

Effects of familiarization on odor hedonic responses and food choices in children with autism spectrum disorders

Autism
2019, Vol. 23(6) 1460–1471
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DOI: 10.1177/1362361318815252
journals.sagepub.com/home/aut


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Abstract

This study assessed whether olfactory familiarization can render food odors more pleasant, and consequently food more attractive, to children with autism spectrum disorder. Participants were first presented with a series of food odors (session 1). Then, they were familiarized on four occasions (time window: 5 weeks) with one of the two most neutral odors (the other neutral odor was used as control) (session 2). In session 3, participants smelled the entire series of odors again. Both verbal and facial responses were compared from session 1 to session 3. After session 3, the children were presented with two identical foods (one containing the familiarized odor and one the control odor) and were asked to choose between these foods. Results revealed (1) a specific increase in positive emotions for the familiarized odor and (2) that 68% of the children chose the food associated with the “familiarized odor” (children who chose the “familiarized odor” food exhibited significantly more sensory particularities). These findings suggest that it is possible to modulate olfactory emotions and expand the dietary repertoire of children with autism spectrum disorder. Application of this paradigm may enable innovative prospects for food education in autism.

Keywords

autism spectrum disorder, emotion, familiarization, food, memory, olfaction, perception

Introduction

According to the American Psychiatric Association’s *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM-5), autism spectrum disorder (ASD) is characterized by both (1) deficits in social communication and social interaction and (2) stereotyped, restricted, repetitive patterns of behavior, interest, or activity including atypical speech and movement, resistance to change, and atypical sensory behavior. Modification in sensory functioning in ASD has been well documented in the last decade (Robertson and Baron-Cohen, 2017) for the visual (Simmons et al., 2009), tactile (Puts et al., 2014), auditory (O’Connor, 2012), and olfactory systems (Ashwin et al., 2014; Kumazaki et al., 2016; Muratori et al., 2017; Tonacci et al., 2017; Wicker et al., 2016); these symptoms are present in early childhood and combine to limit and impair everyday life and notably eating behavior.

Eating disorders affect 13%–50% of typically developed (TD) children, but affect more than 80% of children with ASD (Ledford and Gast, 2006; Nadon et al., 2013).

The primary outcome of food learning is to widen the diversity of foods a child accepts, so as at least to cover their needs. Achieving this aim is especially complex for children with ASD; selectivity, defined as the consumption of a limited number of foods, this is by far the most common issue encountered by these children (Cermak et al., 2014; Rastam and Wentz, 2014; Sharp et al., 2013). Therefore, one of the main challenges in the field is to understand by which mechanisms and by what methodology it is possible to expand the dietary repertoire of children with ASD. The main objective of our study is to

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provide new and significant responses to this scientific and societal issue.

When deciding whether to consume a food or not, TD children rely primarily on the visual (Dovey et al., 2008; Lafraire et al., 2016; Wadhwa and Capaldi-Phillips, 2014) and olfactory stimuli (Dovey et al., 2008) present. Perception of sensory stimuli activates more or less familiar “traces” in memory with strong sensory motor and emotional components (Versace et al., 2014) and then influences decision-making processes. For TD children, emotion and familiarity are thus key components in this decision-making process, and this is especially true in the domain of food choice, since children eat what they like and appreciate what they know (Cooke, 2007).

In TD children, repeated exposure to a novel (a priori unattractive) food may lead children to appreciate it (Cooke, 2007; Cooke and Fildes, 2011). This practice is based on a process known in psychology as the “mere exposure effect,” which is defined as the increase in the preference for a stimulus that is repeated several times without being reinforced (Zajonc, 1968). To our knowledge, only one published study has explored this effect in adolescents and adults with ASD (South et al., 2008). Two different studies (Parma et al., 2013, 2014) found that the presence of a maternal body odor facilitated imitation tasks in children with ASD. One of the characteristics of the maternal odor is precisely to be familiar to the child. Moreover, previous studies identified a link between the appreciation of a sensory dimension (vision or olfaction; Luisier, 2017; Luisier et al., 2015) and food neophobia—the inability of children with ASD to accept a new food. The more positive valence a child attributes to visual or olfactory stimuli, the less neophobic he or she is. This association was not found in TD children. Taken together, these studies suggest that the allocation of a positive valence to a sensory dimension (sight, smell) of a given food could favor the acceptance of this food in children with ASD. This relationship could therefore allow food acceptance in children with ASD to be modified, since if one can make a food visually or olfactorily more pleasant for a child, then the food could be more acceptable and one can widen the child’s food choices. It is this new hypothesis that we have tested in this study.

Given the strong link between olfaction, emotion, and food behavior (Dovey et al., 2008; Gaillet-Torrent et al., 2014; Lafraire et al., 2016), the olfactory modality was chosen as the sensory entry to test this hypothesis in a group of children with ASD. To increase odor valence in this sample, we set up an experimental paradigm based on an olfactory familiarization task. This paradigm was inspired by Delplanque et al. (2015), who showed that the mere exposure effect (*described above*) increased the appreciation of an odor in healthy adults. To verify that olfactory familiarization increased odor valence (Aim 1) in children with ASD, we measured affective states

induced by odors before and after familiarization. Since most children with ASD exhibit difficulties in verbally expressing their emotional feelings (Cascio et al., 2016; Gaigg, 2012; Hill et al., 2004; Legiša et al., 2013; Robledo et al., 2012; Savarese, 2013), both subjective (verbal) and more objective approaches (facial expression measured automatically) were used to characterize the emotional changes (Garcia-Burgos and Zamora, 2013) induced by repeated exposure. Finally, to assess the effect of odor familiarization on food choices (Aim 2), at the end of the experiment, children with ASD were presented with two identical foods (one scented with the familiarized odor and one with a control odor) and were asked to choose between these foods. Therefore, the experiment consisted of a longitudinal study design in which each child experienced a test condition (i.e. familiarized odor) and a control condition (i.e. control odor).

Methods

Participants

In total, 49 children (mean age \pm standard error of the mean (SEM): 109.4 ± 3.2 months; 6 females) diagnosed with ASD were included in the study approved by the Commission Cantonale Valaisanne d’Ethique Médicale institutional review board (IRB number: CCVEM 022/14). A parental consent was required for all children. The diagnosis of ASD was confirmed using the Autism Diagnostic Observation Schedule (ADOS) (ADOS-1 for 4 children and ADOS-2 for 45 children; Dolan, 2009; Lord et al., 1999, 2012). Note that the entire spectrum of autism was represented in the sample (range ADOS comparison score: from 3 to 10).

Raven’s Coloured Progressive Matrices (RCPM; Raven et al., 1998) were used to assess general intelligence level (maximum possible score: 35). This test requires no verbal responses and minimizes the need for verbal instructions, and is particularly suitable for children with ASD (Barbeau et al., 2013). Out of 49 children, 8 were not able and/or refused to perform the test and 1 child was absent during the test completion. The range of Raven’s scores was between 8 and 35.

In terms of general language abilities, 19 children had fluent speech and 30 children had no spoken language or very limited spoken language (according to caregivers).

Food neophobia was assessed by the parents on a standard 10-item questionnaire (the French Adapted Food Neophobia Scale (AFNS)) with good internal consistency (Reverdy et al., 2008). For each item, parents were required to indicate to what extent the corresponding statement was true, on a 7-point scale from “Very true for me” to “Not at all true for me.” The 10 items were as follows: (1) My child is very particular about the foods he or she will eat (reversed scoring); (2) My child likes foods from different

countries; (3) My child doesn't trust new foods (reversed scoring); (4) My child likes to try unusual foods; (5) When my child has the choice between different flavors for a certain food (e.g. ice-cream or sweets), he or she likes to choose a flavor that he or she doesn't know; (6) My child will try a dish, even if he or she doesn't know what's in it; (7) The foods my child knows are sufficient for him or her (reversed scoring); (8) My child is willing to eat anything that is offered; (9) My child is afraid to eat things he or she has never had before (reversed scoring); and (10) My child will not taste a food when he or she doesn't 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 adding the scores for the 10 questions (range: 10–70); the higher the score, the higher the neophobia grade. Scores from 46 participants were usable. The mean \pm SEM food neophobia score was 46.5 ± 2.0 . A great diversity of scores was observed (from 10 to 70).

Finally, to characterize the sensory profile of each participant, the French version (translation and publication by ECPA (Editions du Centre de Psychologie Appliquée)) of the Short Sensory Profile (SSP; Dunn, 2010) was completed by the parents. The SSP is a standardized questionnaire that includes seven sections: (1) tactile sensitivity (seven items), (2) taste/smell sensitivity (four items), (3) movement sensitivity (three items), (4) under-responsive/seeks sensation (seven items), (5) auditory filtering (six items), (6) low energy/weak (six items), and (7) visual/auditory sensitivity (five items). The internal reliability, using Cronbach's alpha, for the test total and sections ranges from 0.70 to 0.90 (Dunn, 1999). Scores from 36 participants were usable. SSP scores range from 92 to 170 (on a scale from 38 to 190) reflecting a large heterogeneity in the sample of children with ASD.

Stimuli

Six food odorants (Firmenich SA, Geneva, Switzerland) varying in quality and pleasantness were selected: ghee (cheese-like), fish, orange, pineapple, strawberry, and banana. Odors were selected on the basis of previous publications (Bensafi et al., 2007; Delplanque et al., 2015; Hrdlicka et al., 2011; Wagner et al., 2013). All odorants were diluted in propylene glycol according to concentrations determined from a pilot study on 8 adult neurotypical individuals (18–53 years; 5 males) that showed that the smells were not too strong and not different in terms of perceived intensity ($F(5, 47)=0.963$; $p=0.451$). Olfactory stimuli were presented in 30 mL (nominal volume) flasks (opening diameter: 3.05 cm; height: 4.5 cm) filled with 4 mL dilution absorbed on scentless polypropylene fabric (3 cm \times 8 cm; 3M, Valley, NE, USA) to optimize evaporation and air/oil

partitioning. A total of six odorous stimuli and a flask containing only 4 mL propylene glycol ("non-odorized" flask) were thus used (seven stimuli in total).

Procedure

The experiment started with a detailed explanation of the procedure to the child (Figure 1(a)). The experimental procedure then included four sessions: (1) a "pre-familiarization exposure" session (T0) in which participants had to perceive six odors; (2) a "familiarization" session in which they were exposed four times (i.e. four separate subsessions in a time window of 5 weeks) to one olfactory stimulus (presented in the first session); (3) a "post-familiarization exposure" session in which they were asked to smell the six odors presented in the first session; (4) a "food choice" session, immediately after the third session, in which they were asked to choose between two identical foods that differed in their olfactory properties (one food scented with the "familiarized odor" and one food scented with a "control odor").

Pre-familiarization exposure session (session 1). In this session, participants were first asked to sit down on a chair. Facial reactions in response to odors were videotaped with a digital video camera (Sony Alpha 6000 Hybrid, EAN : 4905524974287) located in front of the child's face (Figure 1(b)). The camera was run in autofocus mode (phase-detection AF/contrast-detection AF) to achieve optimum focus, exposure, and white balance. The face of the child was framed on a regular basis and the illumination of the participant's face was optimized using two light diffusers (Philips 8718696510148 cool White LED 1521 lm, 4000 K) on each side of the child. A light gray background was also used. These controls enabled us to optimize shadows and contrasts and facilitated the automatic analysis by the facial recognition software. Regarding odor presentation, the odor-presenting device was placed on the table next to the experimenter. The six odors were presented in open glass flasks. A behavioral measure of affective reactions to odor was performed using an automatic analysis of the emotional facial patterns by adapting the procedure of Garcia-Burgos and colleagues (Garcia-Burgos and Zamora, 2013; Rocha-Parra et al., 2016) (Figure 1(c)).

To habituate the participant to the experimental setting, we presented an empty flask to the child before starting the experiment. This empty stimulation was used to set up a baseline for facial emotion measurement (see "Data and statistical analyses" section). Then, seven stimuli (six odors and a "non-odorized" flask containing only the solvent) were presented in a random order (Hasard® software). To this end, the experimenter opened the flask and placed it on the rotary arm of the flask-presenting device (see Figure 1(b)). The stopwatch was started when the flask was below the participant's face (the flask was

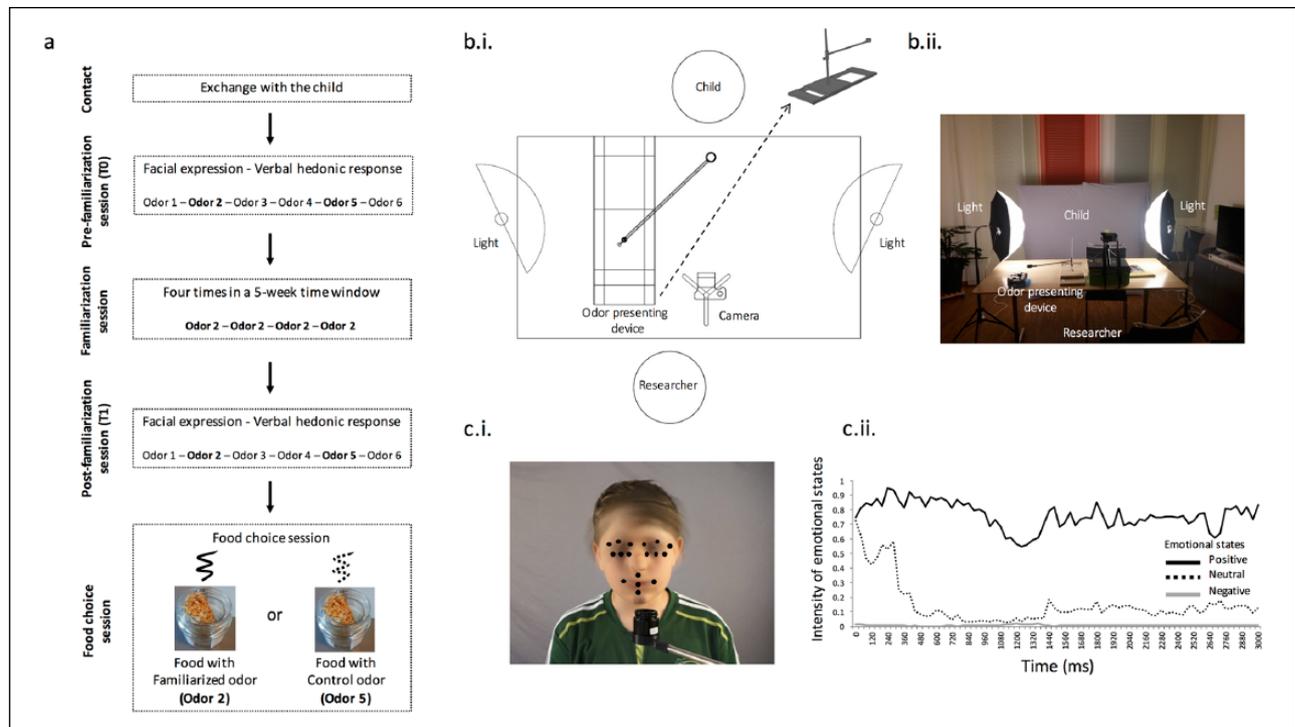


Figure 1. Experimental protocol: (a) graphical representation of the experimental procedure. In this example, Odor 2 and Odor 5 elicited the lowest hedonic reaction for a given child. During the familiarization task, Odor 2 was used as the “familiarized odor.” During the food choice session, Odor 5 was used as the “Control odor.” (b) Experimental room with light and video systems showing the position of the child, the experimenter, and the odor-presenting device with a rotated arm and a flask container. (c.i.) Example of a face with the odor-presenting device and the emotion valence analysis. (c.ii) An example of intensity of positive, neutral, and negative emotional states as a function of time with the smell of orange.

positioned below the chin so that the entire face of the child was visible and could be analyzed). After 10s of presentation, the flask was removed by rotating the arm toward the examiner, who closed the flask. After 30s, the examiner asked the child whether he or she liked the odor or not. A new flask was then presented to the child after about 20s. In sum, the total duration for a trial was about 60s, which represents a sufficient time window to prevent olfactory adaptation occurring.

Familiarization session (session 2). For each participant, two odors for which each child showed the least hedonic reactivity (“low-hedonic” odors) were selected for the familiarization session. Here, we selected odors that were a priori not rejected by the children, since according to Delplanque et al. (2015), chosen smells in such mere exposure paradigm must not be a priori repulsive. Thus, the fishy odor was never considered for this session since it often causes negative hedonic reactions (Luisier et al., 2015). Moreover, odors eliciting intense hedonic positive reactions were also discarded.

Among the two “low-hedonic” odors, one odor was used for the familiarization (“familiarized odor”) and the second was used as control in the food choice session (“control odor,” see section “Food choice session (session

4”)). Four familiarization sessions were proposed over a 5-week period depending on both children’s and school schedules. We chose to use a 5-week familiarization period since Delplanque et al. (2015) revealed that this time window was sufficient to elicit a mere exposure effect in olfaction. Familiarization never took place on the days of pre-/post-familiarization sessions. Moreover, two familiarization sessions never took place on the same day. Four exceptions were made: for two children one session was done in the morning, and the other in the afternoon; for one child three sessions were distributed over 1 day; and for another child, the last session was conducted on the day of the post-familiarization session (but early in the morning).

To facilitate interactions around the odor between the researcher and the children, we opted for a clinical and dialogical posture paradigm. Thus, the familiarization session was not simply an “odor exposure task,” but consisted of building with each child a “space of communication” around the odor chosen for familiarization, as has been done in the field of educational sciences and specialized pedagogy (see theory of proximal zone development (Vygotskii, 2012)). Most of the sessions were conducted by the researcher (six children did their last session with their caregiver).

At each session, the researcher proposed to the child to interact with him or her around the odor. In the space of communication, the odor was presented in a flask, and the researcher encouraged the dialog in a positive emotional context. Communication materials consisting of gestural support and images were available to all the children. These materials were presented in addition to the child's usual communication tools. They were proposed by the experimenter, and the child was free to use them. The task of smelling an odor was proposed; the child was free to smell it or not. When considering the entire study, no child refused to smell the odor at any session. The session duration (for children who completed all the phases) was between 1:24 and 7:16 min, depending on the child's desire to interact. This duration included all child-experimenter interactions including odor exposure but also verbal exchanges not related to the odor, nonverbal communication, periods of silence, and so on.

Post-familiarization exposure session (session 3). This session was an exact replication of the pre-familiarization session, with the difference that a different randomized order of odor presentation was used for each participant. The post-familiarization session was immediately followed by a food choice session.

Food choice session (session 4). In this session, a food appreciated by the child was selected. This a priori selection was made either by the child, or by the teacher or educator who usually eats with the child. To this end, four criteria were used: the food had to (1) be known and appreciated by the child, (2) smell as weak as possible, (3) belong to children's diets, and (4) be easily handled and present no hygiene issues. From these criteria, different foods were selected: madeleines (with or without gluten), plain potato chips, shortbread, Kambly biscuits, dried apple, gluten-free biscuits, pancakes, and vanilla cream. Only one food per child was selected. The food was placed in a small glass container, itself placed in a glass jar. Two versions of the same food were proposed to the child. One version contained the "familiarized odor," and one version contained the "control odor" (see section "Familiarization session (session 2)"). In both versions, the odor dilution (volume of 5 mL) was absorbed on scentless polypropylene fabric (3 cm × 8 cm; 3M, Valley, NE, USA), to optimize evaporation and air/oil partitioning, which was placed between the two containers. The child's task was to choose between the two foods (he or she could see it and smell it, but not taste it) and to indicate the one he or she preferred (the two foods were presented one after the other, using a random-order presentation). In a second round, the child was asked whether he or she would like to eat it. The test took place before a meal so that all children were in the usual physiological state before a meal.

Sample reduction

Although we attempted to optimize our protocol for the children, it was not possible for all of them to complete the entire study. Measurement of facial expressions was the main issue identified. The child was asked to stay facing the camera for at least 3 s, without lowering his or her head toward the odor flask and without speaking. Because of all the difficulties encountered, of the original 49 participants, a total of 25 followed the instructions and completed the entire study for the "familiarized odor" and the "control odor" during all four sessions (i.e. the pre- and post-familiarization sessions, the familiarization session, and the food choice session). Note that a sample size of 25 children remains consistent since it amounts to 9% of the ASD population frame in the four French Swiss cantons in which the study took place, and it represents the whole ASD spectrum (as said above, we recruited children with ASD across the whole ASD spectrum and not only children with the highest cognitive level or the more compliant behavior). Such a sample, which is large in size according to regional comparisons, and representative of the diversity of the reference population, ensures the robustness of the results as well as the fair and equitable distribution of the benefits of research according to the principle of distributive justice.

To compare the included sample ($n=25$) with the participants who did not complete the entire study ($n=24$), we analyzed both groups along the food neophobia, SSP, ADOS, and Raven's scores. The included sample did not differ from the non-included sample for the food neophobia score (mean \pm SEM—*included sample*: 45.5 ± 3.0 , *non-included sample*: 47.5 ± 2.6 ; Mann-Whitney test: value=243, $p=0.652$) and for the SSP total score (mean \pm SEM—*included sample*: 133.3 ± 4.6 , *non-included sample*: 134.7 ± 4.7 ; Mann-Whitney test: value=150.5, $p=0.835$). However, among the 25 retained children, 17 (initially 19) had fluent speech and 8 (initially 30) had no or very limited spoken language. Moreover, the retained children had higher scores on Raven's test (better performances; mean \pm SEM—*included sample*: 27.8 ± 1.4 , *non-included sample*: 18.9 ± 1.7 ; test value=315; $p < 0.001$) despite higher scores on ADOS (greater severity of autism disorder; mean \pm SEM; *included sample*: 8.0 ± 0.4 , *non-included sample*: 6.6 ± 0.4 ; test value=350.5; $p=0.025$).

Data and statistical analyses

For all analyses, the level of statistical significance was set at 0.05. Analyses were performed using JASP software (<https://jasp-stats.org>).

Hedonic verbal data during the pre- and post-familiarization sessions. For the pre- (T0) and post-familiarization (T1)

sessions, the hedonic response to the question “Do you like this odor?” was scored with three values (−1; 0; 1): “1” for a “Yes” or nod of the head or any positive response such as “Yes, it was alright” (*Oui ça allait*), “Yes, quite” (*Oui assez*), and “So so” (*Ca va*); “−1” for a “No” or any negative response such as “Not so much,” “Not really,” and “Not too much”; or “0” for an unclear or non-hedonic response such as “I don’t know,” “Medium,” “A little bit strange” (*Un peu bizarre*), and “It smells a little bit good and not good” (*Ca sent un petit peu bon et pas bon*). Responses such as “There is nothing” (*Il n’y a rien*) and “I don’t smell anything” (*Je ne sens rien*) were not considered as a hedonic response since the children did not smell anything. For statistical analyses, we computed for each child the difference between the hedonic score at T1 and the hedonic score at T0 for the “familiarized odor,” d_{fam}^{T1-T0} , and for the “control odor,” d_{con}^{T1-T0} . The Wilcoxon test for paired data was used to compare d_{fam}^{T1-T0} versus d_{con}^{T1-T0} .

Facial expression data during the pre- and post-familiarization sessions. Measurement of facial expressions took place for the pre- and post-familiarization sessions. Here, the video files were run through FACET™ SDK software (iMotions Inc., Cambridge Innovation Center, Cambridge, MA, USA). The automatic facial expression recognition software tracked and analyzed frame-by-frame (1/25 s) the intensity (as estimated by expert human coders from 0 (=absent) to 1 (=very high intensity)) of positive valence (as a measure of overall feeling). To standardize the measurements and to compare the valence of facial expressions at T0 and at T1, the first 3 s after perceiving the odor stimuli were taken for analysis. In this time window, at least 70% of the video frames were analyzable for each child and each odor. The facial expression data analysis during the presentation of the empty flask served as baseline. At T0 and T1, and for each odor, the intensity of positive valence was calculated by subtracting the intensity of the empty flask. The intensity of positive valence was then smoothed by computing the mean of the obtained values every 1/10th of a second. For each child and each odor, missing intensity data values were replaced by the mean of the two nearest non-missing preceding values and the two subsequent non-missing values.

Regarding statistical analyses, first, for each child and each type of odor (“familiarized odor” and “control odor”), the means at T0 and at T1, m_{fam}^{T0} , m_{fam}^{T1} , m_{con}^{T0} , and m_{con}^{T1} of the 30 data-point intensities obtained during the first 3 s with the FACET™ SDK software were calculated.

We then assessed the null hypothesis against the chance that the data were normally distributed, using the Shapiro–Wilk test. The statistical results indicated that the null hypothesis could be rejected for the positive valence ($w=0.919$, $df=24$, $p\text{-value}=0.05$). For this reason, comparison of m_{fam}^{T1} versus m_{fam}^{T0} and m_{con}^{T1} versus m_{con}^{T0} used the Wilcoxon test for paired samples (*unilateral hypothesis*). Second, for each child and each type of odor,

the difference of the means was calculated: $m_{fam}^{T1-T0} = m_{fam}^{T1} - m_{fam}^{T0}$ and $m_{con}^{T1-T0} = m_{con}^{T1} - m_{con}^{T0}$. Comparison of m_{fam}^{T1-T0} versus m_{con}^{T1-T0} for each valence used the Wilcoxon test for paired samples. Additional comparisons m_{fam}^{T0} versus m_{con}^{T0} were conducted for each valence using the Wilcoxon test for paired samples. Finally, note that in complementary analyses, we applied the same statistical processing for both neutral and negative emotions.

Food choice session data. Regarding the food choice session, for each child, we attributed the value “1” if the child chose the food with the “familiarized odor” and the value “0” if the child chose the food with the “control odor.” For statistical purposes, the number of individuals who scored “1” (nb_1) was compared to the number of individuals who scored “0” (nb_0) using a chi-square test to test the a priori hypothesis that $nb_1 > nb_0$.

Results

Effect of familiarization on verbal hedonic responses to odors

Verbal hedonic responses to odors were obtained for 24 children. On a descriptive level, the mean values obtained ([95% confidence interval (CI)]) were 0.00 [−0.119; 0.119] for d_{fam}^{T1-T0} and −0.12 [−0.395; 0.155] for d_{con}^{T1-T0} . No significant difference between d_{fam}^{T1-T0} and d_{con}^{T1-T0} was observed (Wilcoxon test: $W=7.0$; $p=0.571$).

Effect of familiarization on facial expression responses to odors

For positive emotion valence, no significant difference was observed at T0 between the two types of odor (“familiarized” and “control”) (Wilcoxon test: intensity of positive valence: $W=128$, $p=0.367$). Comparison between T0 and T1 showed that the intensity of the positive valence was significantly higher at T1 than at T0 for the “familiarized odor” (Wilcoxon test: $W=95$, $p=0.035$). No such significant difference was observed for the “control odor” (Wilcoxon test: $W=161$, $p=0.489$) (Table 1).

Note that complementary analyses performed on negative and neutral emotions revealed: (1) no significant difference at T0 between the two types of odor (“familiarized” and “control”) for negative emotions ($W=141$, $p=0.578$) and neutral emotions ($W=196$, $p=0.381$), and (2) no significant increase from T0 to T1 either for the negative valence or for the neutral valence (see Table 1).

Finally, the change (delta) of positive valence between T0 and T1 was significantly higher for the “familiarized odor” compared to the variation observed for the “control odor” (mean values [95% CI]: “familiarized odor” 0.064 [−0.023; 0.152], “control odor” 0.006 [−0.075; 0.0188]; Wilcoxon test: $W=232$, $p=0.031$) (Figure 2(a)).

Table 1. Mean facial expression as a function of valence for T0 and T1 for both the familiarized odor and the control odor [95% CI].

Valence	m_{fam}^{T0}	m_{fam}^{T1}	W	p	m_{con}^{T0}	m_{con}^{T1}	W	p
Positive	0.158 [0.090; 0.2013]	0.223 [0.150; 0.295]	95	0.035	0.173 [0.123; 0.223]	0.179 [0.118; 0.240]	161	0.489
Negative	0.127 [0.085; 0.169]	0.125 [0.062; 0.189]	204	0.138	0.156 [0.086; 0.227]	0.156 [0.090; 0.222]	170	0.427
Neutral	0.665 [0.552; 0.778]	0.592 [0.478; 0.707]	198	0.353	0.654 [0.548; 0.760]	0.634 [0.524; 0.744]	172	0.812

Bold font: *p < 0.05.

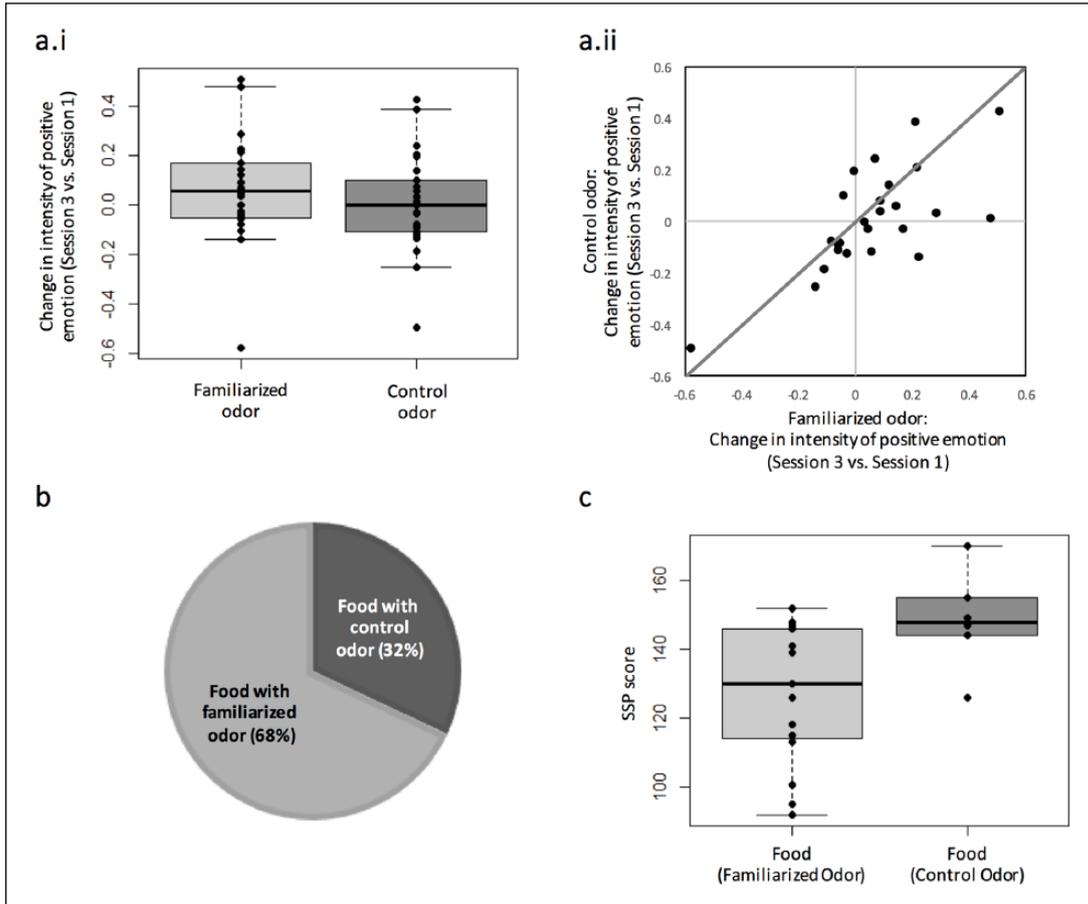


Figure 2. Experimental results: (a.i) Change (session 3 vs session 1) in intensity of positive emotion for the “familiarized odor” is greater following training with the “familiarized odor” than for the “control odor” (displayed as box plot, each dot corresponding to one individual, $p < 0.05$). (a.ii) Each point corresponds to an individual: note that the majority of individuals (18 out of 25) are below the unit slope line, indicating that they exhibited a greater positive emotion after training for the “familiarized odor” than for the “control odor.” (b) After training, 68% of the children with ASD chose the food that contained the “familiarized odor.” (c) When considering the Short Sensory Profile (SSP), the analysis revealed that children with ASD who chose the food scented with the “familiarized odor” had lower sensory profile (more sensory difficulties) (displayed as box plot, each dot corresponding to one individual, $p < 0.05$).

Food choice after familiarization

Regarding food choice, 68.0% of children chose the food with the “familiarized odor” and 32.0% of children chose the food with the “control odor” (Figure 2(b)). This difference was nearly significant ($\chi^2(1)=3.240, p=0.072$). Interestingly, when the data from the SSP were considered, we showed that children who chose the food containing the “familiarized odor” were also those who scored low on the SSP total score

(one-way analysis of variance (ANOVA), mean \pm SEM—“familiarized odor”: 127.2 ± 5.3 , “control odor”: 148.5 ± 5.9 ; $F(1, 19)=5.30, p=0.033$) (Figure 2(c)). The difference was not significant when the data from the food neophobia score (one-way ANOVA, mean \pm SEM—“familiarized odor”: 44.71 ± 3.366 , “control odor”: 47.57 ± 6.499 ; $F(1, 22)=0.184, p=0.672$), ADOS score (one-way ANOVA, mean \pm SEM—“familiarized odor”: 7.88 ± 0.50 , “control

odor”: 7.38 ± 0.63 ; $F(1, 23)=0.359$, $p=0.555$), and Raven’s score (one-way ANOVA, mean \pm SEM—“familiarized odor”: 27.12 ± 1.69 , “control odor”: 29.12 ± 2.52 ; $F(1, 22)=0.45$, $p=0.501$) were considered.

Discussion

The aim of our study was twofold: to examine—in children with ASD—the effects of olfactory familiarization (1) on the appreciation of an odor (Aim 1) and (2) on food choice (Aim 2). Regarding the first aim, measurement of facial expressions when smelling the “familiarized odor” showed a significant increase in the intensity of the positive valence after familiarization. This effect was not observed for the negative and neutral valences whose intensities remained similar after versus before familiarization. Thus, olfactory familiarization performed in a positive relational and emotional context seems to be an effective way of increasing the perceived valence of an odor in ASD children. Considering these findings, an important question to discuss is which factors of the olfactory familiarization (stimulus and/or contextual variables; Bornstein and Craver-Lemley, 2017) contributed to the success of the task. The olfactory nature of the stimulus gives it a particular emotional status. Indeed, if all the sensory cues enable the revival of a memory, smell is the one that best activates the emotions associated with it (Herz, 2004, 2016). Moreover, when odors evoke positive memories, they have the ability, among other stimuli, to increase the positive emotions experienced at the moment of evocation (Herz, 2016; Versace et al., 2014). These memorized positive emotions are not only related to the intrinsic odor valence but also to the context in which the odor exposure occurred (Herz, 2004, 2012; Herz and Schooler, 2002). On an experimental level, conducting an olfactory familiarization with a population of children with ASD was not obvious even if the protocol seemed at first sight very simple: to smell a flask and to name, sign, and/or show an image corresponding to the odor. In practice, we had to adapt the experimental space to each child, to get him or her to carry out the task. In spite of the diversity of the processes involved, thanks to a qualitative phenomenological analysis of the familiarization sessions (Luisier, 2017), we were able to extract some of the invariant and prominent contextual conditions: creation of a relationship with the child, co-construction with him or her of the possibility of carrying out the task, and finally, providing support to him or her to smell the odor and to interact with us around it. In sum, in our study, we presented the odor, but more importantly, we created a positive emotional context during the familiarization process. The contribution of all these factors is therefore prominent and non-dissociable at this stage.

Note that an important factor that may have affected the results was the duration of the odor exposure session

during the familiarization phase. Estimating the duration of the odor exposure during the familiarization session is, however, not a simple task since it requires (1) a reliable measure of the duration of each familiarization session and (2) a reliable measure of the duration of odor exposure during this familiarization session. Regarding the first point, it must be noted that within each session, the children’s behaviors were very heterogeneous: whereas most children were very good in keeping their attention on the task, it was not the case for others. For instance, some children left the experimenter for a few seconds or minutes and moved away to show or manipulate an object in the experimental room before going back to the session. Thus, measuring an exact duration of familiarization in these conditions was not easy. We were able to record a reliable duration for all four sessions in only 52% of the children (as stated in the “Methods” section, the duration range was from 1:24 to 7:16 min). Regarding the second point, the familiarization sessions were unfortunately not videotaped and it was not possible to dissociate odor exposure periods from non-olfactory interactions. To sum up, it is not unlikely that the duration of the odor exposure influenced the final results and future protocols may set up reliable measures of this factor, through video recordings for instance.

In sum, for each session of the familiarization process, we created conditions to help the children pay attention to the olfactory stimulus. We adopted a clinical and dialogical posture to promote interaction with the children and encourage them to communicate around the odor. We interacted with them with communication supports (words, gestures, pictograms, or the children’s own means of communication), leaving the children to choose their own strategy to achieve the fixed goal, namely, to smell the odor. Through these interactions, and considering the fact that the children were smelling in a repeated way, one can assume that the odor became more familiar. Familiarization may have contributed to the cognitive re-evaluation of the intrinsic acceptance of an odor and can thus be seen as a process of emotional regulation. According to Gross and Jazaieri (2014), emotion regulation occurs when one activates—either implicitly or explicitly—a goal to influence the emotion generative process. In Moors et al. (2013), this process is not viewed as an external process, but occurs progressively (as in our 5-week familiarization task) within the emotional appraisal itself.

With regard to the second aim, more than two-thirds of the children chose the food associated with the “familiarized odor.” Although these proportions remain just below statistical significance, our familiarization process opens up interesting perspectives in the field of food education in children with ASD. Moreover, we showed that children who chose the food with the “familiarized odor” had significantly more sensory particularities (as measured by the SSP questionnaire) than children who chose the food with

the “control odor.” Interestingly, previous works have shown that children who have the most sensory particularities are also those who have the greatest problems with food (Cermak et al., 2010, 2014; Mari-Bauset et al., 2014; Nadon et al., 2011; Suarez et al., 2012). These same sensory particularities are also associated with the severity of the ASD (Kern et al., 2007) and with greater social difficulties (Hilton et al., 2010). This result therefore suggests two different ramifications with regard to food intake in individuals with autism: (1) from a fundamental point of view, since it highlights the heterogeneity of the effect of sensory familiarization procedures on the behavior of children with ASD, and (2) from a more applied point of view, because the present protocol seems to be more beneficial to children with ASD who have the most atypical sensory profile and (maybe) atypical food profile, a finding that has significant implications at clinical level.

Interestingly, when looking at the sample reduction we had to perform, we noticed that the retained children had a more fluent speech and higher Raven’s scores, although they had higher ADOS scores. This observation is in line with previous meta-research findings showing that children with ASD having minimally verbal as well as minimally cognitive functioning are less often involved in scientific studies (Tager-Flusberg and Kasari, 2013), in particular, because their (more severe) communicative and cognitive characteristics may jeopardize reliable or valid direct assessments. In our protocol, the choice to include the minimally verbal and cognitive subgroups was an ethical decision related to a position known as distributive justice, which implies that neglecting a subgroup in research inevitably leads to it being deprived of the benefits of the research. Several precautions were taken to support the children’s participation and to mitigate the impact of their language impairments, comprehension problems, and/or anxiety. As mentioned earlier, the children’s own alternative and facilitated means of communication were used, as well as pictograms. Any rituals were respected. Nevertheless, the more frequent missing data in those subgroups confirm what a challenge it is for them to participate. The limitations encountered could perhaps be overcome in future studies using neurophysiological measures such as galvanic response in order to detect arousal patterns in reaction to stimuli or tasks (Fenning et al., 2017), as recently recommended (Tager-Flusberg and Kasari, 2013).

While this study provides new information about food education for ASD children, some of the methodological issues require discussion. First, as stated in the “Methods” section, facing the camera without speaking and moving the head was particularly difficult for children with ASD, and future studies should be careful with this issue regarding the experimental setting. Second, when considering the verbal hedonic responses to odors, our study did not show any influence of olfactory familiarization on this

subjective variable. This lack of influence may be due to the fact that children with ASD exhibit difficulties in verbally expressing their hedonic appreciation (Casco et al., 2016; Hill et al., 2004; Legiša et al., 2013; Robledo et al., 2012; Savarese, 2013). Although we were confident in analyzing some of these verbal hedonic responses, some other responses were difficult to evaluate since some children seemed to always say *yes*, others seemed to be inattentive, and others showed nonverbal attitudes (e.g. disgust) inconsistent with the verbal answer. Moreover, the hedonic scale used contained few values (−1; 0; +1), and it is likely that this limited range has impacted the results. Third, food choice was a fairly difficult task for ASD children. They were asked to see and smell the food, to choose which one they preferred and then they had the choice to eat it or not. It is likely that it was not natural for the child to have to smell consciously before making a decision; some children wanted to grasp the food as soon as the jar was presented. Fourth, although the general aim of our study was to provide alternative methods enabling children with ASD to widen their food dietary repertoire, it would not have been an easy task to test such an original paradigm with foods that were not eaten at all and that may elicit aversive reactions in these children. In order to provide a first scientific proof of concept that olfactory familiarization has an effect on food choice, we therefore decided to test the protocol with foods that were known and consumed by the children. Therefore, whether such effect can be generalized to foods that are not consumed and not liked by the children with ASD constitutes a challenge that needs to be tested in future studies. Fifth, considering the high selectivity of some children and specific exclusion regimes, we did not have a large food choice, and the smell of certain foods could have partially covered the associated odor (although these effects were minimized by selecting foods with no or very little odor). Sixth, another point that needs to be raised concerns the odors’ congruence with children’s favorite food. For example, we had to work with salted chips for some children who did not accept any other food. These chips could be associated with fruit odors which are non-congruent with salty products. The possibility cannot be ruled out that this association could have disturbed some children.

Another issue that may be raised relates to the fact that the children’s reactions cannot be attributed only to the introduction of the odor. As discussed earlier, the children’s reactions must indeed be understood as an effect of the whole familiarization procedure, including both the most general aspects of our intervention and the tailor-made adaptations we used to respond to the neurodiverse needs of this population and to best fit the individual functioning of each child. The individual adaptations raise questions, however, about the sampling procedure in populations known to present a certain heterogeneity and/or consisting of subgroups, which is the case for people with

ASD (Brunsdon and Happé, 2014; Georgiades et al., 2013; Morales-Hidalgo et al., 2018; Wiggins et al., 2017). Given the limited data available to characterize the participants, the sample would have benefited from being selected from a given subgroup in order to be more homogeneous. Choosing another protocol, that is, single-case experimental design, could also have been considered for a more comprehensive individual child-centered analysis of the effects of the familiarization procedure. With the same protocol, additional cognitive and communicative measures would have allowed a better sample characterization and more fine-grained analyses, by taking into account both broader patterns and particular features like the ability to categorize, for instance (Rutter, 2014).

In conclusion, notwithstanding the above limitations, we have shown in this study that familiarization (using sensory, contextual, and social cues) enhances odor preferences in ASD children. For most children, and especially those with greater sensory (and maybe food) atypical behavior, this familiarization influenced food choices. In the near future, the present protocol should be improved by considering foods that are not liked and not consumed by the children in order to enable the generalization of our findings. Moreover, if we used a larger palette of methods including, response time recordings during both the familiarization time and the food choice task, accompanied by psychophysiological recordings, we would be able to better understand the behavioral and emotional underpinnings of the effect of odor exposure on food choice at both individual and group levels. Finally, in the long term, application of such protocols could be used as new approaches for food education in children with ASD, based on pleasure and social associations, and aimed at widening food diversity in this population.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This project was funded by the MI of CNRS.

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