describe food refusal, limited food choices, and/or food fussiness.
Method: We used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)-Scoping Review Guidelines to systematically identify the relationship between food selectivity and oral sensory sensitivity and the possible consequences of food selectivity on nutrient intake in children with ASD.Thirty studies were included in the review based on search terms from three online databases.
Results: Assessment of food selectivity, oral sensory sensitivity, and nutrient intake was found to be focused primarily on the parent-report technique. Only a handful of studies have used Cronbach's alpha to measure the psychometric properties. Twenty-one of the included studies reported a higher rate of food selectivity in children with ASD than typically developing (TD) children. Notably, several studies (n =7) have identified oral hypersensitivity (e.g., taste/smell) as a significant risk factor for food aversion and/or limited variety in children with ASD. Compared with TD children, the ASD group significantly consumed significantly fewer fruits/vegetables (n = 8). The intake of micronutrients, including vitamin A, vitamin B6, folate, vitamin B12, vitamin C, vitamin D, calcium, iron, and zinc that associates with food selectivity, was also low (n=13).
Conclusion: Implementation of screening and assessment protocols using valid and reliable instruments to identify food selectivity and oral sensory sensitivity is crucial for the medical evaluations of children with ASD.

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1. Introduction

Children with autism spectrum disorder (ASD) are five times more likely to develop feeding difficulties associated with food selectivity than children without ASD, and the ASD group has a higher risk of dietary inadequacies (Sharp et al., 2013). Available evidence supports that food selectivity correlates with children with ASD, indicating that taste, smell, and texture play important sensory roles in accepting or rejecting food (Marí-Bauset, Llopis-González, Zazpe-García, Marí-Sanchis, & Morales-Suárez-Varela, 2014; Marí-Bauset, Zazpe, Mari-Sanchis, Llopis-González, & Morales-Suárez-Varela, 2014). Food selectivity is often used to describe food refusal, limited food variety based on type or food texture, and increased consumption of specific food items, or rejection of certain food groups such as vegetables (Bandini et al., 2010; Field, Garland, & Williams, 2003). In addition, Williams, Dalrymple, and Neal (2000) identified that food selectivity in children with ASD is affected by various factors, such as restricted food selection (88 %), texture (69 %), food presentation (58 %), gustatory sensitivity (45 %), olfactory sensitivity (36 %), and food temperature(22 %). Similarly, the results of a survey among parents of children with ASD indicated that 72 % of children with ASD had a limited dietary range of foods and strong food preferences for sweet and salty tastes (e.g., ice cream, cookies, chicken nuggets, hot dogs, pizza, potato chips, and French fries) (Schreck & Williams, 2006).

Sensory oversensitivity to food texture, smell, or taste may influence food selectivity in children with ASD (Cermak, Curtin, & Bandini, 2010; Marshall, Hill, Ziviani, & Dodrill, 2013; Paterson & Peck, 2011). For instance, children with ASD had more sensory symptoms (94 % vs. 65 %) than children with developmental disabilities (DD), in which the taste/smell and visual domains were significantly affected (Leekam, Nieto, Libby, Wing, & Gould, 2007). In addition, the ASD and sensory modulation disorder (SMD) groups showed comparable sensitivities to tactile stimuli compared to typically developing (TD) children; however, the ASD group showed more distinct patterns of olfactory and gustatory inputs than the SMD group (Schoen, Miller, Brett-Green, & Nielsen, 2009). This finding is in line with a recent systematic review that revealed individuals with ASD have a greater risk of olfactory difficulties (Tonacci et al., 2017). Furthermore, a close relationship exists between sensory sensitivity and eating problems among children with ASD; for example, those who had sensitivities to taste/smell are most likely to avoid fruits and vegetables (Dunn, Little, Dean, Robertson, & Evans, 2016). Suarez, Nelson, and Curtis (2014) conducted a longitudinal study to examine the associated risk factors for selective eating in children with ASD, and the results showed that sensory over-responsivity significantly influences food selectivity as well as repetitive and stereotyped behaviours. The study also highlighted that children with ASD aged 3−11 years who exhibit food selectivity are likely to be persistent, and this problem would not improve within a short time; thus, a standardised screening protocol concerning food selectivity is crucial to be conducted by a multidisciplinary healthcare team. Prior research has indicated the role of sensory sensitivities (e.g., taste, smell, and tactile) in contributing to atypical mealtime behaviours in the ASD population. The recent Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5) acknowledged that hyper- and hypo-sensory sensitivity, including severe food selectivity, manifested as a symptom of ASD (APA, 2013; Stein, 2014).

There are inconsistent findings concerning nutrient inadequacies in ASD. For instance, Bicer and Alsaffar (2013) reported that the majority of children with ASD aged 4–18 years had inadequate intake of calcium, zinc, vitamin B_6, and folate. Similarly, a study by Sharp et al. (2018) showed that 67 % of children with ASD are at risk of having five or more nutrient inadequacies, including vitamin D, vitamin E, calcium, iron, zinc, and fibre. Conversely, the findings of a recently published meta-analysis by Esteban-Figuerola, Canals, Fernández-Cao, and Arija Val (2019) demonstrated that although children with ASD consumed less calcium, phosphorus, selenium, vitamin D, thiamine, riboflavin, and vitamin B12 than their typical peers owing to restricted dietary consumption, their daily intake was still above the minimum recommended nutritional requirements. Heterogeneity in the methodology used to determine nutrient intake, reference values, population and control groups, dietary habits (Graf-Myles et al., 2013), and underlying medical problems (i.e., reflux, constipation, and diarrhoea) were found to be the contributing factors that could influence the variability in the findings associated with nutrient inadequacies among children with ASD (Lobato, 2011). In addition, the available evidence from the literature

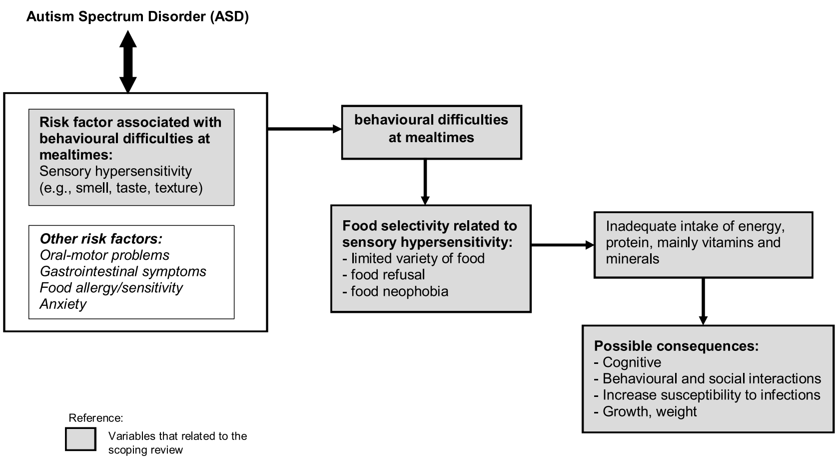

Fig. 1. Conceptual model on the relationships between oral sensory sensitivity, food selectivity, and nutritional outcomes in children with ASD.

review supports the interrelationships among food selectivity, oral sensory sensitivity, and nutritional outcomes in children with ASD (Bryant-Waugh, Markham, Kreipe, & Walsh, 2010; Ranjan & Nasser, 2015; Twachtman-Reilly, Amaral, & Zebrowski, 2008). These possible connections can be explained using the conceptual model shown in Fig. 1.

Despite the numerous reports on higher rates of food selectivity in children with ASD (Ahearn, Castine, Nault, & Green, 2001; Field et al., 2003; Schreck & Williams, 2006) the potential role of oral sensory sensitivity has not been systematically investigated in relevant studies. According to a review by Kral, Eriksen, Souders, and Pinto-Martin (2013), selective eating in children with ASD is related to the type of food, textures, utensils or presentation of food that may put them at risk of long-term nutritional inadequacies. Therefore, it is suggest for a comprehensive investigation of the relationships between children's responses to sensory characteristics of foods (e.g., taste and texture) and overall health in children with ASD who have heightened sensory reactivity is needed. Furthermore, several reviews agree on the methodology constraints, mainly on potential bias in parent-report instruments used to evaluate mealtime behaviours associated with food selectivity and variability in the definitions of food selectivity, which may limit the comparability of the studies (Marí-Bauset, Llopis-González et al., 2014; Marí-Bauset, Zazpe et al., 2014; Margari, Marzulli, Gabellone, & de Giambattista, 2020). Therefore, this review aimed to examine (1) the inter-relationship between mealtime behaviour associated with food selectivity and oral sensory sensitivity in children with ASD; (2) the impact of food selectivity on selected micronutrients, fruits, and/or vegetable intake in children with ASD; and (3) quality assessment of the existing parent-report instruments including studies for measuring mealtime behaviours associated with food selectivity and oral sensitivity in children with ASD selected in this review.

2. Methods

We conducted a scoping review using the framework proposed by Arksey and O'Malley (2005) (Arksey & O'Malley, 2005). Evidence from 1978 to 2012 has shown that food selectivity is a common problem among children with ASD (Cermak et al., 2010; Marí-Bauset, Llopis-González et al., 2014; Marí-Bauset, Zazpe et al., 2014). Although considerable evidence has been accumulated regarding food selectivity, the role of sensory sensitivity in feeding problems is yet to be thoroughly discussed. A scoping review approach was chosen instead of a systematic literature review (SLR) because of the limited number of relevant randomised controlled intervention studies conducted in this area (Marí-Bauset, Llopis-González et al., 2014; Marí-Bauset, Zazpe et al., 2014). Following the latest recommendation by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping review (PRISMA-ScR: Tricco et al., 2018), the literature was reviewed from 2010 to October 2021 using EBSCO Discovery, Science Direct, and Scopus as the three prominent multidisciplinary and peer-reviewed databases. The search also included reference lists of relevant articles to identify additional publications related to the review scope.

The combination of search strings included (autism OR "autism spectrum disorder" OR autistic) AND (children OR adolescents) AND ("eating behaviour" OR "mealtime behaviour" OR "food selectivity" OR "food refusal" OR "picky eating" OR "dietary intake" OR "nutrient intake" OR "nutritional status") AND ("sensory sensitivity" OR "sensory processing" OR "sensory modulation" OR "atypical sensory").

Inclusion criteria determined for the review process are as listed below: (I) recent scientific research papers published within 2010-October 2021, (II) articles with full text and written in English language, (III) children aged between 1 and 18 years with a confirmed diagnosis of ASD based on DSM-IV/DSM-IV (TR)//DSM-5 criteria, (IV) observational studies that include a control and/or comparison group (e.g., case-control, cohort, or longitudinal), and (V) established methods to evaluate the following: (a) eating behaviour such as Brief Autism Mealtime Behaviour Inventory (BAMBI: Lukens & Linscheid, 2008), Children's Eating Behaviour Questionnaire (CEBQ: Wardle, Guthrie, Sanderson, & Rapoport, 2001), Behaviour Paediatrics Feeding Assessment Scale (BPFAS: Crist & Napier-Phillips, 2001) or others, (b) dietary intakes such as 3-day food record (3-DFR), Food Frequency Questionnaire/Inventory (FFQ/FFI) or 24 h dietary recall, (c) sensory processing measures such as Sensory Profile (SP: (Dunn, 1997), or Short Sensory Profile (SSP: McIntosh, Miller, Shyu, & Dunn, 1999). For dietary information, data collection focused on the following micronutrient indicators: vitamin A, vitamin B6, folate, vitamin B12, vitamin C, vitamin D, calcium, iron, magnesium, zinc, and fruit and vegetable consumption. The selection of micronutrients was based on a review by a few authors that emphasised micronutrient inadequacy and food selectivity in children with ASD (Kral et al., 2013; Ranjan & Nasser, 2015).

Mendeley Reference Manager and Microsoft Excel were used to systematically arrange the records, monitor material duplication, bibliography, and reference lists. The extracted research information extracted was based on the following characteristics: (1) characteristics of food selectivity and oral sensory sensitivity in children with ASD; (2) micronutrients, fruit/vegetable intake, and biochemical indices of nutrition between children with ASD and TD children; (3) methodological quality of each study per measurement property of mealtime behaviours and sensory processing; and (4) methodological quality assessment of mealtime behaviours and sensory processing instruments.

In this present study, we employed the COnsensus-based on Standards for the selection of health Measurement INstruments (COSMIN) checklist (Mokkink et al., 2018), a risk of bias tool examining the methodological quality of the psychometric properties, to examine six methodology quality namely (1) structural validity to evaluate sufficient information on the methods involved in factor analysis; (2) internal consistency to evaluate the correlation of the items in scale or subscales; (3) cross-cultural validity to evaluate whether any translation or adaptation studies had been conducted, as well as whether validation studies had been performed following translation process; (4) reliability involved test-retest reliability, inter-rater reliability, and intra-rater reliability; (5) construct validity involved convergent and discriminant validities to establish a relationship between different groups or instruments; and (6) measurement error is the difference between the observed value of the variable and its true value. The methodological quality of the psychometric properties of the selected studies was rated as follows: 1 = inadequate, 2 = doubtful, 3 = adequate, and 4 = very good. This work was independently performed by two reviewers (MNZ and NHH). A third reviewer (MK) resolved disagreements between the two reviewers.

3. Results

3.1. Characteristic of studies and participants

Thirty studies met the review objectives and eligibility criteria for food selectivity, oral sensory sensitivity, micronutrients, and fruit/vegetable intake. Fig. 2 illustrates the search strategy and processes involved in data selection. The studies selected in this review used TD children, siblings, and children with DD as the control and comparative groups. The sample size ranged from 14 to 2,102 of children with ASD aged between 1 and 18 years. Multiple sources were used to select the study population, which involved healthcare and community settings, such as clinics/rehabilitation centres, public or special education schools, and family members.

3.2. Food selectivity and oral sensory sensitivity

3.2.1. Reports on food selectivity

Overall, 70 % (21/30) of the studies included in this review highlighted that food selectivity as a common feeding problem in children with ASD. Food selectivity has been linked with behaviours related to food refusal, eating a limited variety of foods, and being picky/fussy eaters (Table 1). Picky eating terms that had been identified by articles included in this review as "very choosy," "food fussiness," or "extreme picky eating" (Dovey, Kumari, & Blissett, 2019; Liu et al., 2016; Malhi, Venkatesh, Bharti, & Singhi, 2017; Smith, Rogers, Blissett, & Ludlow, 2020; Tomova, Soltys, Kemenyova, Karhanek, & Babinska, 2020).

In addition, food refusal has often been reported in children with ASD (Al-Kindi et al., 2016; Bandini et al., 2010; Chistol et al., 2018; Handayani, Herini, & Takada, 2012; Zobel-Lachiusa, Andrianopoulos, Mailloux, & Cermak, 2015) and is associated with food texture, temperature, and cooking style (Nadon, Feldman, Dunn, & Gisel, 2011; Provost, Crowe, Osbourn, McClain, & Skipper, 2010). Additionally, children with ASD have a significantly reduced number of food items consumed in their diet compared with their neurotypical peers (Bandini et al., 2010; Chistol et al., 2018; Malhi et al., 2017; Shmaya, Eilat-Adar, Leitner, Reif, & Gabis, 2017;

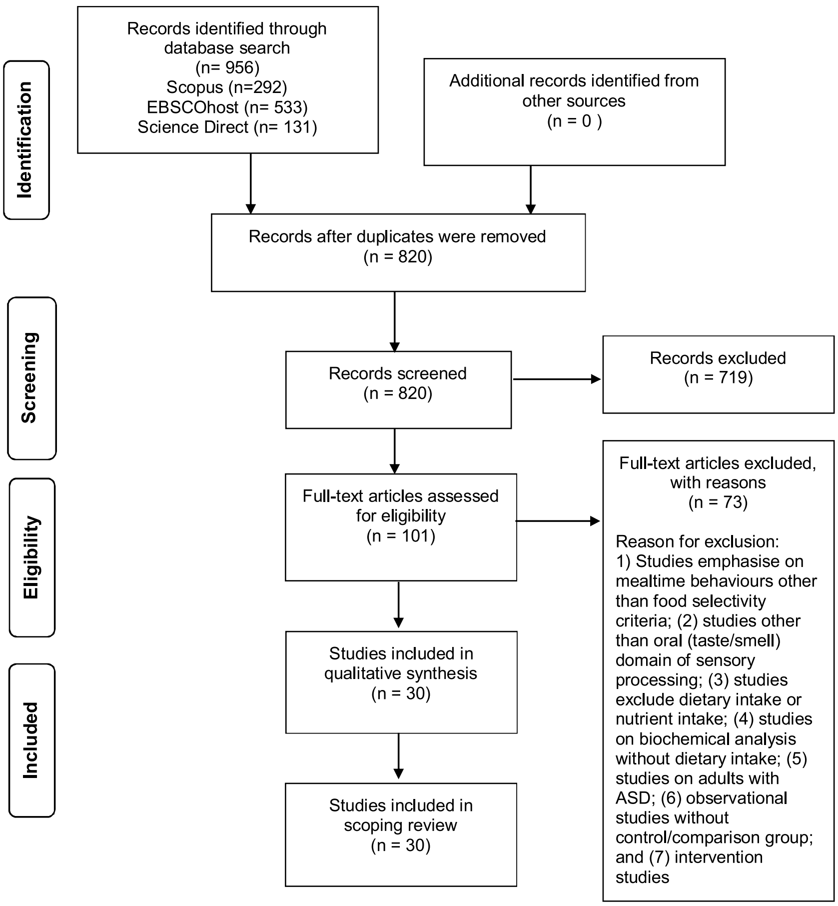

Fig. 2. PRISMA-ScR Flowchart.

Table 1
Characteristics of food selectivity and oral sensory sensitivity in children with ASD.

Author	Study design	Age (years)	Total sample size (N)	ASD Group (n)	Control group TD (n)	Comparison group (n)	Mealtime Behaviours	Sensory Processing	3-days food record	FFQ/ FFI	Oral Sensory Sensitivity	Limited food variety	Food refusal e.g. texture, colour, smell, taste, brand, temperature, mixed foods	Picky eating/ food fussiness
(Smith et al., 2020)	Case-control	6–17	98	27	27	TS (27); ADHD (17)	CEBQ	SSP		√	Neuro-developmental groups had a significant difference than TD children*** Risk factor for selective eating			Neuro-developmental groups differ significantly in food fussiness than TD children ** ASD group had a lower intake of fruit *** and vegetables* than TD children
(Panerai et al., 2020)	Comparison between subgroups	2–12	111	37/74		ASD without FP (74)	BAMBI CEBQ	SSP			ASD with FP had a higher rate of oral sensory sensitivity than ASD without FP***	ASD with FP had more limited preferences than ASD without FP***	ASD with FP refused food more frequent than ASD without FP***	ASD with FP differ significantly in food fussiness than ASD without FP***
(Tomova et al., 2020)	Case-control	9.57 ± 4.4	62	46	16					√				A higher rate of food selectivity in the ASD group (59 % vs 25 %)* ASD group had a significantly reduced in micronutrients* ASD group with picky eating had more GI and social problems than ASD without picky eating*
(Mayes & Zickgraf, 2019)	Case-control	1–18	2102	1462	313	ADHD, ID, LD (n = 327)	CASD: feeding problems (5 sub-items)					Limited preferences: 88.5 % Mostly ASD group prefer carbohydrate foods and chicken nuggets	Texture 46 %Brand 27 %	Neuro-developmental groups differ significantly in food fussiness than TD children ***
(Dovey et al., 2019)	Case-control	6–8	487	56	259	ARFID (29); PE (143)	BPFAS, CEBQ	SEQ			NA: SEQ measure for the social domain			Neuro-developmental groups differ significantly in food fussiness than TD children ***
Author	Study design	Age (years)	Total sample size (N)	ASD Group (n)	Control group TD (n)	Comparison group (n)	Mealtime Behaviours	Sensory Processing	3-days food record	FFQ/ FFI	Oral Sensory Sensitivity	Limited food variety	Food refusal, e.g. texture, colour, smell, taste, brand, temperature, mixed foods	Picky eating/ food fussiness
(Chistol et al., 2018)	Case-control	3–11	111	53	58			SP	√	√	ASD group differ significantly in oral sensory sensitivity than	ASD group had a more limited food choices than TD children (19	ASD group had a more significant food refusal	

(continued on next page)

Table 1 (*continued*)

Author	Study design	Age (years)	Total sample size (N)	ASD Group (n)	Control group TD (n)	Comparison group (n)	Mealtime Behaviours	Sensory Processing	3-days food record	FFQ/ FFI	Oral Sensory Sensitivity	Limited food variety	Food refusal, e.g. texture, colour, smell, taste, brand, temperature, mixed foods	Picky eating/ food fussiness
											TD children (64–66% vs 7–9%)***	± 4.9 vs 22.5 ± 4.6) ***	than TD children (41.7 ± 21 vs 18.9 ± 15.6)***	
Bandini et al., 2017	Fup cohort from Bandini et al., 2010	BL: 6.8 Fup: 13.3	18	18		35 ASD not in the cohort	MIOH		√	√		From BL to fup visit: Increased intake of fruits and vegetables ~ 1 serving/day 44 % (n = 8) had persistent behaviour-related to high food selectivity (>33 % of foods refused)	From BL to fup visit: Declined food refusal (47 % vs 31 %) **Reduced food refusal on texture (94 % vs 39 %)** Reduced food refusal on mixed foods (50 % vs 28 %)*	
(Shmaya et al., 2017)	Case-control	3–6	91	50	12	SB (29)	BAMBI	SP	√		ASD group with oral sensory sensitivity had limited food choices than ASD without sensory symptoms*	ASD group had a limited food variety than TD children and siblings *		
(Malhi et al., 2017)	Case-control	4–10	113	63	50		CEBI		√	√		ASD group consumed less fruit, vegetables, protein than TD *		ASD group consumed <30 foods than TD children (12.7 % vs. 2%)*
(Al-Kindi et al., 2016)	Case-control	4–13	375	163	212		BAMBI					Difference between ASD vs TD children***	Difference between ASD vs TD children***	
(Castro et al., 2016)	Case-control	4–16	98	49 (M)	49		BPFAS		√				ASD children avoid fruits (20.4 %) and vegetables (28.6 %)	

Author	Study design	Age (years)	Total sample size (N)	ASD Group (n)	Control group TD (n)	Comparison group (n)	Mealtime Behaviours	Sensory Processing	3-days food record	FFQ/ FFI	Oral Sensory Sensitivity (taste/ smell)	Limited food variety	Food refusal, e.g. texture, colour, smell, taste, brand, temperature, mixed foods	Picky eating/ food fussiness
(Liu et al., 2016)	Case-control	5.21 ± 1.83	227	154	73		MBQ		2D					Severe picky eating was reported in ASD children than TD children (26 % vs 11 %)**
(Zobel-Lachiusa et al., 2015)	Case-control	5–12	68	34	34		BAMBI	SSP			Difference between ASD vs TD children in SSP total scores**	Difference between ASD vs TD children***	Difference between ASD vs TD children***	
(Hubbard et al., 2014)	Case-control	3–11	111	53	58			SP		√	SD group differ significantly with TD children (49 % vs 5%)***		ASD group had more sensitivity in: texture than TD children (77.4 % vs. 36 %)*** mixed food (45.3 % vs. 25.9 %)*	

(*continued on next page*)

Table 1 (*continued*)

Author	Study design	Age (years)	Total sample size (N)	ASD Group (n)	Control group TD (n)	Comparison group (n)	Mealtime Behaviours	Sensory Processing	3-days food record	FFQ/ FFI	Oral Sensory Sensitivity (taste/ smell)	Limited food variety	Food refusal, e.g. texture, colour, smell, taste, brand, temperature, mixed foods	Picky eating/ food fussiness
													andbrand (15 % vs. 1.7 %)*	
(Graf-Myles et al., 2013)	Case-control		120	69	37	DD (14)		SSP	√		Difference between ASD vs TD children***			
(Zimmer et al., 2012)	Case-control	8 ± 3.2	44	22	22					√		ASD group had a reduced list of food in a month (33.5 ± 12.6 vs 54.5 ± 18.9)***		ASD group with picky eating had a lower intake of vitamin A,* D***, B12*, calcium*** and protein* than non-picky eater ASD and TD children
(Handayani et al., 2012)	Case-control	3–6	393	52	341		BAMBI					Reluctant to try new foods in children with ASD*	Children with ASD avoid contact with food*	
(Berlin et al., 2011)	Case-control		286	14		DD, B (n = 272)	BPFAS Retrospective data					Reduced food variety between ASD vs DD vs B children*		

Author	Study design	Age (years)	Total sample size (N)	ASD Group (n)	Control group TD (n)	Comparison group (n)	Mealtime Behaviours	Sensory Processing	3-days food record	FFQ/ FFI	Oral Sensory Sensitivity	Limited food variety	Food refusal e.g. texture, colour, smell, taste, brand, temperature, mixed foods	Picky eating/ food fussiness
(Nadon et al., 2011)	Case-control	3–12	64	44	20 SB		Eating Profiles					ASD group had diet < 20 types of foods than TD children***	Significant differences between ASD vs. TD children: texture*** temperature*** recipe***	
(Emond et al., 2010)	Cohort	0.5–4.5	12,980	79	12,901					√		ASD group exhibited limited food choices at the age of 1 year+		ASD group was fussy eater at the age of 1 year + until 4.5 years than TD***
(Bandini et al., 2010)	Case-control	3–11	111	53	58				√	√		ASD had limited food choices than TD children***	ASD group refused food more common than TD children***	
(Provost et al., 2010)	Case-control	3–6	48	24	24		Mealtime Survey					ASD group was more selective in texture than TD children*		ASD group had a higher rate of picky eating than TD children**

Abbreviations: TDTypically Developing; ASDAutism Spectrum Disorder; ADHDAttention Deficit Hyperactive Disorder; IDIntellectual Disability; LDLearning Disability; DDDevelopmental Disability; SBsiblings; ARFIDAvoidant/Restrictive Food Intake Disorder; FPfeeding problems; BLBaseline; FupFollow-up; PEPicky Eating; BBehavioural; MMale; 2D; 2 Days; BAMBIBrief Autism Mealtime Behaviour Inventory; CEBIChildren's Eating Behaviour Inventory; CEBQChild Eating Behaviour Questionnaire; BPFASBehavioral Paediatrics Feeding Assessment Scale; MIOHMeals in Our Household Questionnaire; MBQMealtime Behavioural Questionnaire; FFQFood Frequency Questionnaire; FFIFood Frequency Inventory; CASDChecklist for Autism Spectrum Disorder; SPSensory Profile; SSPShort Sensory Profile, SEQ, Sensory Experiences Questionnaire; NANot Available; GIGastrointestinal.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Zimmer et al., 2012), siblings (Nadon et al., 2011), and children with DD (Berlin, Lobato, Pinkos, Cerezo, & Leleiko, 2011; Mayes & Zickgraf, 2019). A cohort study by Bandini et al. (2017) demonstrated that adolescents with ASD aged 13 years had significantly reduced food refusal habits by improving the list of foods accepted in the diet, increased tolerance to food texture, and food mixed within an average of 6 years from the baseline study. In contrast, 44 % of the adolescents with ASD had persistent behaviours related to high food selectivity throughout the cohort study.

The ASD group had a significantly higher rate of being picky eaters than the TD group (Dovey et al., 2019; Liu et al., 2016; Malhi et al., 2017; Smith et al., 2020; Tomova et al., 2020;). Similarly, a longitudinal study by Emond, Emmett, Steer, and Golding (2010) found that younger children with ASD exhibited selective eating patterns resulting in different food choices and intakes than other family members by aged 24 months. Additionally, some studies have reported reduced intake of specific micronutrients and proteins and an increase in gut-related problems in children with ASD who were fussy eaters compared with typical eaters with ASD and TD children (Zimmer et al., 2012). Children with ASD also had a significantly lower food acceptance response (Liu et al., 2016; Nadon et al., 2011; Provost et al., 2010) and a higher preference for repetitive food choices at mealtimes than their typical peers (Al-Kindi et al., 2016).

3.2.2. Inter-relationship between food selectivity and oral sensory sensitivity

A total of 20 % ($n = 6$) ofstudies revealed that children with ASD had a significantly greater oral sensory sensitivity than TD children (Chistol et al., 2018; Graf-Myles et al., 2013; Hubbard, Anderson, Curtin, Must, & Bandini, 2014; Shmaya et al., 2017; Smith et al., 2020; Zobel-Lachiusa et al., 2015). In contrast, one study identified the differences in oral sensory processing between the ASD group with food selectivity and ASD without food selectivity (Panerai et al., 2020) (Table 1).

Children with ASD have also been reported, tend to have a significant food aversion due to texture, smell/taste hypersensitivity, food preferences according to a specific brand and dislike of food mixed on the plate (Hubbard et al., 2014). Similarly, children with ASD display a significantly lower intake of fruits and vegetables associated with atypical oral sensory processing than their typical peers (Chistol et al., 2018; Smith et al., 2020). Moreover, children with ASD presented with oral sensory sensitivity have greater mealtime challenges associated with a restricted range of food acceptance (Shmaya et al., 2017) and selective eating habits (Smith et al., 2020). (Table 1 and 2).

3.3. Determining nutrient intake and adequacy

A majority of 60 % (18/30) of the studies explored the relationship between dietary patterns and nutrient intake in children with ASD (Table 2). The majority of studies used standard reference guidelines, Dietary Recommended Intakes (DRIs) from the United States (US) Institute of Medicine (IOM) to measure the nutritional adequacy of the participants, and DRIs consist of three components: (I) Estimated Average Requirement (EAR: Bandini et al., 2010 Castro et al., 2016; Graf-Myles et al., 2013; Hyman et al., 2012; Malhi et al., 2017; Marí-Bauset, Llopis-González, Zazpe-García, Marí-Sanchis, & Morales-Suárez-Varela, 2015; Zimmer et al., 2012), (II) Recommended Dietary Allowance (RDA: Barnhill et al., 2018; Graf-Myles et al., 2013; Meguid et al., 2017), and (III) Adequate Intake (AI) refers to the average daily intake level based on observed or estimates of nutrient intake of a group (or groups) of apparently healthy people that are assumed to be adequate, and AI will be calculated when there is insufficient scientific evidence for EAR value (Institute of Medicine (US) Food and Nutrition Board (1998). AI was used in a few studies in this review (Castro et al., 2016; Liu et al., 2016; Sun et al., 2013). However, only two studies used their national country standard guidelines, the Chinese Nutrition Academy (2000), as dietary intake references (Liu et al., 2016; Sun et al., 2013). For adequate dietary consumption, the DRI value is considered similar to or higher than 100 % of DRI, and marginal intake is between 80–99 % of the DRI. In contrast, less than 80 % of DRI reflects inadequate dietary consumption that may influence health-related risks in the vulnerable groups of children, including those with ASD (Barnhill et al., 2018).

3.3.1. Intake of fruits and/or vegetables

Children with ASD have been observed to have a significantly reduced intake of fruits and/or vegetables concerning selective eating compared with TD children (Bandini et al., 2010; Chistol et al., 2018; Evans et al., 2012; Malhi et al., 2017; Marí-Bauset et al., 2015; Raspini et al., 2021; Smith et al., 2020; Tomova et al., 2020) (Table 2). Interestingly, a longitudinal study by Bandini et al. (2017) demonstrated that the dietary patterns of adolescents with ASD (mean age 13.3 years) showed a daily increase in one serving of fruit/vegetables compared with the baseline findings (mean age, 6.8 years old) (Table 1).

3.3.2. Intake of micronutrients from dietary assessments

Compared with TD children, the literature reported a significantly reduced intake of certain vitamins in children with ASD, including vitamin A (Bandini et al., 2010; Barnhill et al., 2018; Hyman et al., 2012), vitamin B6 (Barnhill et al., 2018; Tomova et al., 2020), folate (Al-Farsi et al., 2013; Barnhill et al., 2018; Malhi et al., 2017; Meguid et al., 2017), vitamin B12 (Al-Farsi et al., 2013; Barnhill et al., 2018; Zimmer et al., 2012), vitamin C (Emond et al., 2010; Hyman et al., 2012; Malhi et al., 2017; Marí-Bauset et al., 2015; Sun et al., 2013; Tomova et al., 2020), and vitamin D (Bandini et al., 2010; Emond et al., 2010; Graf-Myles et al., 2013; Zimmer et al., 2012) (Table 2).

In addition, a subgroup of children with ASD following a gluten-free (GF) or casein-free (CF) diet showed significantly insufficient intake of folate, grains, and dairy products (Graf-Myles et al., 2013). Furthermore, a substantial number of children with ASD have significant dietary mineral deficiencies, including calcium (Bandini et al., 2010; Barnhill et al., 2018; Graf-Myles et al., 2013; Marí-Bauset et al., 2015; Sun et al., 2013; Zimmer et al., 2012), iron (Barnhill et al., 2018; Castro et al., 2016; Marí-Bauset et al., 2015 ;

Table 2
Comparison of micronutrients, fruits and/or vegetables, and biochemical indices of nutrition between children with ASD and TD children.

Author	Age (years)	Total sample size (N)	ASD Group (n)	Control group (TD)	Comparison group	3-days food record	FFQ/ FFI/ FPQ	24 h diet recall	Biochemical data (serum/ plasma)	Reference Guidelines (DRI/RDA/ EAR/AI)	Fruits and/ or vegetables	Calcium	Iron	Zinc	Magnesium	Vitamin A	Vitamin B6	Folate	Vitamin B12	Vitamin C	Vitamin D
(Raspini et al., 2021)	1.3–6.4	147	65	√			√				↓***										
(Smith et al., 2020)	6–17	98	27	√	√		√				↓***										
(Tomova et al., 2020)	9.57 ± 4.4	62	46	√			√				↓***		↓*				↓*			↓*	
(Chistol et al., 2018)	3–11	111	53	√		√	√			√	↓***										
(Barnhill et al., 2018)	2–8	143	86	√		√				√		↓**a	↓**	↓**		↓**	↓*	↓**	↓***		a
(Malhi et al., 2017)	4–10	113	63	√		√	√			√	↓*							↓***		↓a*	
(Meguid et al., 2017)	4–6	160	80	√		√			√	√		↓*** ↓b	↓*** ↓b		↓*** ↓b		↑***	↓*** ↓b	↓*** ↓b	↑***	
(Castro et al., 2016)	4–16	98	49	√		√				√		↑*a	↓*a					↑*a			
(Liu et al., 2016)	5.21 ± 1.83	227	154	√		2D		WM	√	√			↓b*			↓b*					
(Marí-Bauset et al., 2015)	6–10	153	40	√		√				√	↓**	↓**a	↓*a					a		↓*a	a
(Graf-Myles et al., 2013)		120	69	√	√	√			√	√		↓***									↓***
(Sun et al., 2013)	4–6	106	53	√		√			√	√		↓*a ↓b**		a		a ↓b**	a	↓b*		↓*a	
(Al-Farsi et al., 2013)	3–5	80	40	√		√			√									↓ * ↓***b	↓ * ↓***b		
Author	Age (years)	Total sample size (N)	ASD Group (n)	Control group (TD)	Comparison group	3-days food record	FFQ/ FFI/ FPQ	24 h diet recall	Biochemical data (serum/ plasma)	Reference Guidelines (DRI/RDA/ EAR/AI)	Fruit and/ or vegetables	Calcium	Iron	Zinc	Magnesium	Vitamin A	Vitamin B6	Folate	Vitamin B12	Vitamin C	Vitamin D
(Zimmer et al., 2012)	8 ± 3.2	44	22	√			√			√		↓*a		a	↑*				↓*a		↓*a
(Hyman et al., 2012)	2–11	921	362	√		√				√		a		↓* 4–8†		↓**4–8†				↓***4–8†	a
(Evans et al., 2012)	3–11	111	53	√			√				↓**										
(Bandini et al., 2010)	3–11	111	53	√		√	√			√	↓***	↓*a				↓*					↓*a
(Emond et al., 2010)	0.5–4.5	12,980	79	√			√				↓									↓**	↓**

Abbreviations: TD, Typically Developing Children; EAR, Estimated Average Requirement; DRI, Daily Recommended Intake; RDA, Recommended Dietary Allowance; AI, Average Intake; FFQ, Food Frequency Questionnaire; FFI, Food Frequency Inventory; 2D, 2 Days Food Record; WM, Weighing Method.
↓ = lower dietary intake than TD children; ↑ = higher dietary intake than TD children; † = age in year.
a = inadequate nutrient intake <80 % according to EAR/RDA/AI; ↓b = low biochemical concentration either measured from blood serum or plasma than TD children.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3
Methodological quality of each study per measurement property of mealtime behaviours and sensory processing based on the COSMIN checklist.

Type of measure	Measures	Reference	Structural validity	Internal consistency	Cross-cultural validity	Reliability	Construct/ criterion validity	Measurement error
Parent-report	CEBQ	(Smith et al., 2020)	NR	Adequate Food fussiness, α: 0.68	NR	NR	NR	NR
		(Panerai et al., 2020)	NR	NR	NR	NR	NR	NR
		(Dovey et al., 2019)	NR	NR	NR	NR	NR	NR
	BPFAS	(Dovey et al., 2019)	NR	NR	NR	NR	Very good (Dovey, Jordan, Aldridge, & Martin, 2013)	NR
		(Castro et al., 2016)	NR	NR	NR	NR	NR	NR
		(Berlin et al., 2011)	NR	NR	NR	NR	NR	NR
		(Panerai et al., 2020)	NR	NR	NR	NR	NR	NR
		(Shmaya et al., 2017)	NR	NR	NR	NR	NR	NR
	BAMBI	(Handayani et al., 2012)	NR	Very good Japan, α: 0.74; Indonesia, α: 0.73	Doubtful	NR	NR	NR
		(Al-Kindi et al., 2016)	NR	Very good Arabic, α: 0.72	Doubtful	NR	NR	NR
		(Zobel-Lachiusa et al., 2015)	NR	NR	NR	NR	NR	NR
	CEBI	(Malhi et al., 2017)	Doubtful	Doubtful	Doubtful	NR	NR	NR
	MiOH	(Bandini et al., 2017)	NR	NR	NR	NR	NR	NR
	Eating Profile	(Nadon et al., 2011)	NR	NR	Doubtful	NR	NR	NR
	MBQ	(Liu et al., 2016)	NR	NR	NR	NR	NR	NR
	Mealtime Survey	(Provost et al., 2010)	NR	NR	NR	NR	NR	NA
	SP	(Chistol et al., 2018)	NR	NR	NR	NR	NR	NR
		(Shmaya et al., 2017)	NR	NR	NR	NR	NR	NR
		(Hubbard et al., 2014)	NR	NR	NR	NR	NR	NR
	SSP	(Smith et al., 2020)	NR	Very good Tactile, α: 0.88 Smell/taste, α: 0.95 Visual/Auditory, α: 0.90	NR	NR	NR	NR
		(Panerai et al., 2020)	NR	NR	NR	NR	NR	NR
		(Zobel-Lachiusa et al., 2015)	NR	NR	NR	NR	NR	NR
		(Graf-Myles et al., 2013)	NR	NR	NR	NR	NR	NR
Semi-structure interview	CASD	(Mayes & Zickgraf, 2019)	NR	NR	NR	NR	NR	NR

Abbreviations: NR, Not neported; BAMBI, Brief Autism Mealtime Behaviour Inventory; CEBI, Children's Eating Behaviour Inventory; CEBQ, Child Eating Behaviour Questionnaire; BPFAS, Behavioral Paediatrics Feeding Assessment Scale; MIOH, Meals in Our Household Questionnaire; MBQ, Mealtime Behavioural Questionnaire; SP, Sensory Profile; SSP, Short Sensory Profile; CASD, Checklist for Autism Spectrum Disorder.

Table 4
Methodology quality assessment of mealtime behaviours and sensory processing instruments based on the COSMIN checklist.

Measures	Author (s)/ Country	Structural validity	Internal consistency	Cross-cultural validity	Reliability	Construct validity	Measurement error
BAMBI 18-item	(Lukens & Linscheid, 2008) USA	Very good EFA = 45 % of the variance (3 factors) CFA: RMSEA = .076 and.072 (3–4 factors) Sample size>100	Very good Total items = 0.88 Limited variety = 0.87 Food refusal = 0.76 Features of autism = 0.63	Very good Psychometric properties (DeMand, Johnson, & Foldes, 2015) 4 factors (15-item) RMSEA = 0.063, TLI = 0.92; CFI = 0.94; New cut-off point ≥ 34 concerning atypical mealtime behaviours	Adequate Test-retest: 7 months (5–13 months) r (33) = 0.87 Inter-rater: r (16) = 0.78	Very good Convergent: Interrelation between factors of BAMBI Discriminative: ASD vs. TD children Criterion: BPFAS/YAQ/ GARS	NR
CEBQ 35-item	(Wardle et al., 2001) USA	Adequate EFA: PCA	Very good Subscales = 0.74–0.91	Adequate Has been used in multiple English-speaking	Adequate Test-retest: 2 weeks r = 0.52–0.87	Very good Discriminative: (Smith et al., 2020); (Dovey et al., 2019) Neuro-developmental groups differ significantly in food fussiness than TD children ($p < 0.05$)	NR
CEBI 40-item	(Archer, Rosenbaum, & Streiner, 1991) Canada	NR	Adequate Different in sub-groups: 0.58–0.76	NR	Adequate Test-retest: 4–6 weeks (n = 28 clinic group; n = 10 TD) ICC = 0.87 (total eating problem) ICC = 0.84 (perceived item to be a problem)	Very good Discriminative: significant difference between non-clinic and clinic groups on total eating problem scores ($p < 0.001$)	NR
MiOH	(Anderson, Must, Curtin, & Bandini, 2012) USA	NR	Very good Overall = 0.77	NR	Adequate Test-retest: 10–30 days (n = 44) r_s = 0.8 -0.95 2 study: CHAMPS, Ohio	Very good Discriminative: significant difference between TD children vs. ASD group Convergent: Inter-correlation between domains	NR
BPFAS 35-item	(Crist & Napier-Phillips, 2001) Canada	Very good EFA: PCA varimax rotation (5 factors) CFA: good model fit (Allen et al., 2014) (n = 374) EFA: (3 factors) CFA: good model fit, RMSEA < 0.08 evaluated among children with ASD	Very good All subjects = 0.76 clinical groups = 0.78	Adequate Has been used in multiple English-speaking	Adequate (Marshall, Raatz, Ward, & Dodrill, 2014) Test-retest: 2 weeks, ICC = 0.91	Very good Discriminative: significant difference between control and clinical groups. Convergent: (Allen et al., 2014) Correlation between BPFAS and ADOS, CBCL, SRS, RBS-R, MPR, PLS, VABS, CSHQ, PSI with medium effect size, r = 0.02–0.48 Criterion: (Dovey et al., 2013) Child frequency = 61 (Sn = 0.86, Sp = 0.87, PPV = .46) Child problem = 6 (Sn = 0.84, Sp = 0.85, PPV = 0.42) Parent frequency = 20 (Sn = 0.80, Sp = 0.79, PPV = 0.33)	Very good (Marshall et al., 2014) ICC = 0.91 SD = 16.8 SEM = 5.04 SDC = 13.97

(*continued on next page*)

Table 4 (*continued*)

Measures	Author (s)/ Country	Structural validity	Internal consistency	Cross-cultural validity	Reliability	Construct validity	Measurement error
						Parent problem = 2 (Sn = 0.81, Sp = 0.85, PPV = 0.32) BPFAS can accurately distinguish 87 % of children into feeding problems vs. without feeding problems	
Eating Profile	(Nadon et al., 2011) USA	NR	NR	Doubtful	NR	NR	NR
Mealtime Survey	(Provost et al., 2010) USA	NR	NR	NR	NR	NR	NR
CASD 30-item Consist of feeding problem (5 sub-item: (i) picky eater, (ii) sensitivity to textures, (ii) pica, (iv) peculiar eating pattern (e.g., brand specific), (v) pockets food *# screening and diagnostic instrument for ASD*	(Mayes, 2012) USA	Adequate EFA:PCA (2 factors)	Very good Overall = 0.97	NR	Adequate r = 0.93	Very good Discriminative: ASD vs. ADHD (99.5 %); ASD vs. TD children (100 %) Convergent: Inter-correlations between CARS (0.82) and GADS (0.81)	NR
SP 125-item	(Dunn, 1997) USA	Adequate EFA: PCA (9 factors)	Adequate (Pearson Education, 2008) 0.47 to 0.91	Very good Psychometric properties: (Chuang, Tseng, Lu, & Shieh, 2012) Chinese (Kayihan et al., 2015): Turkish (Crasta et al., 2014) India	Very good (Ohl et al., 2012) test-retest: ICC (2,1) = 0.80–0.90 for 4 quadrants; ICC (2, 1) = 0.69–0.88 for factor scores; ICC (2,1) = 0.50–0.87 for section scores	Very good Discriminative: TD vs. ASD vs. ADHD	Very good SEM = 1.0–2.8
SSP 38-item	(McIntosh et al., 1999) USA	NR Shorter version from SP 125-item for screening and research purpose	Very good r = 0.70 to 0.90	Very good Psychometric properties: (Ee, Loh, Chinna, & Marret, 2016): Malay CFA: RMSAE = 0.05; TLI = 0.91; CFI = 0.92 (Engel-Yeger, 2010): Hebrew: EFA (7 factors)	Adequate (Ee et al., 2016) Seven sections (ICC) = 0.84–0.96	Very good Discriminative: 95 % children with vs. without sensory difficulties Convergent: Inter-correlation between subsections: r = 0.25–0.76	NR

Abbreviations: NR, Not neported; BAMBI, Brief Autism Mealtime Behaviour Inventory; CEBI, Children's Eating Behaviour Inventory; CEBQ, Child Eating Behaviour Questionnaire; BPFAS, Behavioral Paediatrics Feeding Assessment Scale; MIOH, Meals in Our Household Questionnaire; MBQ, Mealtime Behavioural Questionnaire; SP, Sensory Profile; SSP, Short Sensory Profile; CASD, Checklist for Autism Spectrum Disorder; YAQ, Youth/Adolescent Questionnaire; GARS, Gilliam Autism Rating Scale; CARS, Childhood Autism Rating Scale; GADS, Gilliam Asperger Disorder Scale; ADOS, Autism Diagnostic Observation Schedule; CBCL, Child Behavior Checklist; SRS, Social Responsiveness Scale; RBS-R, Repetitive Behavior Scale-Revised; M-P-R, Merrill-Palmer-Revised; PLS-4 Preschool Language Scale, Fourth Edition; VABS-II, Vineland Adaptive Behavior Scales, Second Edition; CSHQ, Children's Sleep Habits Questionnaire; PSISF, Parenting Stress Index-Short Form; TD, typically developing; ASD, Autism Spectrum Disorder; ADHD, Attention Deficit Hyperactive Disorder; EFA, exploratory factor analysis; CFA, confirmatory factor analysis, PCA, principal component analysis; CFI, comparative fit index; TLI, Tucker–Lewis index; RMSEA, root mean square error of approximation; ICC, intra-class correlation coefficient; SD, standard deviation; SEM, standard error of measurement; SDC, small detectable change; Sn, sensitivity; Sp, specificity; PPV, positive predictive value.

Tomova et al., 2020), and zinc (Barnhill et al., 2018; Hyman et al., 2012). Conversely, Zimmer et al. (2012) reported a higher magnesium intake in children with ASD than in TD children (Table 2). Nevertheless, the most consistent nutritional findings from studies included in the review demonstrated that children with ASD have calcium and vitamin D inadequacies, with a DRI < 80 % (Bandini et al., 2010; Barnhill et al., 2018; Hyman et al., 2012; Marí-Bauset et al., 2015; Sun et al., 2013; Zimmer et al., 2012).

3.3.3. Biochemical analysis in relation to nutrient intake

Biochemical assessment is crucial in clinical settings to confirm the diagnosis of specific diseases and determine an individual's nutritional status (Ranjan & Nasser, 2015). Compared with the control group, children with ASD showed significantly lower mineral and vitamin concentrations either in serum or plasma, including iron (Liu et al., 2016), calcium (Sun et al., 2013), and vitamin A (Sun et al., 2013). In contrast, one study reported that vitamin C concentrations in the ASD group were higher than those in the TD group (Meguid et al., 2017) (Table 2).

Al-Farsi et al. (2013) revealed that children with ASD had substantially lower dietary intake and serum levels of folate and vitamin B12 levels than TD children due to higher food selectivity rates and feeding-related problems such as gastrointestinal, pica, and oral motor deficits. These conditions may hinder adequate nutrient intake in children with ASD. In contrast, homocysteine levels were significantly higher, whereas methionine levels were lower in children with ASD, which may be due to inadequate dietary folate and vitamin B12 as the main substances required for methionine synthesis (Al-Farsi et al., 2013). Furthermore, Meguid et al. (2017) reported positive relationships between dietary intake of folate, vitamin B12, calcium, iron, and magnesium and the participants' serum parameters. However, the serum concentrations of all measures were lower concentrations in the children with ASD than in the control group. For instance, Liu et al. (2016) found a significant negative correlation between level of vitamin A levels and the severity of autism (Table 2).

3.4. Methodology quality assessment of measures to identify mealtime behaviours associated with food selectivity and oral sensory sensitivity

A majority of the 94 % ($n = 16$) of articles reviewed in this study used a parent-report questionnaire whereas only 6% ($n = 1$) used semi-structured interviews by healthcare professionals to assess mealtime behaviours (Table 3). Therefore, the rigor of the articles was further assessed using a quality assessment tool. The results show that the majority of the reviewed articles were rated as "not reported" for the validity and reliability of the relevant instruments used to evaluate mealtime behaviours. Notably, only a few studies in this review assessed internal consistency ranging from doubtful (Malhi et al., 2017), adequate (Smith et al., 2020), and very good (Al-Kindi et al., 2016; Handayani et al., 2012). One study rated criterion validity very well, performed by a similar author in a previous psychometric study (Dovey et al., 2019).

In total, eight instruments were reviewed to assess the quality of the methodology for investigating mealtime behaviours associated with food selectivity (Table 4). Unfortunately, we could not locate any information on the validity and reliability of the Eating Profile and Mealtime Survey. Three instruments (i.e., BPFAS, BAMBI, and CEBQ) were rated as having adequate to very good ratings for the assessment of validity and reliability. The BPFAS is the only instrument that outperforms other measures in terms of reliability associated with the calculation values of the measurement error. On the other hand, although the CASD performed quite well for the validity and reliability results of the instrument, it was developed mainly for screening and diagnostic tools and only part of the questions evaluating the problems associated with feeding.

Following oral sensory sensitivity, three studies used parent-reported SP, while SSP was utilised in the remaining four studies to assess sensory processing ability in children with ASD (Table 3). However, the majority of studies rated as "not reported" for the validity and reliability, except one study examined the internal consistency that was rated as "very good" (Smith et al., 2020). Meanwhile, the SP measure had adequate to very good ratings for the six aspects of validity and reliability testing (Table 4).

4. Discussion

This scoping review incorporates evidence from articles published between 2010 and October 2021 on food selectivity and oral sensory sensitivity in children with ASD. Based on our findings, there was a limited conceptual definition of food selectivity resulting from the variability in terminology and different measurement tools used to describe food selectivity. For example, Field et al. (2003) categorised food selectivity by type and texture, where type refers to the limited dietary variety and tendency to omit entire foods from one or more food groups, whereas selectivity by texture refers to the refusal of specific food textures. On the other hand, Bryant-Waugh et al. (2010) classified food selectivity into several clinical terms including selective eating associated with a limited range of food accepted in the diet and common brand specificity, avoiding trying and accepting new foods as a definition of food neophobia, while food refusal due to sensory-based characteristics refers to an aversion to specific characteristics of food (e.g., smell, taste, and texture). Other authors have defined food selectivity as food refusal, limited food preferences, and increased daily consumption of a similar type of food (Bandini et al., 2010). A picky eating spectrum is also described as refusal to eat familiar foods or try new foods to the extent that it disrupts daily activities that may affect parent-child relationships (Ekstein, Laniado, & Glick, 2010). Additionally, food neophobia is a component of a picky eating spectrum related to thefear of trying new foods or reluctance to eat novel foods that have been linked with a diet that is rigidly similar on a daily basis (Dovey, Staples, Gibson, & Halford, 2008). In the present review, the criteria for food selectivity and related terms were identified based on the literature as limited food variety, food refusal, and highly selectivity based on texture, taste, smell, brand, temperature, or mixed foods, and reports on picky eating and food fussiness (Bandini et al., 2010; Cermak et al., 2010; Field et al., 2003).

From the 30 studies included in this review, only two studies measured feeding habits longitudinally; children from 6 months to 54 months, in five repeated measurements (Emond et al., 2010), and from childhood to adolescence, periods measured at two different points of intervals (mean 6.4 years) to evaluate food refusal and food repertoire habits (Bandini et al., 2017). Thus, these cohort studies may reflect complete comparisons of developmental milestones, feeding intake, and difficulties between children with ASD and TD children. The findings from both studies indicated that younger children with ASD were more selective and had more limited food choices than TD children. Although they can tolerate a variety of food textures when they enter adolescence, restricted food choices remain persistent and lead to inadequate consumption of nutrients in the long term.

All six studies that examined the relationship between food selectivity and oral sensory sensitivity (Chistol et al., 2018; Graf-Myles et al., 2013; Hubbard et al., 2014; Shmaya et al., 2017; Smith et al., 2020; Zobel-Lachiusa et al., 2015) demonstrated that smell/taste hypersensitivity might contribute to food refusal and selective eating in children with ASD. For instance, a study showed that 95 % of children with ASD displayed difficulty in tactile and taste/smell processing, which impedes their daily mealtime activities (Tomchek & Dunn, 2007). Suarez et al. (2014) demonstrated a strong relationship between sensory oversensitivity and food selectivity in children with ASD, regardless of age. Furthermore, children with ASD exhibit greater proportion of oral sensory processing differences than children with attention deficit hyperactivity disorder (ADHD) and TD children (Little, Dean, Tomchek, & Dunn, 2018). Parent reports showed that children with ASD who experienced hypersensitivity to texture, taste, smell, and food presentation had a limited food repertoire and rejected new foods more frequently (Field et al., 2003; Marshall et al., 2013; Martins, Young, & Robson, 2008; Schreck & Williams, 2006). According to Bennetto, Kuschner, and Hyman (2007), children with ASD have a considerable difficulties in smell and taste detection compared to TD children, particularly for sour and bitter tastes. Moreover, children with ASD presenting with oral hypersensitivity had a significantly lower fibre intake, particularly in fruits and vegetables, and exhibited more difficulties during mealtimes than children on the spectrum with typical oral processing (Marshall, Hill, Ware, Ziviani, & Dodrill, 2016).

Compared with TD children, although energy intake did not differ in both groups for the majority of the studies, inadequate intake of micronutrients was reported in children with ASD for vitamins A, B6, B12, C, D, folate, and minerals such as calcium, iron, and zinc (Barnhill et al., 2018; Emond et al., 2010; Hyman et al., 2012; Malhi et al., 2017; Marí-Bauset, Llopis-González et al., 2014; Marí-Bauset, Zazpe et al., 2014; Meguid et al., 2017; Sun et al., 2013; Tomova et al., 2020; Zimmer et al., 2012;). Five studies mentioned a similarity in BMI values between children with ASD and the control group. However, children with ASD had significantly reduced consumption of micronutrients that were associated with a limited food repertoire and selective eating habits (Barnhill et al., 2018; Emond et al., 2010; Malhi et al., 2017; Tomova et al., 2020; Zimmer et al., 2012).

Previous studies have explored nutritional assessments and health-related consequences of inadequate micronutrient intake. For instance, Chiu and Watson (2015) published a case report on children with ASD presenting with clinical symptoms of vitamin A deficiency; xerophthalmia, a progressive eye disorder associated with night blindness due to a restrictive and low-quality diet consisting of only nuggets and chips. In addition, studies have indicated that children with ASD who have limited dietary ranges with the long-term exclusion of fruit and vegetables have skin hematomas, gingival inflammation, and difficulty walking independently due to vitamin C deficiency (Niwa et al., 2012; Swed-Tobia et al., 2019). Similarly, Ma, Thompson, and Weston (2016) revealed that the incidence of scurvy is associated with heightened sensory input to texture, smell, or taste in children with ASD and children with sensory processing disorder (SPD) which led to selective eating.

Moreover, selective eating patterns and prolonged inadequate dairy consumption may predispose children with ASD to rickets linked to calcium and/or vitamin D deficiency (Tripathi, Shankar, & Baghdassarian, 2018). In addition, children with ASD have a greater risks of low bone mineral density (MBD), which results in an increased incidence of bone fractures which later reduce physical activity. This circumstanceis associated with specific dietary practices (e.g., GFCF diet), and the use of certain medications to treat psychiatric-related illness and seizure conditions (Srinivasan, O'Rourke, Bersche Golas, Neumeyer, & Misra, 2016). Furthermore, children with ASD who presented with vitamin A and D deficiencies were shown to had significantly higher ASD scores and autism traits compared to their non-ASD peers (Guo et al., 2019). However, it is relevant to note that this observational study could not determine causal relationships further. Interestingly, recent studies provided an appropriate dosage of vitamin D_3 supplementation for three months in children with ASD who had lower serum 25−hydroxy vitamin D(25(OH)D) levels ($<$ 30 ng/mL) showed significantly greater social, behavioural, and concentration improvements in the participants (Feng et al., 2017; Saad et al., 2015).

It has also been reported that inadequate iron intake affects behavioural, speech, and cognitive functions in children with ASD (Latif, Heinz, & Cook, 2002). Atypical eating behaviours, oral motor deficits, and inadequate intake of quality protein foods have been identified as significant contributing risk factors in iron deficiency and iron-deficiency anaemia (IDA) among children with ASD and children with global developmental delay (GDD) (Sidrak, Yoong, & Woolfenden, 2014; Yanagimoto, Ishizaki, & Kaneko, 2020). Evidence from a meta-analysis by Miao, Young, and Golden (2015) also indicated that low iron and/or zinc levels are correlated with pica behaviour, a condition of mouthing non-food objects such as dirt, mud, sand, or ice chips in children with ASD. Zinc is an essential mineral that plays a vital role in the activity and regulation of neurotransmitter. Babaknejad, Sayehmiri, Sayehmiri, Mohamadkhani, and Bahrami (2016) demonstrated that children with ASD had significantly lower plasma zinc levels than their TD peers, related to the risk of behaviour-related autistic symptoms.

Addressing the sample size was the initial step of the research methodology. A few studies had a small sample size ($n < 50$), which that could further prevent the generalisation of the findings (Bandini et al., 2017; Provost et al., 2010; Zimmer et al., 2012). According to the methodological quality, only a few of the included studies applied Cronbach's alpha to determine the psychometric properties of the measures used to evaluate food selectivity and oral sensory sensitivity. Since most of these studies were undertaken in Western countries, the original instrument may have been used because it was designed and validated in a similar setting and conversing in the same language. However, several studies included in this review were rated as doubtful in terms of cross-cultural validity because they did not provide sufficient information about their methodologies to fulfill the COSMIN's criteria (Al-Kindi et al., 2016; Handayani et al., 2012; Malhi et al., 2017; Nadon et al., 2011). Moreover, it is important to conduct a factor analysis in the studies involving different countries with diverse cultures and languages. The strength of most studies included in this review is the utilisation of validated and reliable assessment tools, either single or in combination, for the evaluation process. Only one study relied solely on a diagnostic tool for children with ASD, the checklist for ASD (CASD), to assess food selectivity (Mayes & Zickgraf, 2019).

This study had several limitations identified in this review. Only English-language publications and full-text articles were considered because of limitations in understanding publications in other languages. In addition, only three primary databases were used; EBSCO Discovery, Science Direct, and Scopus, to identify relevant studies that matched our review objectives due to limited access.

4.1. Implications for practice

This review elucidates the risk of micronutrient inadequacy relative to food selectivity and oral sensory sensitivity in children with ASD. A recent responsive feeding framework suggested a requirement for a positive connection towards eating among children with food refusal that consists of three essential key elements: (a) early exposure to food without pressure by engagement in food preparation at the kitchen level; (b) building individual skills through experience, and (c) having a trustworthy relationship between parents and children (Cormack, Rowell, & Postăvaru, 2020). Furthermore, multidisciplinary team collaboration is essential for the overall management of feeding difficulties in children with ASD. The multidisciplinary team incorporates four important health professionals including an occupational therapist (OT), for individualised sensory integration therapy; speech-language pathologist (SLP), for evaluation of oral-motor disabilities that might impact on food intake; registered dietitian (RD), for assessment of nutritional status and individualised dietary intervention plan; and behavioural therapist/clinical psychologist to manage behavioural issues in children with ASD (Smith et al., 2020; Twachtman-Reilly et al., 2008; Zimmer et al., 2012).

In a clinical setting, it is suggested to include the assessment of mealtime behaviours and oral sensory processing using validated instruments as part of routine medical evaluations for children with ASD who exhibit selective eating patterns. Furthermore, the assessment may be particularly important during the transition periods (e.g., from preschool to school to college), as these periods involve multiple new social situations in new settings that could influence the distinct patterns associated with feeding-related behaviours. Additionally, children with ASD should be routinely screened for biochemical analysis to evaluate their nutritional status rather than depend on anthropometric measures alone (Liu et al., 2016; Ranjan & Nasser, 2015). Finally, knowledge gaps at the practice level should be the subject of future work (e.g., equip health practitioners with updated evidence-based knowledge, and skills, and family empowerment by involving caregivers in assessment and intervention strategies to manage food selectivity).

5. Conclusion

In summary, food selectivity is more common in children with ASD than in those TD. Previous studies have highlighted that hypersensitivity to oral stimuli can exacerbate this problem. Inadequate micronutrient intake in children with ASD was also found more prevalent than in TD peers, including vitamin A, vitamin B6, folate, vitamin B12, vitamin C, vitamin D, calcium, iron, magnesium, and zinc due to food selectivity. Therefore, health practitioners should consider the relationship between food selectivity and oral sensory hypersensitivity in assessment and intervention protocols for children with ASD. Unique dietary habits displayed by children with ASD require multidisciplinary intervention strategies to minimise food-avoidant behaviours that may hamper their nutritional status and cognitive and social-behavioural performances. To date, no instrument has comprehensively evaluated food selectivity and oral sensitivity. Nevertheless, the BPFAS, BAMBI, CEBQ, and SP showed satisfactory results in the six methodology quality assessments for validity and reliability testing.

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Author contributions

NHH and MNZ devised the main conceptual ideas and outline of the review. MNZ wrote the review and conducted the literature search with support from NHH and MK. NHH, MK and MF provided their expertise and critically revised the article for important intellectual content and editing. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare no conflict of interest.

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