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# Visual and Hedonic Perception of Food Stimuli in Children with Autism Spectrum Disorders and their Relationship to Food Neophobia

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## Abstract
The present study examined whether children with autism spectrum disorder (ASD) and typically developing (TD) children differed in visual perception of food stimuli at both sensorimotor and affective levels. A potential link between visual perception and food neophobia was also investigated. To these aims, 11 children with ASD and 11 TD children were tested. Visual pictures of food were used, and food neophobia was assessed by the parents. Results revealed that children

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with ASD explored visually longer food stimuli than TD children. Complementary analyses revealed that whereas TD children explored more multiple-item dishes (vs. simple-item dishes), children with ASD explored all the dishes in a similar way. In addition, children with ASD gave more negative appreciation in general. Moreover, hedonic rating was negatively correlated with food neophobia scores in children with ASD, but not in TD children. In sum, we show here that children with ASD have more difficulty than TD children in liking a food when presented visually. Our findings also suggest that a prominent factor that needs to be considered is time management during the food choice process. They also provide new ways of measuring and understanding food neophobia in children with ASD.

**Keywords**

autism, sight, food neophobia, hedonic evaluation, eye tracking

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## Introduction

Sensory processing plays a significant role in the acceptance and recognition of foods in typically developing (TD) children (Mennella, 2014; Mennella, Reiter, & Daniels, 2016; Zeinstra, Koelen, Kok, & de Graaf, 2007). Cognitive and affective processing of food-related stimuli are of most importance in dietary development in children (Bullinger, 2013; Doyen, 2011) and are thought to underlie certain difficulties in relation to food, most notably in individuals with autism spectrum disorder (ASD) who exhibit atypical sensory behavior. According to the American Psychiatric Association's Diagnostic and Statistical Manual, Fifth Edition (DSM-5), ASD is a neurodevelopmental disorder characterized by definite impairments in communication and social skills, narrow and intense interests, and stereotyped behaviors. But recent studies (Mottron, Belleville, Rouleau, & Collignon, 2014) have pointed that the phenotype of autism involves heterogeneous adaptive traits (not only disabilities but also strengths, for instance, perceptual strengths as well as sometimes overfunctioning). At least one in every 100 people has some form of autism (Baird et al., 2006; Kim et al., 2011). Autism affects more often boys than girls (4.5:1; Baio, 2014). Core traits of autism first emerge in infancy (Walsh, Elsabbagh, Bolton, & Singh, 2011) and then evolve over the lifespan.

A study performed on 95 children with ASD (Nadon, Feldman, Dunn, & Gisel, 2011a) reported a significant association between sensory issues (as measured with the Short Sensory Profile [SSP] questionnaire) and food-related behavioral problems (as measured with the Food Profile Questionnaire; Nadon et al., 2011a). The prevalence of eating issues is reported in 80% to 90% of children with ASD, compared with 13% to 50% of TD children (Cermak, Curtin, & Bandini, 2010; Fodstad & Matson, 2008; Matson, Fodstad, & Dempsey, 2009; Nadon, Feldman, Dunn, & Gisel, 2011b; Nadon, Feldman, & Gisel, 2013).

According to the typology established by Johnson, Foldes, Demand, and Brooks (2015), dietary behavior particular to children with ASD comprises certain forms of (a) food selectivity, which may be related to the texture or the way in which the food is presented (food selectivity based on type, texture, and presentation), (b) food refusal, and (c) behavioral problems during meals (e.g., "does not stay seated" ; Nadon et al., 2011b). Among the sensory modalities involved in the appreciation of food, sight plays a predominant role. Wadhera and Capaldi-Phillips (2014) detailed the physiological, cognitive, and emotional mechanisms underlying visual influence on food acceptance, notably in children. In the same line, Aldridge, Dovey, and Halford (2009) reported that the visual categories created by children affect their willingness to taste food.

Atypical sensory functioning in individuals with ASD has been well documented in the last decade with regard to the visual system (Simmons et al., 2009). Compared with TD individuals, individuals with ASD present special features in the visual processing of social (Papagiannopoulou, Chitty, Hermens, Hickie, & Lagopoulos, 2014) and nonsocial stimuli (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). For example, visual exploration is improved and intensified for nonsocial stimuli considered particularly attractive by individuals with ASD (South et al., 2008), such as visual images of vehicles, electronic objects, road signs, or sports equipment (Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008). It should be noted that this effect was also reported in TD children, although to a lesser degree. Taken together, these findings suggest that, in experimental settings, the type of stimulus chosen and its salience have an impact on the visual exploration strategies used by individuals with ASD (Saitovitch et al., 2013). The first aim of the present study was to extend these findings to food visual stimuli. To this end, visual processing by children with ASD and TD children was explored using an implicit objective sensorimotor measure, namely eye movement (Aim 1).

Emotions associated with dietary stimuli can also explain part of the relationship between sensory difficulties and altered food behavior. The role of sensory processing and its hedonic dimension (pleasure) in the regulation of eating behavior is well described in TD children (Cooke, 2007; Pliner, 2008; van der Horst, 2012). At a very early stage of development, TD children experience the pleasures of eating: sensory pleasure, pleasure in satiety, and relational pleasure (Bullinger, 2004, 2006, 2013; Holley, 2006). Psychological (Sander, Grandjean, & Scherer, 2005; Scherer, Schorr, & Johnstone, 2001) and biological (Rolls, 2012, 2015) models of affects postulate a strong link between emotion and cognition in the interpretation of environmental objects, including food. Rolls' (2012) model more specifically explores the role of emotion in acceptance or reject and decision-making, postulating that exteroceptive sensory factors perceived by the eater interact with internal signals of satiety in the orbitofrontal cortex to produce a hedonic state, linked with the reward value of food which subsequently causes appetite and leads to the act of eating.

The influence of emotion on food-related behavior has been reported in TD children, for instance, food rejection behaviors driven by visual stimuli perceived or felt as aversive (Brown & Harris, 2012; Lafraire, Rioux, Giboreau, & Picard, 2016; Martins & Pliner, 2006). In children with ASD, understanding how hedonic features extracted from sensory signals are processed may help clarify specificities of this population in relation to food. In nonfood areas, research showed significant differences between TD and ASD children in tasks involving perception and recognition of emotions (Nuske, Vivanti, & Disanayake, 2013; Uljarevic & Hamilton, 2013) and emotional regulation (Samson, Hardan, Lee, Phillips, & Gross, 2015; Samson, Hardan, Podell, Phillips, & Gross, 2015). The second aim of the present study was therefore to extend this concept to food stimuli by comparing hedonic perception of visual food stimuli between children with ASD and TD children (Aim 2).

Finally, a major hindrance in extending the diversity and acceptance of new foods is food neophobia, defined as a reluctance to consume or tendency to reject foods considered new by the eater (Dovey, Staples, Gibson, & Halford, 2008; Lafraire et al., 2016; Loewen & Pliner, 1999). Food neophobia was found to be associated with sensory experience in general (Aldridge et al., 2009; Shim, Kim, & Mathai, 2011) and sight in particular (Wadhera & Capaldi-Phillips, 2014), and with sensory functioning (Cooke, 2007) and anxiety (Galloway, Lee, & Birch, 2003). Interestingly, a recent study showed that the level of food neophobia in children with ASD but not in TD children was negatively correlated with hedonic categorization of olfactory food stimuli (Luisier et al., 2015). The third aim of the present study was therefore to examine whether this relationship between food neophobia and hedonic perception in children with ASD is also observed for visual food stimuli (Aim 3).

## Material and Methods

### *Participants*

Eleven children with ASD (age range: 5.1–15.2 years; no female), and 11 TD children (age range: 5.1–15.2 years; 4 females) were included in the study and matched according to age (±6 months). There was no significant difference between groups in terms of age (TD: $127.5 \pm 28.5$ months; ASD: $125.3 \pm 29$ months; Mann-Whitney $Z = -0.131$, *ns*, Cohen's $d = -.026$, 95% CI [–.92, .86]). Children with ASD were recruited from a specialized educational institute in Sion (Switzerland). They were diagnosed with ASD or pervasive developmental disorder according to the DSM-IV and were eligible for inclusion in the Swiss ASD Observatory. ASD diagnoses were confirmed on the Autism Diagnostic Observation Schedule (ADOS) (ADOS-1 or ADOS-2; Lord, Rutter, DiLavore, Risi, & Gotham, 1999; Lord et al., 2012). Children with ASD all had normal or corrected-to-normal vision. TD children were recruited from schools in the area of Fribourg, Switzerland, and had normal school performance, without any known behavioral or psychological disorder and normal or corrected-to-normal vision.

In both groups, food neophobia was assessed by the parents on a standard 10-items questionnaire (the French version of the Adapted Food Neophobia Scale) with good internal consistency (Reverdy, Chesnel, Schlich, Köster, & Lange, 2008). For each item, parents indicated to what extent the corresponding statement was true, on a 7-point scale from *Very true for my child* to *Not at all true for my child*. The 10 items were as follows: (a) My child is very particular about the foods he will eat (reversed scoring); (b) My child likes foods from different countries; (c) My child does not trust new foods (reversed scoring); (d) My child likes to try unusual foods; (e) When my child has the choice between different flavors for a certain food (e.g., ice-cream or sweets), it likes to choose a flavor that it does not know; (f) My child will try a dish, even if it does not know what is in it; (g) The foods my child know are sufficient for him (reversed scoring); (h) My child is willing to eat anything that is offered; (i) My child is afraid to eat things it has never had before (reversed scoring); and (j) My child will not taste a food when he does not know what it is (reversed scoring). For Questions 2, 4, 5, 6, and 8, the highest score (7 points) was given to the response "Very true for my child" and the lowest (1 point) to "Not at all true for my child"; for Questions 1, 3, 7, 9, and 10, the scores were reversed. The food neophobia score was obtained by summing the scores for the 10 questions (range: 10–70); the higher the score, the higher the neophobia grade.

The sensory profile was assessed with the French version (translation and publication by ECPA: Editions du Centre de Psychologie Appliquée) of the SSP (Dunn, 2010), filled out by the parents. The SSP is a standardized questionnaire that includes seven sections: (a) tactile sensitivity (seven items), (b) taste or smell sensitivity (four items), (c) movement sensitivity (three items), (d) underresponsive or seeks sensation (seven items), (e) auditory filtering (six items), (f) low energy or weak (six items), and (g) visual or auditory sensitivity (five items).

The internal reliability for the total test and sections on Cronbach's alpha ranges from 0.70 to 0.90 (Dunn, 1999).

The study had institutional review board approval (*Commission Cantonale Valaisanne d'Ethique Médicale*: IRB n° CCVEM 022/14). Parental consent was obtained for all children.

## Stimuli

Stimuli comprised digital pictures of foods ($n$=29) regularly served to the ASD children in their institution and culturally familiar in Switzerland. Each picture consisted of a garnished white plate, placed against a light gray background (real diameter: 21 cm; on-screen diameter: 14 cm). The area and position of the food on the plate were checked using a stencil. The on-screen stimuli were presented at a viewing distance of 60 cm (at a visual angle of 13.36°), using the Psychophysics Toolbox (PTB-3: Brainard, 1997; Kleiner, Brainard, & Pelli, 2007) in a MATLAB environment (R2010a; The MathWorks, Natick, MA, USA). The images showed either a single-item dish (with only carrots, beans, peas, or pasta) or multiple-item dish (with a combination of two or three foods).

## Procedure

Participants sat in a dimly lit room, at 60 cm from a 24″ Dell LCD computer screen. The experiment consisted of two sessions. In both sessions, pictures displaying different dishes were presented one at a time in random order on the computer screen. The presentation of the picture was preceded by a white fixation-cross presented in the center of the screen for 2000 ms (Figure 1). Session 1 served to familiarize the children with the experimental setting and consisted in passively viewing the stimuli. Each picture was presented for 5000 ms. Session 2 (main experimental phase) involved a two-alternative forced-choice task in which the child had to decide whether they liked or disliked the food shown. In this task, the picture was presented until the participant answered. During this hedonic task, participants gave their answer using a Swiss computer keyboard in which the "S" key was labeled with a positive smiley and the "K" key with a negative smiley. All participants took part in both sessions.

## Eye-Tracking Recording

Participants' eye movements were recorded with a SR Research Desktop-Mount EyeLink 2K eye-tracker using the Eyelink Toolbox extensions (Cornelissen, Peters, & Palmer, 2002). Gaze location on the screen was recorded for the dominant eye, with a sampling rate of 1000 Hz. A chin-and-forehead rest ensured stable head positioning; all subjects agreed to use the chin-and-forehead rest except from one child with ASD, who sat on the lap of his teacher who stabilized his chin with her hands. Nine-point calibration was conducted before each block; additional calibration was performed when necessary to ensure optimal recording quality.

## Statistical Analyses

To test eye-movement differences between groups (Aim 1), five parameters were extracted from eye-movement data: number of fixations, mean fixation duration (s), sum of fixation durations (s), total path length (pixels), and mean path length (pixels). We applied a linear mixed model (LMM) to analyze children's eye movements. The group (children with ASD

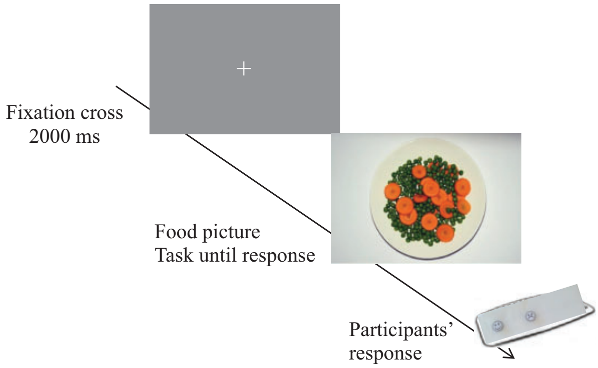


**Figure 1.** Schematic representation of the procedure (viewing with yes or no hedonic response).

coded as 1 vs. TD children coded as 0) was considered as the main explanatory variable. The children and stimuli were considered as random-effect variables. As example, the LMM for mean fixation duration data can thus be expressed as follows:

$$Mean\ fixation\ duration \sim Group + (1|Stim) + (1|Children)$$

For number of fixations, generalized linear mixed model (GLMM) for Poisson distributed data was fitted.

To analyze children's ratings of the pictures (two response levels: like and dislike), a binomial logistic mixed model was applied with group as the main explanatory variable and the observers and stimuli considered as random-effect variables.

All models were fitted with GLMER (package lme4 version 1.1-12; using R 3.2.2 - R Core Team, 2015).

To assess the relationship between hedonic ratings and neophobia scores in both ASD children and TD children (Aim 3), the mean hedonic ratings for all dishes were first calculated for each child. Linear regression was then performed, with neophobia score as independent variable and mean hedonic rating as dependent variable.

Note that in additional analyses, the age variable was included in the model (for eye-movement parameters and hedonic ratings).

## Results

*Questionnaires: Food Neophobia and SSP Scores in Both Groups.* The range of food neophobia score was large for both groups (TD: 20–57; ASD: 17–70). There were significant differences in SSP global score (Mann-Whitney $Z = -2.61$, $p = .008$, Cohen's $d = 1.75$, 95% CI [.57, 2.92]) and for certain items: tactile sensitivity ($Z = -2.75$, $p = .005$, $d = 1.31$, 95% CI [.30, 2.32]) and "under-responsive/seeks sensation" ($Z = -2.97$, $p = .002$, $d = 1.52$, 95% CI [.45, 2.59]) reflecting that ASD children showed more atypical scores than TD children. There were no significant differences for the other SSP items: movement sensitivity ($Z = -.88$, *ns*, $d = .68$, 95% CI [–.26, 1.63]), taste or smell sensitivity ($Z = -1.682$, *ns*, $d = .62$, 95% CI [–0.37, 1.61]), auditory filtering ($Z = -1.92$, $p = .063$, $d = .92$, 95% CI [–.07, 1.91]), low energy or weak ($Z = -.87$, *ns*, $d = .57$, 95% CI [–.36, 1.51]), or visual or auditory sensitivity ($Z = -.84$, *ns*, $d = .41$, 95% CI [–.55, 1.36]).

**Table 1.** Means and Standard Errors of the Five Eye-Movement Parameters and Linear Mixed Model Results of Eye-Movement Variables for Group Effect.

| | ASD | TD | Group effect estimate[a] | *SE* | $\chi^{2b}$ | *df* | $p(>\chi^2)$ |
|---|---|---|---|---|---|---|---|
| Number of fixations | $4.43 \pm 2.89$ | $3.31 \pm 2.08$ | .26 | .17 | 2.24 | 1 | *ns* |
| Mean fixation duration | $0.39 \pm 0.24$ | $0.40 \pm 0.22$ | –.01 | .05 | .09 | 1 | *ns* |
| Sum of fixation durations | $1.39 \pm 0.72$ | $1.09 \pm 0.49$ | .31 | .16 | 4.03 | 1 | .045 |
| Total path length | $646.5 \pm 610.9$ | $364.5 \pm 367.8$ | 281.35 | 139.07 | 4.06 | 1 | .044 |
| Mean path length | $161.4 \pm 82.2$ | $132.2 \pm 79.0$ | 30.39 | 15.60 | 3.75 | 1 | .053 |

*Note.* ASD = autism spectrum disorder; TD = typically developing; SE = standard error; *ns* = not significant.
[a]Children with ASD versus TD children.
[b]Deviance difference to compare model including group variable and model not including group variable.

*Aim 1: Compared with TD children, children with ASD showed different eye-movement activity when perceiving visual food items.* Table 1 shows means and standard errors for the five eye-movement parameters and illustrates the main effects of group for all five eye-movement parameters. Significant group effects were observed for two parameters: Compared with TD children, children with ASD showed longer sum of fixation durations ($p = .045$); they also show longer total path length ($p = .044$). The group effect was close to significance for a third parameter: Compared with TD children, children with ASD showed longer mean path length ($p = .053$). When age variable was included in the model, the group effect remained statistically significant for the sum of fixation durations ($p = .044$) and it became marginally significant for the total path length ($p = .051$). The group effect remained marginally significant for the mean path length ($p = .052$).

*Aim 2: Compared with TD children, children with ASD rated food images as less pleasant.* Statistical analysis revealed a significant effect of group for hedonic ratings (group effect estimate = –2.32; $SE = .001$; $\chi^2 = 7.47$, $p = .006$): TD children rated the food images as more pleasant than children with ASD (Figure 2(a)). Note that when age variable was included in the model, the effect of group remained significant ($p = .005$).

*Aim 3: An association between hedonic ratings and food neophobia score was observed in children with ASD.* When looking at hedonic judgment distribution within each group, it should be noted that ratings were much more variable in children with ASD ($.290 \pm .05$) than in TD children (TD: $.44 \pm .02$). We then examined whether the observed hedonic variability was related to variability in food neophobia. First, a model including a food neophobia score-by-group interaction was computed: Although the interaction was not significant (interaction estimate = –.012; $t = -1.86$, $p = .078$, 95% CI [–.025, .001], and Cohen's $f^2 = .19$), this analysis suggested (on a descriptive level) that the slope of the regression line was stepper for ASD children than for controls. To check this, we analyzed the groups separately. Results revealed a significant negative relationship between food neophobia score and hedonic rating in children with ASD (adjusted $R^2 = .374$, $F(1, 9) = 6.97$, $p = .027$): Children with ASD who rated the food images as more unpleasant were also those with higher food neophobia scores (Figure 2(b)). No significant relationship was observed between hedonic ratings and food neophobia score in TD children (adjusted $R^2 = -.11$, $F(1, 9) = .01$, *ns*; Figure 2(c)).

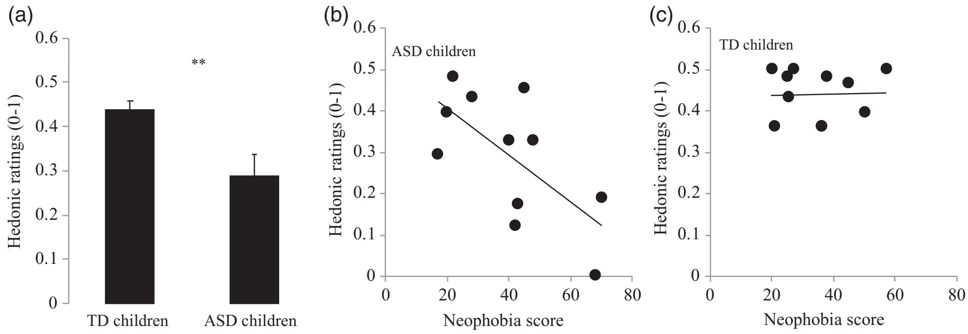


**Figure 2.** Hedonic ratings in TD and children with ASD and neophobia score. (a) TD children perceived the food images as more pleasant than children with ASD (**corresponds to a $p < .01$; bars and variations correspond to means and standard errors). (b) A significant negative relationship was observed between hedonic ratings and neophobia score in children with ASD. (c) No significant relationship was observed between hedonic ratings and neophobia score in TD children.
ASD = autism spectrum disorder; TD = typically developing.

*Complementary Analysis 1: Dish containing a single versus multiple items is processed differently in TD versus ASD children.* Scientific studies conducted in the general population show that children who are "picky and fussy" in their eating are less willing to consume mixed foods or foods they find difficult to identify (Lafraire et al., 2016). Moreover, the overall presentation (e.g., visual appearance and arrangement), the number of foods and their colors as they appear in the plate also play a critical role in the child's visual appreciation of food (Zampollo, Kniffin, Wansink, & Shimizu, 2012): For instance, green foods are rejected more often than orange foods (Mennella, 2014; Mennella et al., 2016; Zeinstra et al., 2007). Given that it is currently unclear whether these effects are also present in children with ASD, we further asked this issue in a first complementary analysis and tested the hypothesis that the nature and diversity of stimuli (i.e., food containing a single vs. multiple items that vary in color and in visual presentation) influence the visual processing of the food in children with ASD. To test this, group differences in eye-movement as a function of diversity was explored by applying a linear mixed model (LMM) including group (children with ASD coded as 1 vs. TD children coded as 0) and diversity (dishes with multiple items coded as 1 vs. dishes with single item coded as 0). The group-by-item-diversity interaction was also examined. The children were considered as random-effect variables. As example, the LMM for mean fixation duration data can thus be expressed as follows:

$$Mean\ fixation\ duration \sim Group + Diversity + Group\ x\ Diversity + (1|Children)$$

Note that, for fixation number, GLMM for Poisson distributed data was fitted.

All models were fitted with GLMER (package lme4 version 1.1-12; using R 3.2.2 - R Core Team, 2015).

Table 2 shows means and standard errors for the five parameters. Table 3 illustrates the main effects of diversity and group and diversity-by-group interaction for all five eye-movement parameters. Effects of diversity were observed for four parameters: fixations' number ($p < .001$), sum of fixation durations ($p = .040$), total path length ($p < .001$), and mean path length ($p < .001$). These effects reflected larger eye movement activity for

**Table 2.** Means and Standard Errors of the Five Eye-Movement Parameters in TD and ASD Participants as a Function of Stimulus Diversity (Single vs. Multiple).

| | TD | | ASD | |
|---|---|---|---|---|
| | Single | Multiple | Single | Multiple |
| Number of fixations | 2.77 ± 1.19 | 3.56 ± 1.47 | 4.43 ± 2.41 | 4.47 ± 2.0 |
| Mean fixation duration | .43 ± .13 | .39 ± .13 | .42 ± .16 | .37 ± .09 |
| Sum of fixation durations | 1.00 ± .16 | 1.1 3± .28 | 1.46 ± .48 | 1.37 ± .47 |
| Total path length | 179.1 ± 160.2 | 384.9 ± 230.2 | 531.2 ± 457.8 | 633.6 ± 426.5 |
| Mean path length | 95.1 ± 40.7 | 146.3 ± 32.8 | 137.1 ± 46.4 | 171.1 ± 39.3 |

*Note.* ASD = autism spectrum disorder; TD = typically developing.

**Table 3.** Complementary Statistical Analyses of Eye-Movement Variables Using Linear Mixed Model for All Variables Except for Number of Fixations (Generalized Linear Model for Number of Fixations).

| | Estimate[a] | *SE* | $t^{b}$ | $p(>\|t\|)$ | $\chi^{2c}$ | *df* | $p(>\chi^2)$ |
|---|---|---|---|---|---|---|---|
| Number of fixations | | | | | 15.48 | 3 | .001 |
| Intercept | .96 | .13 | 7.30 | <.001 | | | |
| Group | .44 | .18 | 2.39 | .017 | | | |
| Diversity | .25 | .07 | 3.57 | <.001 | | | |
| Group × Diversity | –.24 | .09 | –2.66 | .008 | | | |
| Mean fixation duration | | | | | 6.36 | 3 | .096 |
| Intercept | .43 | .04 | 10.92 | <.001 | | | |
| Group | –.01 | .06 | –.12 | *ns* | | | |
| Diversity | –.04 | .03 | –1.55 | *ns* | | | |
| Group × Diversity | –.01 | .04 | –.31 | *ns* | | | |
| Sum of fixation durations | | | | | 10.08 | 3 | .018 |
| Intercept | 1.00 | .12 | 8.38 | <.001 | | | |
| Group | .46 | .17 | 2.74 | .011 | | | |
| Diversity | .13 | .06 | 2.06 | .040 | | | |
| Group × Diversity | –.21 | .09 | –2.41 | .016 | | | |
| Total path length | | | | | 28.50 | 3 | <.001 |
| Intercept | 190.77 | 103.43 | 1.84 | .077 | | | |
| Group | 357.34 | 145.94 | 2.45 | .022 | | | |
| Diversity | 230.57 | 51.79 | 4.45 | <.001 | | | |
| Group × Diversity | –116.49 | 72.45 | –1.61 | ns | | | |
| Mean path length | | | | | 47.08 | 3 | <.001 |
| Intercept | 94.29 | 12.64 | 7.44 | <.001 | | | |
| Group | 43.62 | 17.84 | 2.45 | .020 | | | |
| Diversity | 52.02 | 9.26 | 5.62 | <.001 | | | |
| Group × Diversity | –19.12 | 12.95 | –1.48 | ns | | | |

*Note. SE* = standard error; *ns* = not significant.
[a]Group effect: children with ASD versus TD children; diversity: multiple items versus single item.
[b]z value and $p(>|z|)$ for number of fixations variable.
[c]Deviance difference to compare model including all variables and model including only intercept.

multiple- versus single-item food pictures in terms of number of fixations, sum of fixation durations, total path length, and mean path length. Effects of group were observed for the same variables: Compared with TD children, children with ASD showed a greater number of fixations ($p = .017$), longer sum of fixation durations ($p = .011$), longer total path length

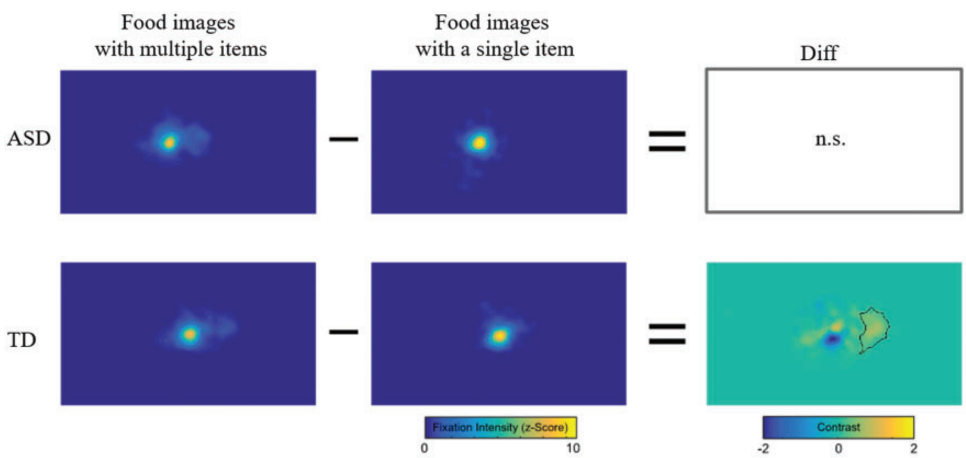


**Figure 3.** Linear contrasts between *multiple* and *single* food displays independently for autistic and control observers using iMap4.
ASD = autism spectrum disorder; TD = typically developing; *ns* = not significant.

($p = .022$), and longer mean path length ($p = .020$). Finally, significant group-by-item-diversity interactions were observed for two eye-movement parameters: number of fixations ($p = .008$) and sum of fixation duration ($p = .016$) reflecting for TD children (but not for children with ASD) greater number of fixations and greater fixation durations for food with multiple items compared with food with single items.

*Complementary Analysis 2: The spatial distribution of the fixation pattern is also modulated by diversity of the food image in TD versus children with ASD.* To further explore the spatial distribution of the fixation pattern, we performed in a second complementary analysis a spatial mapping analysis of the fixation duration using iMap4 (Caldara & Miellet, 2011; Lao, Miellet, Pernet, Sokhn, & Caldara, 2015). iMap4 is a data-driven analysis framework for statistical fixation mapping using linear mixed model (LMM) and nonparametric statistics based on resampling (Lao et al., 2015). The fixation duration vector of each single trial was projected into a two-dimensional space according to the $x$- and $y$-coordinates of the fixation using iMap4. We then smoothed the raw fixation duration map using a two-dimensional Gaussian Kernel function with a sigma around 1° of visual angle. The single-trial smoothed fixation maps were normalized ($z$ score) to better model the spatial pattern. To explore the multivariate structure in the resulting three-dimensional matrix (trials × $x$-size × $y$-size), we applied a representational dissimilarity matrix analysis of the smoothed fixation map basic on Mahalanobis distance (using the rdmfixmap.m function in iMap4). The average multivariate distance between two fixation maps within the same group of observers was computed for each stimulus (Figure 3). Moreover, each pixel in the smoothed fixation map was then fitted in iMap4 as the response variable using the following formula:

$$Fixation\ Intensity_{(x,y)} \sim Group + (1|Stimuli) + (1|Observer),\ 1 \leq x \leq xSize,\ 1 \leq y \leq ySize$$

The linear mixed models were fitted using Maximal Likelihood with the default iMap4 settings. Linear contrast of the model coefficients was performed as hypothesis testing, with

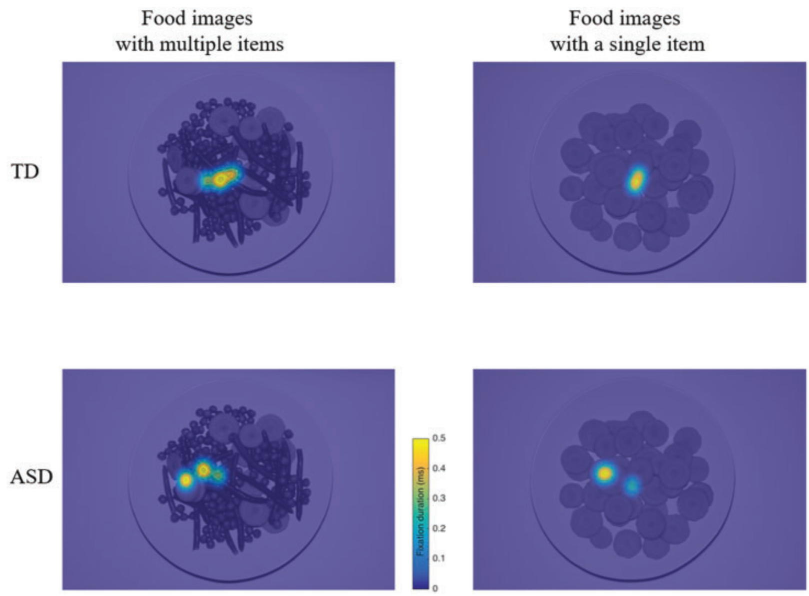


**Figure 4.** Descriptive example of fixation maps for one ADS and one TD observer when viewing two different food images displaying either single (left) or multiple items (right).
ASD = autism spectrum disorder; TD = typically developing.

a bootstrap spatial clustering procedure threshold on the cluster mass as multiple comparison corrections (Lao et al., 2015).

In accordance with the first complementary analysis, results revealed a significant difference in the two-dimensional fixation maps between multiple- and single-food items in the control group (TD children) only: The control observers spent more time and explored more food images with multiple items compared with food images containing a single item (local maximum within the significant cluster: $F(1, 631) = 19.90$, $p < .001$; local minimum: $F(1, 631) = 3.86$; $p = .050$ cluster corrected). Children with ASD spent equal time on both types of food images (multiple and single items), using a similar fixation pattern (*ns*; Figures 3 and 4 for a descriptive example).

## Discussion

The aims of our study were (a) to compare exploratory (e.g., sensorimotor) behavior between ASD and TD children in response to visual food stimuli, (b) to compare ASD and TD children in a task of assigning valence to these visual food stimuli, and (c) to study the relationship between this valence judgment and a behavioral attitude toward food (food neophobia).

Concerning the first two aims, results showed that, compared with TD children, children with ASD explored foods longer (in particular reflected by a significant higher oculomotor activity in terms of sum of fixation durations and total path length) before making a hedonic decision. Deeper exploration of a stimulus to judge its (un)pleasantness could be interpreted either as a difficulty experienced by the children with ASD in identifying their own emotional state, or as a difficulty in categorizing hedonically the stimulus. In one of the most recent empirical studies on alexithymia in children with ASD (25 children with ASD aged 8–13 years vs. 32 TD children aged 8–12 years), Griffin, Lombardo, and Auyeung (2015) demonstrated a higher rate of alexithymia in children with ASD compared with the TD control group. In the field of olfaction, Legiša, Messinger, Kermol, and Marlier (2013), comparing how emotional responses to odors were reflected in peripheral nervous system responses (facial and autonomic responses) in children with ASD and matched controls (aged 8–14 years), reported that children with ASD were less likely to verbally express an affective state corresponding to their facial expression. The difficulty of evaluating the valence of stimuli could thus contribute to lengthening exploration duration. From a pedagogical point of view, this implies that children with ASD may need more time or more sensory explorations to decide whether or not they like food.

Regarding the relationship between hedonic categorization and attitude toward new food (third aim), we found a correlation between valence attribution and the degree of neophobia, specifically in children with ASD and not in TD children. The food neophobia score is an indicator of the risk of a child rejecting food that he or she considers to be new. The neophobia as measured at a given time reflects the relationship to foods based on previous dietary experiences (Dovey et al., 2008) and the cognitive features that characterize the eater at the time of measurement (Dovey, Aldridge, & Dignan, 2012; Lafraire et al., 2016). The observed correlation supports the hypothesis of a link between visual processing and the ability to appreciate food in children with ASD. Interestingly, the relationship between visual processing, neophobia, and hedonic processing is in line with observations in the olfactory domain; Luisier et al. (2015) found that less contrasted odor hedonic categorization was negatively correlated with food neophobia scores in children with ASD: The less they discriminated hedonically (especially for pleasant odors), the more neophobic they were.

Another result of interest revealed by complementary analyses was that children with ASD visually processed all dishes in a similar way, regardless of diversity (single or multiple items). In contrast, a more discriminating pattern was observed in TD children who visually inspected complex food stimuli more intensively than simple stimuli. Interestingly, this finding was observed with both quantitative (numbers of fixation and sum of fixation duration) and qualitative (spatial pattern) analyses. In children with ASD, this lesser differentiation in visual processing according to stimulus diversity is in agreement with the hypothesis of Mottron's perceptual model (Mottron et al., 2006). This model states that, in children with ASD, local processing of visual information (*bottom-up*—real immediate sensitive experience) is preferred (processing by default) and that the top-down (concept-driven) regulation (Hadjikhani et al., 2004; Müller & Nussbeck, 2008; Ropar & Mitchell, 2002), optional in this population, is never used when the local processing is felt to be more effective. In the dishes used as stimuli in the present study, each type of food had intrinsic nuances and irregularities (color, size, area, etc.) that could attract the attention of children with ASD and favor local processing (details apprehension) instead of descending conceptual processing (category apprehension). Conversely, in TD children, conceptual categorization (e.g., carrot, beans, peas, considered as types of items regardless of the manner in which they were prepared or presented) precedes the sensory visual processing of details favored by children with ASD: Food becomes complex by accumulation of conceptual categories rather than of visual details. In children with ASD, local processing may lengthen processing duration for stimuli already encountered but presented in a slightly different form, without difference in processing according to stimulus diversity (single vs. multiple items).

Regarding ratings of liking per se, children were asked to judge whether or not they liked the food presented on the screen. Children with ASD significantly more often attributed a negative valence to the food images than TD children. In TD children, the mechanisms underlying food rejection involve sensory and perceptual processing, categorization, and emotional evaluation (Lafraire et al., 2016). Recognition of food generally is a prerequisite for acceptance. If not recognized, the food is usually rejected (Cooke, 2007; Dovey et al., 2008; Lafraire et al., 2016). An assumption that may be raised here is that similar mechanisms linking recognition to hedonic appreciation may also affect children with ASD.

Memories and in particular emotions evoked by the sight of food may also partly explain lack of appreciation. However, vegetables, which were particularly numerous in the present study, are generally less liked by children than other foods, especially because of their flavor and texture (Williams, Gibbons, & Schreck, 2005). Difficulty in texture acceptance often involves strong tactile oral defensiveness (=overresponsiveness, first described by Ayres [1964], which have been shown to correlate with food-related difficulties in many TD children [Smith, Roux, Naidoo, & Venter, 2005]). Interestingly, in the present study, the SSP showed a significant difference in tactile score between the two groups.

The present study was essentially an exploratory study with a relatively small sample. Although our study revealed preliminary—but new—findings, certain potential limitations need to be discussed. First, to maximize control of the nutritional context, as well as educational methods around meals and the known food repertoire of the children with ASD participating in the study, we chose to work with a single institution where children had at least one meal per working day. The total number of children participating in the study and the overrepresentation of boys depended on the number of children diagnosed with ASD in the institution and the parental approval. According to the sample size which was in fact low and the gender balance, it will therefore be necessary to replicate the study with a larger number of children. Second, the hedonic judgment requested in the study was only based on a binary choice between *I like* and *I don't like*. Despite the fact that the this kind of instrument is recommended when researchers made the decision to collect information directly from individuals with special needs (Cuskelly, Moni, Lloyd, & Jobling, 2013; Hartley & Maclean, 2006) and despite the fact that all participants were able to make judgments using a binary choice effectively, we cannot discard the possibility that binary choices force the respondent to choose one or the other response and hide hesitations or ratings that may fall between these two options. Third, in order to avoid verbal means of collecting children's hedonic responses, we used a push-button device, which seemed to be suitable for most children. However, the children's understanding of the instructions was not checked; training in the use of the device might reduce any risk of misunderstanding. This device could be interesting in nonverbal children, to enable them to express their appreciation. Fourth, another major limitation deals with the specificity of the stimuli used for testing the influence of diversity on eye-movement parameters and categorization. The question whether our findings are specific to food stimuli or can be extended to other semantic domains (such as manufactured objects, like cars, toys . . . ) should then be explored in future studies. Moreover, the images used for the study represented only foods belonging to children's daily lives; it would be interesting to study the visual exploration of foods unknown to children, in order to better characterize exploratory behavior in unfamiliar situations.

## Conclusions

In conclusion, our study suggests that children with ASD have more difficulties than TD children in liking a food when presented visually. Such effect may be related to the diversity of the food, which might be more difficult to recognize due to intrinsic variation or varied presentation. Moreover, our study suggests that a prominent factor that needs to be considered is time management during the food choice process: Giving the child enough time to explore the food and then deciding on appreciation and acceptance can enable him or her to manage the sensory experience autonomously and could contribute to establishing food familiarity. Finally, given the different processes (attention to details and categorization mechanisms) that seem to be involved in the hedonic processing of visual food stimuli, it would be interesting for future research to investigate whether there are salient sensory cues that could facilitate the recognition of a food by a child with ASD. Given the link between sensory processing and food neophobia, increasing valence for a sensory dimension that would make sense for children with ASD (e.g., smell and taste) could make the food carrying this dimension more familiar and favor its acceptance.

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