Running title: Sensory sensitivity and food fussiness in neurodevelopmental disorders

The relationship between sensory sensitivity, food fussiness and food preferences in children with neurodevelopmental disorders

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Abstract

Heightened sensitivity to sensory information has been associated with food fussiness in both atypical and typical development. Despite food fussiness and sensory dysfunction being reported as common concerns for children with neurodevelopmental disorders, the relationship that exists between them, and whether they differ between disorders, has yet to be established. The current study aimed to examine sensory sensitivity as a predictor of food fussiness in three different neurodevelopmental disorders, whilst controlling for comorbidity amongst these disorders. Ninety-eight caregivers of children with Attention Deficit Hyperactivity Disorder (ADHD; n=17), Tourette Syndrome (TS; n=27), Autism Spectrum Disorder (ASD; n=27), and typical development (TD; n=27) were compared using parental reports of child food fussiness, food preferences and sensory sensitivity. Children with neurodevelopmental disorders were reported to have significantly higher levels of both food fussiness and sensory sensitivity, with children with ASD and TS also showing significantly less preference for fruit than children with TD. Importantly, higher levels of taste/smell sensitivity predicted food fussiness for all four groups of children. In addition, taste/smell sensitivity fully mediated the differences in food fussiness between each group of neurodevelopmental disorder compared to the TD group. The findings highlight that food fussiness is similar across these neurodevelopmental disorders despite accounting for comorbidity, and that greater sensitivity to taste/smell may explain why children with neurodevelopmental disorders are more likely to be fussy eaters.

Keywords: Tourette syndrome; Attention Deficit Hyperactive Disorder; Autism Spectrum Disorder; food fussiness; sensory sensitivity

1. Introduction

Neurodevelopmental disorders comprise a broad range of conditions emerging in childhood and are primarily associated with impairments in the development of the central nervous system and the brain (Posthuma & Polderman, 2013). These can encompass a range of aetiologies, including a known mutation on a single gene (Fragile X syndrome), disorders with polygenetic or unknown genetic origins (e.g. Attention Deficit Hyperactivity Disorder [ADHD], Autism Spectrum Disorder [ASD], Tourette Syndrome [TS]), and disorders from early/perinatal factors (e.g. cerebral palsy; Cascio, 2010). Population-based twin studies have shown high genetic correlations between

ASD, tic disorders and ADHD (Lichtenstein, Carlström, Råstam, Gillberg & Anckarsäter, 2010), and it is this group of disorders which formed the focus of the current study.

Each of these three neurodevelopmental disorders, as defined in the DSM-5, are characterised by a distinct set of diagnostic features, such that TS is characterised by involuntary, repetitive and non-rhythmic motor and vocal tics, ADHD by excessive and impairing inattentive, hyperactive and impulsive behaviour, and ASD by language development, social and communication deficits (American Psychiatric Association, 2013). Despite this, these disorders have also been recognised as sharing many overlapping features, in addition to being highly comorbid with each other. For example, ADHD is diagnosed in 60% of individuals with TS (Freeman et al., 2000). Recent studies have also documented that TS is comorbid with ASD (Cath & Ludolph, 2013), with research showing the presence of autistic symptoms in two thirds of individuals with TS (Kadesjö & Gillberg, 2000), and the relationship between autism symptomology in TS is particularly strong for individuals with early onset of TS (Zappella, 2002). Furthermore, it is estimated that 50% of individuals with ADHD will meet the criteria for diagnosis of ASD (Kochhar et al., 2011). Importantly in the context of the current study, individuals with these disorders have also all been identified as showing difficulties with feeding and eating concerns which extend beyond the developmental stages of childhood, in which feeding and eating problems are very common (Johnson, 2014). This raises the possibility that the comorbidity of these disorders may explain their similarities in eating outcomes.

More specifically, the two eating outcomes which form the focus of this paper are food preferences, understanding the likings of different food groups, and children's behaviour towards food in terms of fussiness. Food fussiness can be defined as consuming 'an inadequate variety of foods' (Galloway, Fioritio, Lee & Birch, 2005, p. 542). Caregivers commonly report food fussiness in children with typical development, with around 46% of children reported as being picky eaters at some point between 1.5 and 6 years (Cardona-Cano et al., 2015). Although picky/fussy eating are relatively stable traits (Mascola et al., 2010), a substantial proportion of children show reductions in picky eating by 6 years (Cardona-Cano et al., 2015). In contrast, food fussiness is more frequent and persistent in children with neurodevelopmental disorders (Bandini et al., 2017; Suarez, Atchison & Lagerwey, 2014). For example, food fussiness has been found to be one of the most commonly reported feeding problems in children with ASD (Williams, Field & Seiverling, 2010), with a narrow range of foods being selected based on food type, temperature, texture and colour (Seiverling, Williams & Sturmey, 2010). This is important, given the emotional and health implications of food fussiness (Dovey, Staples, Gibson & Halford, 2008). Research has identified fussy eaters to consume fewer foods containing vitamin E, C and fibre, likely due to their low intake of fruit and vegetable. A lack of nutrient-rich foods can lead to nutritional deficiencies, including magnesium and iron deficiencies, as well as slower growth patterns (Xue et al., 2015; Antoniou et al., 2016). Food fussiness has also been associated with additional stress and frustration for the child and their families (Rogers et al., 2012; Curtin et al., 2015), along with difficulty eating in social environments (Nadon et al., 2011). These various adverse effects highlight the need for interventions to increase food intake, in terms of variety and healthy foods, in children with fussy eating.

For children with typical development, research has established several methods to encourage children to reduce food fussiness and increase consumption of fruit and vegetables. These include parent modelling, which can help increase consumption of novel foods through observational learning, and repeated re-offering of food to help familiarise the child with the foods until they are willing to try (Holley, Haycraft & Farrow, 2015; Wardle, Carnell & Cooke, 2005). However, not only have children with heightened levels of food fussiness been shown not to respond to these methods in the same manner as typically developing (TD) children (Wolke, Schmid, Schreier & Meyer, 2009), research addressing these interventions in children with neurodevelopmental disorders is limited.

Recommendations often given to parents, such as only presenting family meals instead of the child's preferred foods, have found to be ineffective for children with ASD who have feeding problems and may lead to severe nutritional deficiencies (Rogers et al., 2012). Behavioural interventions, such as behavioural momentum (Patel et al., 2007) have been reported to be effective in reducing feeding problems and increasing food consumption in children with ASD. However, these are single case studies and pre-post intervention studies are needed to demonstrate the generalisability of treatment effects (Matson & Fodstad, 2009). Ultimately, it is important to understand the underlying aetiology of food fussiness in these clinical groups to devise the most effective intervention strategy.

Given the comorbidity between TS, ASD and ADHD, it is important to understand whether the underlying causes of food fussiness is syndrome specific or the shared pathologies across the three neurodevelopmental disorders accounts for the high levels of food fussiness evidenced in these groups of children (Smith, Rogers, Blissett & Ludlow, 2019). One potential explanation for food fussiness is the associated pathologies unique to the disorder. For example, some feeding difficulties may reflect limited interests and difficulty in accepting change (Curtin et al., 2015). Evidence also suggests that children with heightened motor impulsivity and reduced inhibitory control and/or characteristics of ADHD weigh more. Children with ADHD are also more susceptible to altered food intake patterns dependent on stressors, such as distress or external cues including the time of day (Bennett & Blissett, 2017).

A common feature of all three neurodevelopmental disorders is an impairment in sensory processing, which could provide an alternative explanation for food fussiness. Impaired sensory processing may lead to over-responsiveness to stimuli (resulting in more fussy eating), or under-responsiveness to stimuli (which may result in a desire for more sweet, salty or fatty foods). Both sensory processing issues have been shown to limit the range of food consumed and social enjoyment of eating (Johnson et al., 2014). Furthermore, in children with both typical and atypical development, the perceived sensory properties of food are often considered to underlie children's reasons for rejecting food (Martins & Pliner, 2005). The focus of the current study is to explore sensory over-responsiveness across these neurodevelopmental disorders in relation to food fussiness.

Individuals with sensory over-responsiveness "respond to sensation faster, with more intensity, or for a long duration than those with typical sensory responsivity" (Miller, Anzalone, Lane, Cermak & Osten, 2007, p.136). This increased sensitivity to sensory information, such as taste, smell and touch, has been identified as an inherent characteristic that makes one particularly vulnerable to be a fussy eater. For example, a reluctance to eat new foods and/or eat fruit and vegetables has been associated with higher levels of tactile and taste/smell sensitivity (Coulthard & Blissett, 2009). For example, tactile oversensitivity has also been shown to have an impact upon the eating habits and food selection in children with and without atypical development (Cermak, Curtin & Bandini, 2010). High levels of taste/smell sensitivity (Tomchek & Dunn, 2007), and difficulty with texture have been associated with a lack of variety in the diet in children with ASD (Schmitt, Heiss, & Campbell, 2008), and TS (Smith et al., 2019). Importantly, oral sensitivity which also forms part of tactile sensitivity, has also been associated with food fussiness in children with ASD and ADHD (Chistol et al., 2018; Ghanizadeh, 2013). Greater prevalence of sensory sensitivities have been found in children with children with ASD (Bizzell, Ross, Rosenthal, Dumont, & Schaaf, 2019; Simpson, Adams, Alston-Knox, Heussler, & Keen, 2019), ADHD (Ghanizadeh, 2011; Lane, Reynolds, & Thacker, 2010), and TS (Belluscio, Jin, Watters, Lee & Hallett, 2011) compared to TD children. The relationship between sensory processing and food fussiness in children with these neurodevelopmental disorders, without comorbidity within these disorders, therefore warrants further investigation.

Despite the similarities in food fussiness found across these neurodevelopmental disorders, there has been no research carried out directly comparing food fussiness across different neurodevelopment disorders and/or examining which factors are particularly associated with eating difficulties in children without comorbid neurodevelopmental disorders. The current study therefore aimed to be the first study to directly compare food fussiness and food preferences, along with the role of sensory sensitivity in predicting these eating outcomes, amongst children with ADHD, ASD, TS and TD children. It was hypothesised that children with neurodevelopmental disorders would display higher levels of food fussiness and sensory sensitivity than TD children, and that levels of food fussiness would be comparable across each neurodevelopmental disorder despite no other comorbid disorder being present. It was also predicted that sensory sensitivity would be a predictor of eating outcomes for all groups of children.

2. Method

2.1 Participants

One hundred and thirteen mothers reported information on their children between Spring 2017 and Autumn 2018. Children were screened for missing data (N = 6) and comorbidity for other neurodevelopmental disorders (N = 7; 2 TS were removed for having comorbidity with ASD, 1 TS with ADHD, 3 ASD with ADHD, and 1 TS with ADHD and ASD) by asking caregivers for their child's full diagnosis and whether they had been diagnosed with any additional disorders. Data from 98 mothers aged 25-67 years (M=40, SD=1) remained. Twenty-seven children had a diagnosis of TS, 27 had a diagnosis of ASD, 17 had a diagnosis of ADHD, and 27 were typically developing children with no known clinical diagnosis (5 females, 22 males) recruited through local schools and forums. The groups did not differ in age, F (3,98) = .64, p = .59.

2.1.1 Children with Tourette syndrome

Twenty-seven children with a clinical diagnosis of TS (5 females, 22 males) were aged between 6 years 7 months and 15 years 11 months. Caregiver report of a TS diagnosis and the Premonitory Urge for Tics Scale (PUTS; Woods, Piacentini, Himle, & Chang, 2005) were used to confirm children's status in the TS group only. This measure reflects the presence and frequency of premonitory urges, along with the relief that may be experienced after tics have been performed, and is a tool used to estimate impact of symptoms. A score above 31 indicates extremely high intensity with probable severe impairments. In the current sample scores ranged from 9 to 35 (M=22, SD = 5). Of the children with TS taking medication (n = *13*), the most commonly reported was melatonin (n = 6). Other prescription drugs recorded were sertraline (n = 4) and clonidine (n = 2).

2.1.2 Children with Autism Spectrum Disorder

Twenty-seven children with a clinical diagnosis of an ASD (11 females, 16 males) were aged between 6 years 7 months and 17 years. Children with ASD were required to meet the appropriate cut off on the Autism Spectrum Screening Questionnaire (ASSQ; Ehlers, Gillberg, Wing, 1999). The ASSQ comprises 27 items rated on a 3-point scale, 0 indicating normal, 1 some abnormality and 2 definite abnormality. The range of score is 0–54. Eleven items tap topics regarding social interaction, six cover communication problems and five refer to restricted and repetitive behaviour. The remaining five items measure motor clumsiness and other associated symptoms including motor and vocal tics. All children reached the cut-off scores of 19 or more (M = 27, SD = 7), with mean scores on subscales: Social Interaction (M = 11, SD = 7), Communication (M= 8, SD = 3), Restrictive and Repetitive Behaviours (M = 4, SD = 2), and Motor skills and clumsiness (M =4, SD = 2). Of the children with ASD taking medication (n = 15), the most commonly reported was melatonin (n = 6). Other prescription drugs recorded were Prozac (n = 2) and clonidine (n = 2).

2.1.3 Children with Attention Deficit Hyperactive Disorder

Seventeen children with a clinical diagnosis of ADHD combined type. (7 females, 10 males) were aged between 6 years 2 months and 16 years 8 months. All of the children met the required T-score of 65 or above on the Connors' Parent Rating Scale-Revised (CPRS-R; Conners et al., 2008). Children's T-scores were reported as follows on the content scales: Inattention (*M* = 85, *SD* = 7), Hyperactive/Impulsive (*M* = 86, *SD* = 6); Learning Problems (*M* = 77.57, *SD* = 10.29), Executive Functioning (*M* = 84, *SD* = 10), Aggression (*M* = 77, *SD* = 16), Peer Relations (*M* = 86, *SD* = 6), and for the symptom scales: DSM-IV ADHD Inattention (*M*=84, *SD* = 9), DSM-IV ADHD Hyperactivity-Impulsive (*M* = 87, *SD* = 6), Conduct Disorder (*M* = 70, *SD* = 19), and Oppositional Defiant Disorder (*M* = 79, *SD* = 12).

2.2 Measures

Demographic variables collected included: child's sex, birth date, any clinical diagnosis including comorbid disorders. Caregivers were asked to provide a measurement of their child's weight and height, which was then converted to a BMI standard deviation score (SDS). The Child Growth Foundation Package (1996) was used to standardise the measurements for age and sex according to standardised norms for a UK sample. Caregivers were also asked to describe their age, ethnicity and their relation to the child. Finally, all caregivers were asked to complete the following questionnaires:

2.2.1 The Short Sensory Profile (SSP; McIntosh, Miller, Shyu & Dunn, 1999)

The SSP is a 38-item an adapted version of the original Sensory Profile (Dunn, 1999) designed to assess children's responses to sensory stimuli. The three subscales from the questionnaire, which have been found to be common correlates of food fussiness, were used to assess children's tactile sensitivity (e.g. avoids going barefoot, especially in grass and sand), taste/smell sensitivity (e.g. avoids tastes or food smells that are typically part of a child's diet), and visual/auditory sensitivity (e.g. covers eyes, or squints to protect eyes from light). Caregivers responded to items on a 5-point Likert scale ranging from 1 (always) to 5 (never) with lower scores indicating higher sensory sensitivity. SSP total scores can range from a minimum of 38 (greatest frequency of sensory symptoms) to 190 (no sensory symptoms). McIntosh et al., (1999) have shown good psychometric properties internal consistency of the total and subscale scores (Cronbach's alpha ranged from 0.68 to 0.92) with a discriminant validity of 95% in distinguishing children with and without sensory modulation difficulties. In the current study good to excellent internal reliability was found for the subscales used; tactile sensitivity (Cronbach α=.88), taste/smell sensitivity (Cronbach α=.95), visual/auditory sensitivity (Cronbach α=.90).

2.2.2 The Food Preference Questionnaire for children (FPQ; Fildes et al., 2015)

The FPQ requires caregivers to rate their child's liking for 75 commonly consumed individual foods from 6 food groups: fruit, vegetables, meat/fish, dairy, snacks and starches. Originally developed using data from a cohort of United Kingdom twins born in 2007 Gemini study (n=2686), the food items on the questionnaire are rated on a 5-point Likert scale, ranging from 1 (dislikes a lot) to 5 (likes a lot), with an option of 'never tried' which is scored as a missing response. The mean score of items pertaining to each subscale was calculated, with the higher the score indicating an increased like towards the given food category. This measure has been used to understand the children's food preferences longitudinally (Skinner, Carruth, Bounds & Ziegler, 2002) and food preferences have been previously found to be a predictor of food consumption (Drewnowski & Hann, 1999). In terms of psychometric properties, the current study found a good to excellent internal reliability for the food groups; fruit (Cronbach α=.95), vegetables (Cronbach α=.93), meat/fish (Cronbach α=.92), snacks (Cronbach α=.82), dairy (Cronbach α=.74), however the reliability for the starch subscale was lower (Cronbach α=.66).

2.2.3 The Children's Eating Behaviour Questionnaire (CEBQ: Wardle, Guthrie, Sanderson & Rapoport, 2001)

The Children's Eating Behaviour Questionnaire (CEBQ) is a 35-item parent-report questionnaire that assesses individual eating styles of children. The food fussiness subscale of the CEBQ was used in the current study to assess parental perceptions of their child's food fussiness behaviour (Sandvik, Ek, Eli Somaraki, Bottai & Nowicka, 2019). This subscale consists of six items and includes how difficult the child is to please with meals; how often the child refuses to taste new foods subscale (food neophobia) and the variety of foods the child will eat (picky eating). Caregivers rated the frequency of which the child exhibits the behaviour on a 5-point Likert scale ranging from 1 (never) to 5 (always). An average of the six food fussiness items was calculated. A high score indicates that the child displays high levels of food fussiness. Development of the questionnaire revealed good internal reliability coefficients

(Cronbach's alpha) for all the subscales, ranging from 0.74 to 0.91 (Wardle et al., 2001). In the present study Cronbach's alpha for food fussiness was 0.68.

2.3 Procedure

Ethical approval for this research was obtained from the University of Hertfordshire University Ethical Advisory Committee Protocol Number: aLMS/PGT/UH/02784(4) and the research was performed in accordance with the Declaration of Helsinki. Participants were recruited through Tourettes Action, National Autistic Society charity online website, online forums, local organisations, and mainstream and Special Education Needs (SEN) schools who agreed to advertise the study. Participants volunteered to partake by clicking on the given link, which directed them to the online survey. The online participant information sheet provided further details about the study, and those wishing to continue were required to provide informed consent by signing an online consent form. Following this, every participant was presented with the questionnaires in the same order. Information on how to seek further advice if the parents had any concerns regarding their child's eating behaviours was also provided. The survey took approximately 25 minutes to complete and was active for two months. Families were provided no incentive to take part. At the end of the study, participants were provided details of support groups for any concerns around difficulties in their child's eating behaviours and reminded how to they could withdraw their data from the study.

2. 4. Analysis

A one-way ANOVA was first computed to compare differences in BMI SDS between groups. Secondly, an independent t-test was conducted to examine whether there were sex differences in outcome measures; Levene's test examined homogeneity of variance and significance was reported appropriately. Subsequently, Two-tailed Pearson's correlations were used to establish whether child age or BMI SDS were related to food fussiness.

To investigate differences between the children with and without neurodevelopmental disorders, a series of one-way ANOVAs and post-hoc tests were conducted for each of the questionnaires (SSP, FPQ & CEBQ). To examine whether sensory sensitivity was a predictor of eating outcomes in the four groups (TS, ASD, ADHD & TD), a series of multiple linear regressions were carried with three of the sensory subscales (tactile, taste/smell, visual/auditory) as a predictors of food fussiness.

Mediational analyses were used to evaluate differences between each group of neurodevelopmental disorders compared to TD in relation to food fussiness, and to examine whether sensory sensitivity mediated this relationship. Three separate mediations were carried out using the procedure and macros provided by Preacher and Hayes (2008). The effect of the group (coded 0 =TD, 1 = clinical group) was used as an independent predictor of food fussiness in separate analyses for each clinical group, including taste/smell sensitivity as a mediator of this relationship. Categorical data has been shown to be appropriate to use as an independent variable in a mediation analysis (Iacobucci, 2012). The recommendations of Hayes (2013) were followed, using dummy coding to represent comparisons of interests and using the asymmetric bootstrap Confidence Interval.

3. Results

3.1. Descriptive statistics

A one-way ANOVA revealed no significant differences in BMI SDS between the four groups of children, F (3, 73) = 1.05, $p < .38$. Across the total sample of children, two-tailed Pearson's correlations indicated that child food fussiness was not significantly associated with child age, r (99) = -.115, p = .26), or BMI SDS, r (75) = -.059, p = .61).[1] An independent samples t-test revealed no significant difference in food fussiness between males and females when comparing the total sample of children, t = (96) = .26, p = .13. Therefore, these measures were not controlled for in further analyses. Two-tailed Pearson's correlations were also carried out to see if food fussiness was associated with any of the symptom measures in children with neurodevelopmental disorders. For children with TS, PUTS total was not significantly correlated with food fussiness, r (24) = -.24, p = .26. For the children with ASD, the ASSQ total was not significantly correlated with food fussiness, r (26) = .17, p = .41. For children with ADHD, none of the subscales from Conner's parent rating scale significantly correlated

[1] Food fussiness did not correlate with age or BMI SDS when split into diagnostic groups.

with food fussiness, including DSM-IV Inattention, *r* (15) = .28, *p* = .31, DSM-IV Hyperactivity, *r* (15) = .28, *p* = .38.

3.2. Differences in food fussiness, food preference and sensory sensitivity

To examine whether there were group differences in food fussiness, measured by the CEBQ, a one-way ANOVA was conducted. The results revealed significant differences between the groups on food fussiness, *F* (3, 97) = 6.29, *p* = .001. Tukey's HSD post hoc tests, as shown in Table 1, revealed children with TS (*p* = .004), children with ASD (*p* = .001), and children with ADHD (*p* = .02) to have significantly higher levels of food fussiness compared to children with TD. There were no significant differences in food fussiness between the three different clinical groups (TS vs ASD *p* = .99; ADHD vs TS *p* = .99; ADHD vs ASD *p* = .98). Mean scores and standard deviations are shown in Table 1.

Table 1: Mean scores (standard deviation) for each of the questionnaires for children with neurodevelopmental disorders and typically developing children.

	TD (n=27)	TS (n=27)	ASD (n=27)	ADHD (n=17)
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Demographics				
Age	9.7(2.4)	10.2(2.6)	10.4(3.2)	10.8(3.6)
Height	143.5(16.5)	146.7(17.6)	144.7(26.4)	147.8(28.0)
Weight	37.4(18.4)	39.4(17.8)	42.4 (19.2)	60.5(10.6)
BMI SDS kg/m^2	-.5(1.9)	.6(4.1)	.9(1.3)	.6(2.2)
CEBQ				
Fussiness	3(1.0)	4(1.3)	4(1.02)	4(.9)
FPQ				
Meat/Fish	4(.5)	4(.8)	4(1.0)	4(.6)
Dairy	3(.6)	3(.8)	3(.8)	4(.8)
Starches	4(.6)	4(.7)	3(1.1)	3(.7)
Snacks	4(.7)	4(.6)	4(.5)	4(.6)
Fruit	4(.6)	3(1.0)	3(1.2)	4(.6)
Vegetables	3(.8)	3(1.0)	3(1.1)	3(.8)
Sensory Profile				
Tactile	32(5.0)	22(6.6)	23(6.7)	25(5.0)
Taste/Smell	18(3.1)	11(6.1)	11(5.5)	13(4.1)
Visual/Auditory	24(2.2)	16(5.9)	13(5.4)	19(5.0)
Overall	165(23.6)	114(30.2)	127(45.9)	112(20.9)

To examine whether there were group differences in preference to food categories, as defined by the FPQ, a series of one-way ANOVAs were conducted. The results revealed significant differences between the groups on the following food categories: Starch, *F* (3, 97) = 4.97, *p* = .003, Fruit, *F* (3, 98) = 7.64, *p* < .001 and Vegetables *F* (3, 98) = 3.41, *p* = .02.. There were no significant differences for Meat, *F* (3, 96) =2.32, *p* = .08; Dairy, *F* (3, 97) = .62, *p* = .61; Snacks, *F* (3, 97) = .77, *p* = .52. To further explore the group differences in preference for starch and fruit and vegetables, post-hoc Tukey's HSD tests were conducted. Children with TS (*p* = .002) and children with ASD (*p* < .001) had significantly lower preference for fruit than TD children. Children with ASD (*p* = .011) had significantly lower preference for vegetables than TD children. The children with TS (*p*= .02) and TD children (*p* = .005) had a significantly greater preference for starch than children with ASD. The remaining comparisons did not yield significant differences in these food categories, and there were no differences in preference for any food categories between children with ADHD and the other groups.

Finally, to examine whether there were group differences in sensory sensitivity, the SSP total score and three selected subscales were analysed through a series of one-way ANOVAs. The results revealed significant differences between the groups on overall sensory sensitivity, *F* (3, 97) = 14.25, *p* < .001; taste/smell, *F* (3, 96) = 11.07, *p* < .001; tactile *F* (3, 96)= 14.52, *p* < .001; and visual/auditory sensitivity, *F* (3, 97) = 23.29, *p* < .001. Compared to TD children, post-hoc Tukey's HSD tests revealed children with TS, children with ASD and children with ADHD showed greater overall sensitivity (*p* <.001), and greater sensitivity to the following: taste/smell (TS, ASD and ADHD *p* < .001), tactile (TS *p* < .001; ASD *p* < .001; ADHD *p* = .002), and visual/auditory information (TS *p* < .001; ASD *p* < .001; ADHD *p* = .003). There were no significant differences between the three neurodevelopmental groups on any of the four sensory measures tested.

3.3. Multiple regressions

Multiple linear regression analyses were carried out to explore the relationship between the individual sensory subscales as predictors of food fussiness, and these were all entered into the model in the same step. As shown in table 2, taste/smell sensitivity was found to be the only significant predictor for food fussiness in all groups.

Table 2: Standard Coefficients of the three sensory profile subscales predicting food fussiness

	Tactile	Taste/	Visual/	R^2	*F*

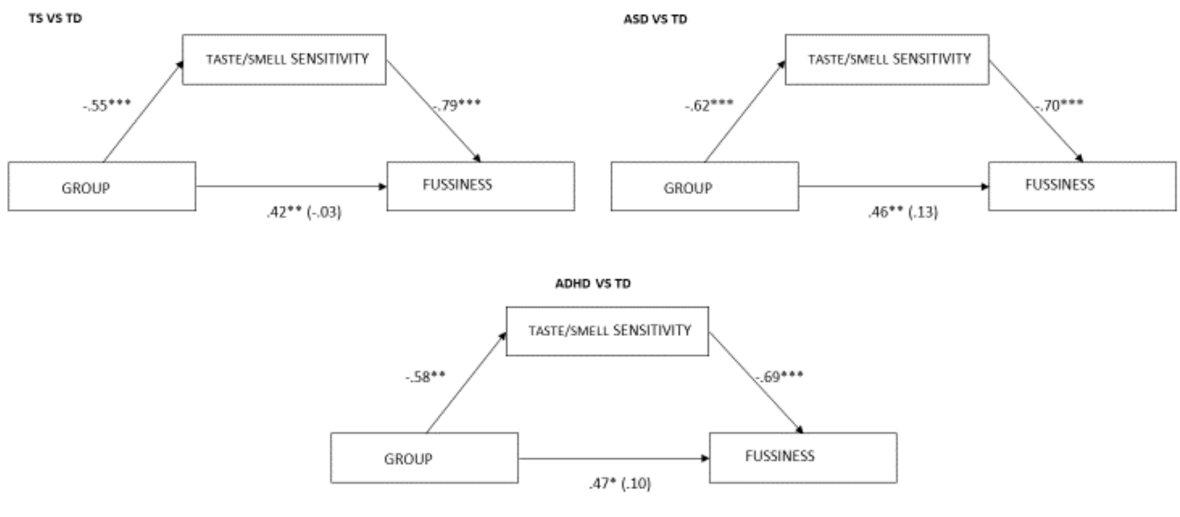
		Smell	Auditory		
TD					
Food Fussiness	-.02	-.64***	-.46	.45	7.99**
TS					
Food Fussiness	.11	-.81***	-.13	.63	15.43***
ASD					
Food Fussiness	.33	-.55*	-.47	.39	6.03*
ADHD					
Food Fussiness	.13	-.75*	.14	.27	2.95

*Note: *** = p < .001, ** = p < .01, * = p < .05*

3.3. Mediation analyses

The findings from the previous multiple regression analysis revealed only taste/smell sensitivity to be an independent predictor of food fussiness in all four groups of children. Therefore, we addressed whether the taste/smell sensitivity subscale was also an independent mediator of the relationship between food fussiness for each neurodevelopmental group compared to the TD group. Separate multiple linear regressions were used to explore the mediating role of taste/smell sensitivity on differences between food fussiness for each neurodevelopmental disorder compared to TD (e.g. TS vs TD, ASD vs TD, ADHD vs TD).

The difference in food fussiness between each neurodevelopmental group compared to TD was found to be mediated by taste/smell sensitivity. As Figure 1 illustrates, the standardized regression coefficient between group differences and taste/smell sensitivity was statistically significant, as was the standardized regression coefficient between groups and food fussiness. A significant Sobel test was found for each group analysis (TS vs TD, $Z = -4.07$, $p < .001$, ASD vs TD, $z = -3.63$, $p < .0013$, and ADHD vs TD $z = -3.02$, $p < .001$) showing differences existed between each neurodevelopmental group compared to TD, and that their food fussiness was fully mediated by the level of taste/smell sensitivity. These findings were confirmed using a bootstrapping method with 5,000 resamples and 95% confidence intervals (Hayes, 2013). Results showed that the confidence interval did not include 0 in each of three separate analyses (TS vs TD LCI =-1.64: HCI = -.61; ASD vs TD LCI = -1.26: HCI = -.38; ADHD vs TD LCI =-1.23: HCI = -.36), confirming the indirect effect was statistically significant for each case.



Note ***$p < .001$ **$p < .01$ *$p <.05$

Figure 1: Mediation model of group and taste/smell sensitivity on food fussiness

4. Discussion

The present study was the first to directly compare food fussiness across three different neurodevelopmental disorders, whist excluding comorbidity among these disorders. The findings failed to differentiate levels of food fussiness between TS, ASD and ADHD, demonstrating heightened food fussiness and sensory sensitivity for each disorder compared to TD children. Importantly, greater taste/smell sensitivity was found to mediate the differences in food fussiness between the TD group compared to the clinical groups, suggesting that it is greater sensitivity to sensory information in the taste/smell domain which can account for why children with these neurodevelopmental disorders have increased levels of food fussiness.

However, differences across the neurodevelopmental groups were also identified in terms of food preferences. In contrast, to previous research showing males with ADHD to consume less fruit and vegetables than TD children, the children with ADHD did not present with any preferential differences to food categories. The research highlights the need to further explore contextual factors in food preferences in children with ADHD children. Only children with ASD were found to show a lower preference for vegetables compared to children with TD. Consistent with previous research, children with TS and children with ASD were found to show lower preference for fruit in comparison to children who were TD (Smith et al., 2019; Maclin, Kandiah, Haroldson, & Khubchandani, 2017). The lack of ADHD preference effect Increased food fussiness and reduced fruit and vegetable preference, across TS and ASD, could lead to an unvaried diet with many adverse health implications. Low consumption of plant-based foods, including both fruit and vegetables, have been associated with an increased risk of cardiovascular disease, obesity and diabetes (Slavin & Lloyd, 2012; Aune et al., 2017), and can lead to fatigue and deficiency in vital vitamins and minerals (Galloway et al., 2005). This highlights the importance of exploring approaches to encourage consumption of healthier foods, and the potential value of a focus on increasing fruit and vegetable acceptance in children with neurodevelopmental disorders. However, akin to existing literature on neurodevelopmental disorders, higher levels of food fussiness were not found to be associated with children's BMI (Curtin, Bandini, Perrin, Tybor & Must, 2005; Emond, Emmett, Steer & Golding, 2010).

Consistent with previous research, higher food fussiness was predicted by taste/smell sensitivity in all groups of children (Cermak et al., 2010; Smith et al., 2019). This provides further verification for the relationship between taste sensitivity and food fussiness in children with both typical and atypical development (Cermak, et al., 2010). However, unlike previous research that has suggested higher levels of tactile sensitivity in ADHD (Ghanizadeh, 2013) and ASD (Schmitt et al., 2008) to be associated with food fussiness, no significant relationship was established using the tactile measure, although this may have been due to the small sample sizes. Instead, this is the first study to show that greater taste/smell sensitivity may account for differences in food fussiness between children with and without neurodevelopmental disorders.

The role of taste/smell sensitivity in food fussiness in children with these neurodevelopmental disorders has important clinical implications, meaning pathways of interventions should prioritise techniques which consider sensory sensitivity. Repeated exposure techniques may be useful to gradually desensitise children and increase their acceptance of different sensory experiences (Farrow & Coulthard, 2012). Although, in children with neurodevelopmental disorders, such interventions may need to be carried out over a lengthier time period than with TD children (Kim, Chung & Jung, 2018), due to resistance to change food repertoire and unwillingness to try novel foods identified in these clinical samples (e.g. Marí-Bauset, Zazpe, Mari-Sanchis, Llopis-González, & Morales-Suárez-Varela, 2014). Additionally, children with ASD have been found to explore foods for longer before making a hedonic decision than TD children (Luisier et al., 2019). It is possible that providing children with neurodevelopmental disorders with more time to explore their food could help them to manage their sensory experiences independently and increase their familiarity with and acceptance of exposed foods. In such cases, a multidisciplinary team, including occupational therapists and registered dieticians, would be useful to individualise interventions to the sensory characteristics of each child.

There are limitations of the current study that need to be noted. Firstly, while the food preference questionnaire identified a reduced preference for fruit in the TS and ASD groups, the absence of a food diary means specific detail on the types of foods children with neurodevelopmental disorders eat, regarding both frequency and portion size, is lacking (Day, McKeown, Wong, Welch & Bingham, 2001). The use of parent report for height, weight and feeding problems has also been highlighted as not being the most reliable method to gain information on children's BMI and feeding difficulties (for a review see Arts-Rodas & Beniot, 1998). For example, parents may perceive even minor feeding problems as major (Archer & Szatmari, 1990). There is a possibility that use of parent-report for anthropometrics may also be discrepant to objective measures and lead to miscalculation of BMI (Weden et al., 2013). Although objective measures are optimal, where this is not feasible studies have highlighted strong and positive correlations of parent-report of height and weight with objective measurements (Haycraft & Blissett, 2012), and parents to be as accurate as a trained clinician in their reporting (Chai et al., 2019). All children should also have been screened for other neurodevelopmental symptomology; screening tools to assure correct inclusion in diagnostic groups were used, but it is possible that screening all the children in the study for each disorder of interest may have identified additional undiagnosed comorbid problems. In the SSP, taste and smell sensory domains are combined into a single subscale meaning there is an inability to differentiate between these characteristics (Hubbard, Anderson, Curtin, Must & Bandini, 2014). Additionally, it is noted that there are some items for the sensory taste/smell subscale that overlap with items for food fussiness. Therefore, further work probably needs to make use of alternative measures and observational sensory tests to confirm the importance and address the specific role of sensory sensitivity in this domain for explaining food fussiness in children with neurodevelopmental disorders.

The present study was the first to demonstrate that similar, high levels of food fussiness are present across several individual neurodevelopmental disorders, thus indicating that comorbid diagnoses do not underlie the effect, as previously suggested. It also suggests taste/smell sensory domains may be responsible for similar patterns of food fussiness that have been evidenced in children with neurodevelopmental disorders. It is clinically important for future research to better understand how interventions, which take into consideration taste/smell sensitivity impairments, may prevent or reduce food fussiness.

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