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Ontogeny of Odor Liking during Childhood and Its Relation to Language Development

Fanny Rinck[1,2], Melissa Barkat-Defradas[3], Amandine Chakirian[1], Pauline Joussain[1], Fanny Bourgeat[1], Marc Thévenet[1], Catherine Rouby[1] and Moustafa Bensafi[1]

[1]Université Lyon 1, CNRS, UMR5020, Neurosciences Sensorielles, Comportement, Cognition, Lyon, France, [2]Laboratoire Modyco, UMR7114, CNRS/Université Paris Ouest Nanterre La Défense and [3]CNRS UMR 5267, Laboratoire Praxiling, Université de Montpellier, Montpellier, F-34090, France

Correspondence to be sent to: Moustafa Bensafi, CNRS, UMR5020, Neurosciences Sensorielles, Comportement, Cognition, Université de Lyon, Lyon, F-69007, France. e-mail: bensafi@olfac.univ-lyon1.fr

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Abstract

One important aspect of odor hedonics is its plasticity during human development. The present study set out to probe the modulators of such olfactory change during that period by testing the hypothesis that language and semantic representations of objects are strong organizers of odor liking. To this end, 15 three-year-old children were tested in a longitudinal study. Participants were exposed to exactly the same 12 odorants once a year over a 3-year period. At each experimental session, they were asked to answer 2 questions: 1) "Do you like or dislike this odor?" and 2) "Can you tell me what it is?" The level of language production was assessed on a standardized test. The 3-year-old children were found to categorize the same number of odorants as liked and as disliked. The follow-up study, in contrast, showed that at 5 years of age they categorized more of these odors as liked and that the shift was significant only in the children with higher language production skills. Taken as a whole, these findings suggest that the 3- to 5-year age range, when children begin to master language, is a turning point in the construction of olfactory hedonic categories during childhood.

Key words: children, hedonic, language, liking, olfaction, pleasantness

Introduction

Odor hedonics is a prominent facet of the olfactory function. A number of researchers reported that olfaction is already functional and emotionally charged in human newborns, chemical stimuli evoking differentiable behavioral and physiological changes (Schaal et al. 1998, 2004). It seems, however, that emotional response to unpleasant odors is more clearly observable at birth than hedonic response to pleasant odors: whereas newborns display behavioral markers of disgust in response to unpleasant odors such as butyric acid (smelling like rancid butter), they do not reliably display positive facial responses to the pleasant smell of vanilla (Soussignan et al. 1997).

Odor hedonics is, nevertheless, well documented in the earliest phases of development: hedonic tone of smells evolves within the first weeks of life, whether by normal postnatal exposure (Marlier et al. 1998) or olfactory conditioning (Sullivan et al. 1991), and in early childhood (Schmidt and Beauchamp 1988).

In comparison, much less is understood about the evolution and construction of odor hedonics at intermediate ages of human development, between the ages of 3 and 5 years, a period of life in which children begin to master language. One central hypothesis in the development of odor hedonics during that period is that language and semantic representations of objects become strong organizers of perception and of odor perception in particular (Engen T and Engen EA 1997). According to Engen T and Engen EA (1997), odor pleasantness may develop from birth on, as does what children are able to say about odors as their language develops. The present study set out to test this hypothesis. To this end, children were exposed to odorants at time points between the critical stages of lexical explosion (18–36 months) and the organization of representations (4–5.5 years old) (Piaget 1937; Farr and Moscovici 1984; Abric 2004). Odor liking was measured for 12 odorants. Verbal response to odorants and general language production ability were also assessed.

Materials and methods

Subjects

Twenty 3-year-old children participated in the experiment at baseline (year 1). Because 5 of the original 20 participants were either absent during the period of testing or moved from the school where the experimental sessions were performed, only 15 children participated in the longitudinal study and were tested at 4 and 5 years of age. Informed consent was obtained from parents and children, and the experimental procedure was also approved by the education authority governing the participating nursery school (in Villeneuve-lès-Maguelone, France). All 15 are native monolingual French speakers. Thirteen have a French cultural background from both parents, one has a mother originating from Spain, and one has a mother originating from Algeria. However, both of these mothers speak only French to their children who consequently are not bilingual neither in reception nor in production.

Odorants

Twelve odorants were used: anise (Euracli), orange blossom water (Euracli), chocolate (Euracli), melon (Euracli), coffee (Euracli), lemon (Euracli), pineapple (Euracli), orange (D-limonene, Sigma-Aldrich), cola (Euracli), moldy orange (D-limonene + terpinen-4-ol, Sigma-Aldrich), moldy (terpinen-4-ol, Sigma-Aldrich), rancid butter (butyric acid, Sigma-Aldrich). All odorants were diluted in mineral oil (Sigma-Aldrich) (between 1/100 vol/vol and 1/10 vol/vol) so as to be perceived as moderately intense by adult judges and presented on paper strips (10 cm length; 1 cm width).

Procedure

One important aspect of children's involvement in the study was that they had been prepared for the experimental sessions a few weeks before. They knew from their teacher and parents that they were going to take part in sensory studies involving olfaction. Experiments were performed at the nursery school of Villeneuve-lès-Maguelone (France), in an isolated room (6 × 6 m) dedicated for the experimental sessions. Participants were first asked to complete a standardized test of French language production (Deltour and Hupkens 1980). This test is commonly used to evaluate children's language abilities as a function of their chronological age. Children are tested individually and asked to give a definition of 30 different lexical items (frequent nouns and verbs). Precisely, the experimenter gives the following instruction: "Can you explain me what is a donkey, truck..." (for frequent nouns)... and/or "Can you explain me what means to eat, to run..." (for verbs). Words (e.g., donkey, truck, to eat, to run, to yawn ...) are orally presented one by one and the definition produced by the child for each one of these words is precisely written down by the experimenter on a preformatted answer sheet. The quotation (0–1 point) depends on the quality of the definition (e.g., for the item "donkey" a basic incomplete definition such as "it is an animal" counts for 0; a precise definition such as "it is a 4-legged animal with long ears and gray hairs that brays (or does "Hee Haw")" counts for 1 point). The maximum score is then 30 and the minimum score is 0. The test, standardized from 245 children from 3 to 5 years of age controlled for sociocultural background, lasts about 20 min.

Upon completion of the language test, the experimenter explained the procedure in detail to the children. Participants were to sit on a chair, in front of the experimenter. They were informed that they would be filmed by 2 digital camcorders (SONY video cameras: one in front of the subject and one placed to view the left profile of the subject) during the experimental session. Once the subject was installed, the experiment started. One experimental session comprised 12 trials (one for each odorant). Each trial started when the experimenter presented the odorized paper strip 1 cm under the nose of the child. The task was to sniff the strip and answer 2 questions: 1) "Do you like or dislike this odor?" (exact wording in French: "*Est-ce que tu aimes ou est-ce que tu n'aimes pas cette odeur?*") and 2) "Can you tell me what it is?" ("*Est-ce que tu peux me dire ce que c'est?*"). Each odorant was presented for 2 s. The interval between 2 stimulations was fixed at 1 min. The order of presentation of the 12 odorants during the experimental session was randomized for each subject. Afterward, the children were debriefed regarding the aims and methods of the experiment.

Data analysis

Analysis of language performance and odor verbalizations

Here, a language production score was calculated for each participant, at each age (maximum score, 30). Within each age group (3, 4, and 5 years old), participants were divided into 2 subgroups according to their language production subtest score (median split: "low language producers" or Low LP vs. "high language producers" or High LP ending in 7 Low LP at 3 years old, 8 Low LP at 4 years old, and 7 Low LP at 5 years old).

For odor verbalizations, responses to the question "Can you tell me what it is?" were analyzed by counting the number of olfactory labels evoked by each odor for each subject. Specifically, whereas the absence of any response or responses such as "I don't know" or "I don't remember" were considered as a "no verbal answer" or as a "verbal answer without any odor label," responses such as "it's lemon," "chocolate," "vanilla," "candies" were included in the analysis and considered as olfactory labels. Because at that age, identification scores are low (Hummel et al. 2007; Monnery-Patris et al. 2009), both wrong (i.e., "lemon" instead of "chocolate," which represent 15% of the responses) and correct (i.e., "chocolate" for "chocolate" which corresponds to 12% of the responses) verbalizations were considered as olfactory labels.

Analysis of odor hedonic response

Measuring odor liking and odor disliking based on verbal reports is a difficult task in children (Schmidt and Beauchamp 1988; Engen T and Engen EA 1997). Here, we used a 2-fold approach, combining verbalization with nonverbal responses on facial video recording. Specifically, verbal response to the question "Do you like or dislike this odor?" was first analyzed. If, for a particular odor trial, the subject did not give any verbal answer, his/her behavior was examined on the appropriate video segment. To this end, for each subject, each film was divided into 12 segments corresponding to each odorant condition, using appropriate software (Volcan). A segment lasted 5 s, starting with the beginning of the presentation of the odor strip and ending 5 s later. When no verbal response was given, the experimenter asked the participants again if they "liked" and if they "disliked" the odor. A naive experimenter (FB), blind to odorant condition, coded the behavioral response on a binary basis: "liked," when the subject moved his/her head as if to say "Yes, I like it"; "disliked," when as if to say "No, I dislike it." Overall, 41.48% of responses indicated a "disliked" odor, 51.85% a "liked" odor, and 6.67% a neutral odor (when no verbal response was given and no behavioral response was observed). Neutral responses were too few to be taken into account in the statistical analysis. Thus, for each subject and each age group, the variable analyzed was the number of odors rated as liked or disliked. The number of liked odors versus disliked odors was compared on the nonparametric Wilcoxon test (separately per age group and per language production level for the effect of language on odor liking).

Analysis of facial affects

The children's facial behavior (positive facial affects [PFAs] and negative facial affects [NFAs]) was coded by 2 different coders. NFAs were defined by the presence of 2 negative facial actions (nose wrinkled and upper lip raised), whereas PFAs were defined by the presence of 2 positive facial affects (lip corner pulled, cheek raised) (Griffin and Sayette 2008). For each olfactory condition, we scored each facial movement category as being present or absent during a 5-s interval beginning when the stimulus was placed under the child's nostril (Camras et al. 2006). A high concordance between coders was achieved (Kendal correlation, $P < 0.0001$), and for each stimulus, only facial actions that had been coded by both coders were taken into account. Given that across all trials, NFA corresponded only to 2.6% (vs. 16.48% for PFA) of all trials, they were not included in the analysis.

Results

Odor liking was first characterized at baseline (year 1). At the age of 3, results showed that, of the 12 odors, the number of disliked odors (mean: 7.30 ± 3.84) tended to be greater than the number categorized as liked (mean: 4.40 ± 3.91), but this difference did not reach significance at the statistical threshold of 0.05 ($z = 1.568$, $P > 0.05$).

One important aspect of the olfactory function is its plasticity, especially during human development (Schaal 1988). The second question addressed by the study was how this hedonic categorization evolves during childhood. To answer this question, 15 of the 20 participants originally tested in the first year were invited to take part in 2 additional experimental sessions (longitudinal study), respectively, 1 and 2 years later. The procedure was exactly the same as at baseline. The number of liked odors versus disliked odors did not differ at the ages of 3 ($z = 1.067$, $P > 0.05$) and 4 ($z = 1.083$, $P > 0.05$) but at 5, more odors were categorized as liked than as disliked ($z = 2.471$, $P < 0.02$) (Figure 1).

To further explore the above effect of age on odor liking, we next analyzed how positive facial affects (PFAs) in response to odors evolved during the longitudinal study. The number of PFA was not significantly different between the ages of 3 and 4 ($z = 0.254$, $P > 0.05$), the ages of 3 and 5 ($z = 0.630$, $P > 0.05$), and the ages of 4 and 5 ($z = 0.917$, $P > 0.05$) (Figure 2). In sum, whereas on the perceptual level, odors evoked more positive reactions (liking) than negative reactions only in 5-year-old children, it seems that this hedonic dissociation is not observed at the behavioral level. Possible causes for such absence of modulation of facial responses with age include the fact that children were asked to perform cognitive tasks (odor liking and verbalization) during odor perception. This is discussed later in the paper.

To ask how odor-liking estimates of children differed from those of adults and how they were related to odor pleasantness and odor intensity ratings, a control experiment was performed in 10 adults (mean age: 33 years, range: 21–48, 5 males and 5 females). Participants were presented in a random order, the 12 odors used in children. They were asked to: 1) decide whether they liked or disliked the odor (binary choice: like vs. dislike), 2) rate odor pleasantness (using

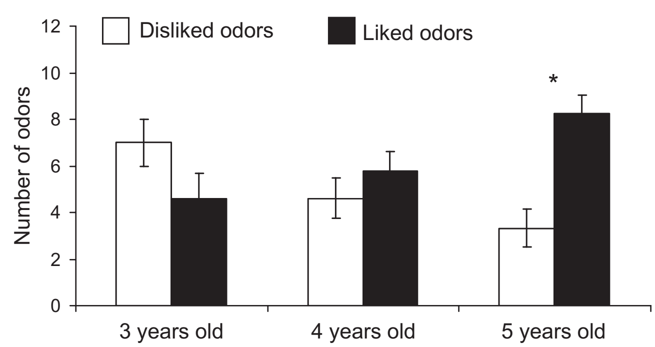

Figure 1 Number of odors categorized as liked (white bars) or disliked (black bars) in 3- to 5-year-old children. The number of odors categorized as liked was significantly greater than the number of odors categorized as disliked in 5 year olds. *, significant difference at the statistical threshold of 5%.

a scale from 1 = "very unpleasant odor" to 9 = "very pleasant odor"), and 3) rate odor intensity (using a scale from 1 = "no odor at all" to 9 = "very intense odor"). The results showed that adults exhibited a very similar behavior as that observed in 5-year-old children: the number of liked odors was significantly greater than the number of disliked odors ($z = 2.521$, $P < 0.02$) (Figure 3a). Moreover, whereas no significant difference in perceived intensity was seen between liked and disliked odors ($F_{1,9} = 2.834$, $P > 0.05$; Figure 3b), liked odors were significantly more pleasant than disliked odors in all adult participants ($F_{1,9} = 60.991$, $P < 0.0001$; Figure 3c). In brief, whereas no differences in perceived intensity were seen between liked and disliked odors, odor liking is strongly related to odor pleasantness as judged by adults.

As deciding whether a stimulus is edible or toxic is a prominent dimension in olfactory perception (De Wijk and Cain 1994), one question that may be raised from the above findings is whether this effect seen in children was effective for all odors or whether differences between food and nonfood odors can be observed. To answer this question, we split the odor set into 2 groups: "food odors" (a group that includes 9 odors: anise, orange blossom water, chocolate, melon, coffee, lemon, pineapple, orange, and cola) and "toxic odors" (a group that includes 3 odors: moldy orange, moldy, and rancid butter). For "toxic odors," no significant effect of age was seen for liking judgments (3 years vs. 4 years: $z = 1.638$, $P > 0.05$; 3 years vs. 5 years: $z = 1.327$, $P > 0.05$; 4 years vs. 5 years: $z = 0.021$, $P > 0.05$). However, for "food odors," a significant increase in liking was seen between 3 and 5 years ($z = 2.551$, $P < 0.02$), 4 and 5 years ($z = 2.240$, $P < 0.03$), but not between 3 and 4 years ($z = 1.182$, $P > 0.05$) (Figure 4). Table 1 illustrates the effect of age on liking for each odor.

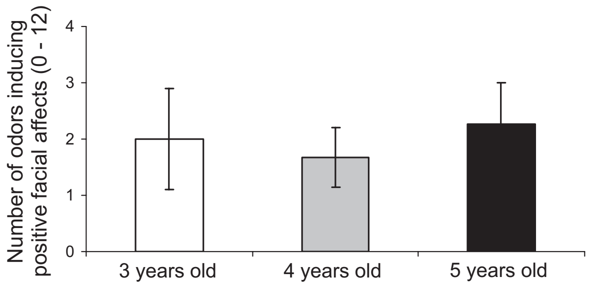

Figure 2 PFAs in responses to odors as a function of age. No effect of age was observed.

Infants and children actively assess the olfactory facets of their physical and social environment and develop semantic knowledge of their odor world (Schaal 1988). Semantic representations of objects may organize sensory perception in general and olfactory perception in particular (Bensafi, Rinck, et al. 2007). The next question addressed by the study was therefore whether the way children modify their olfactory hedonic categories is related to general language ability. To test this, language ability was tested at each age (3, 4, and 5 years) on a standardized test of French language production (Deltour and Hupkens 1980). As expected, language production scores increased significantly from 3 years old to 4–5 years old ($F_{2,42} = 7.011$, $P < 0.003$). This increase in general language production was also observed for the olfactory modality: olfactory verbalizations increased from 3 years old to 4–5 years old ($F_{2,42} = 6.525$, $P < 0.004$) (Table 2). To further explore whether the level of language production can modulate hedonic perception of odors, children were divided into "low language producers" or "high language producers" according to their score on the language production test. Results showed that participants with low language production scores did not categorize more odors as liked than disliked (3 years old: $z = 1.048$, $P > 0.05$; 4 years old: $z = 0.943$, $P > 0.05$; 5 years old: $z = 1.268$, $P > 0.05$). In subjects with high language production scores, however, although there was no significant difference at the ages of 3 ($z = 0.560$, $P > 0.05$) and 4 ($z = 0.507$, $P > 0.05$), at the age of 5 more odors were categorized as liked than as disliked ($z = 2.170$, $P < 0.03$) (Figure 5a,b,c).

To further ask whether the increase in odor liking for High LP children was effective only for food odors, we performed an additional analysis by taking into account 2 factors: the level of language production and the odor type (food and

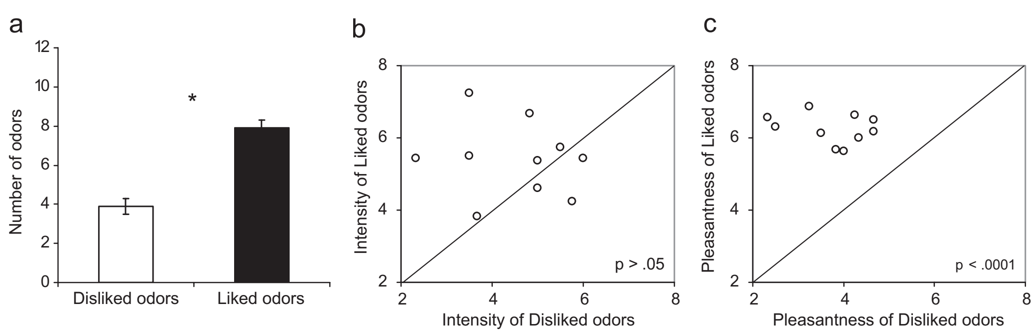

Figure 3 Odor liking in adults. **(a)** The number of odors categorized as liked (black bars) was significantly greater than the number of odors categorized as disliked in adults (white bars) (*, significant difference at the statistical threshold of 5%). **(b)** No significant difference in perceived intensity was observed between liked odors and disliked odors ($P > 0.05$, each circle corresponds to a subject). **(c)** Liked odors were significantly more pleasant than disliked odors in all adult participants ($P < 0.0001$, each circle corresponds to a subject).

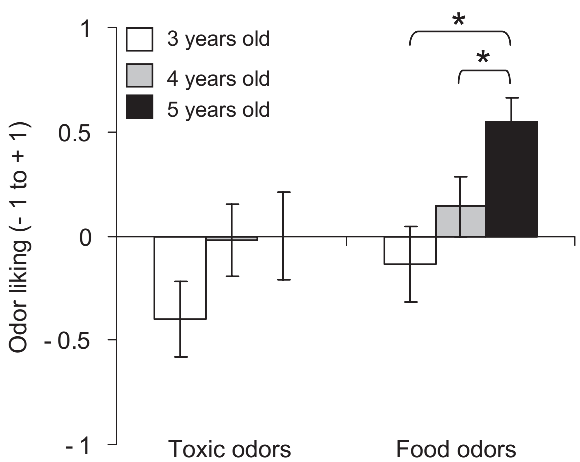

Figure 4 Liking for "toxic odors' and "food odors" at 3 years old (white bars), 4 years old (gray bars), and 5 years old (black bars). A significant increase in liking was observed from 3 to 5 years old and from 4 to 5 years old for food odors but not for toxic odors (*, significant difference at the statistical threshold of 5%).

Table 1 Mean and standard errors of liking for each odor (toxic and food) at 3, 4, and 5 years old

	3 years old		4 years old		5 years old	
	Mean	SEM	Mean	SEM	Mean	SEM
Toxic						
Moldy	−0.73	0.18	0.06	0.24	−0.20	0.26
Moldy orange	−0.40	0.23	0.26	0.22	−0.13	0.25
Rancid butter	−0.06	0.26	−0.40	0.23	0.33	0.25
Food						
Coffee	−0.20	0.26	−0.33	0.23	0.13	0.25
Anise	−0.06	0.26	−0.26	0.22	0.26	0.24
Chocolate	−0.26	0.25	−0.13	0.23	0.33	0.25
Lemon	−0.06	0.26	0.33	0.23	0.33	0.23
Orange	−0.33	0.25	0.06	0.24	0.60	0.21
Pineapple	0.20	0.26	0.60	0.21	0.73	0.18
Orange blossom water	−0.06	0.26	0.46	0.19	0.73	0.18
Cola	−0.20	0.24	0.20	0.24	0.80	0.14
Melon	−0.20	0.24	0.33	0.25	1.00	0.00

SEM, standard error of the mean.

toxic odors). The results revealed that the increase in odor liking was significant only in "High language producers" but only for food odors and not for toxic odors (Figure 6). Specifically, the increase tended to be significant between 3 and 5 years old ($z = 1.785$, $P = 0.069$) and was significant between 4 years old and 5 years old ($z = 2.199$, $P < 0.03$). All the remaining comparison were not significant at the threshold $P = 0.05$.

Table 2 General language production scores and olfactory verbalization as a function of age

	Mean	SEM
Language production score		
3 years old	18.93	2.16
4 years old	25.13	1.12
5 years old	27.40	1.50
Number of olfactory labels		
3 years old	1.20	0.42
4 years old	3.67	0.77
5 years old	4.40	0.71

SEM, standard error of the mean.

Discussion

The present study sought to test the hypothesis that the period of childhood in which language and semantic representations of objects develop and stabilize (i.e., between 3 and 5 years of age) may correspond to a change in odor liking. In this study, the same 12 odors were assessed across 3 years. It was shown that 3-year-old children stimulated with odors categorized the same number as liked and as disliked. The follow-up study showed that, at 5 years of age, those tested again now categorized a greater number of the same odors as liked. This behavioral pattern at 5 years old is very close to the one observed in adults who categorized also a larger number of odors as liked (vs. disliked). Taken together, these results suggest that the 3- to 5-year age range is a turning point in the construction of olfactory hedonic categories during childhood (Engen T and Engen EA 1997).

By considering the semantic quality of smells, we showed that the observed increase in odor liking was significant only for food odors and not for toxic odors. This result is of much interest because it suggests that the alarm system dedicated to detect aversive and toxic odorant sources is preserved during human development, whereas the hedonic perception of food odors is much more sensitive to experience and learning. Arguments for such hypothesis are provided by psychophysical and neuroimaging studies (for a review, see Rouby, Pouliot, and Bensafi 2009) that showed that unpleasant and/or aversive odors are processed faster than pleasant ones (Bensafi et al. 2003; Jacob et al. 2003), already induce specific patterns of olfactomotor response (Johnson et al. 2006; Rouby, Bourgeat, et al. 2009) and neural activation in the primary olfactory cortex (Bensafi, Sobel, and Khan 2007; Zelano et al. 2007). Combined with these findings, our results strengthen the notion of the existence of a "quick and dirty" pathway, fast-tracking decision for bad odors, the activity of which is lowly modulated by human development.

One concern that may be raised from the above results is the absence of behavioral markers of these affective processes: the lack of significant differences in facial affect

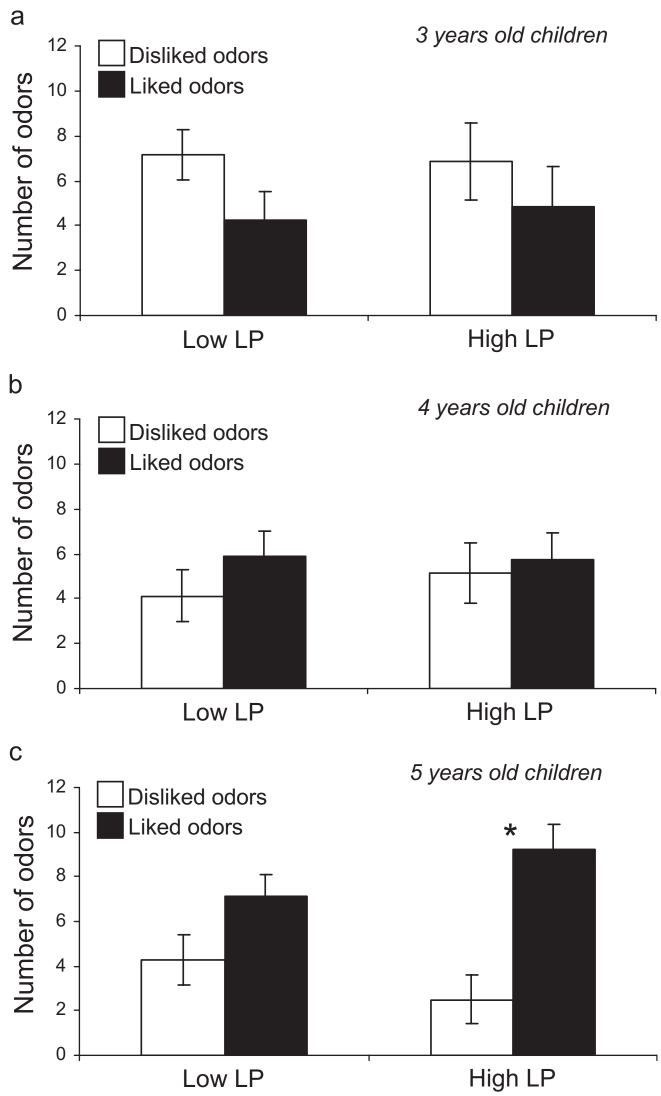

Figure 5 Number of odors categorized as liked or disliked in 3 year olds **(a)**, 4 year olds **(b)**, and 5 year olds **(c)** according to their language production level ("Low LP" corresponds to children with a low level of language production, "High LP" to children with a high level of language production). The number of odors categorized as liked was significantly greater than the number of odors categorized as disliked, specifically in 5-year-old children with a high level of language production **(c)**. *, significant difference at the statistical threshold of 5%.

responses with age. Studies in babies show that facial displays of pleasure or acceptance allow differentiating between odors, but neonates exhibit a large variety of facial actions, and smiling is rather low in presence of odors pleasant to adults, like vanillin. Disgust faces are more frequent and the discrimination of pleasantness is possible only on the proportion of negative displays (Soussignan et al. 1997). Studies in children between 5 and 12 years of age show that negative facial displays are more frequent when children are alone, and positive ones more frequent in the presence of an adult (Soussignan and Schaal 1996). Thus differential facial displays are evoked by odorants but are regulated by social factors. In our study, the social situation was indeed quite demanding, in a master/pupil relationship, where children had to refrain from moving, to be quiet and concentrated on the task. Their facial expressions were serious and rather fixed; this social constraint may explain the quasi-absence of NFAs and perhaps the lack of changes in PFAs with age.

A central question in the study was of the mechanisms underlying this change in hedonic categorization. Specifically, it was hypothesized that language and semantic learning lead to organizing object categories and that the shift toward odor liking relies on higher level cognitive processes. To test this, children were compared according to their language production skills. This measure should be correlated with the conceptual knowledge the child has accumulated and therefore with ease of lexical access to odor names and odor semantic categories (Monnery-Patris et al. 2009). As predicted, verbalization about smells was found to increase in parallel with general language ability between 3 and 5 years of age. Hedonic encoding of smells changes in parallel with language skills, and odor response reduces the proportion of odors categorized as disliked. For a given child, some previously "disliked" odors become "liked." The most convincing finding is that this shift toward odor liking was found only in those children who exhibited higher language production skills. This is in line with the view that, in the 4- to 12-year age range, the ability to memorize and lexicalize odors develops progressively (Richman et al. 1992; De Wijk and Cain 1994; Cain et al. 1995; Lehrner et al. 1999), opening the way to early modulation of olfactory perception (Mennella and Garcia 2000; Poncelet et al. 2010) through top-down impact of lexical knowledge (Stagnetto et al. 2006; Bensafi, Rinck, et al. 2007).

However, the observed tendency toward a positive appreciation of odors with age could be due to other general developmental changes in children's hedonic attitude toward any object in the environment. First, other aspects of their neural development, such as overall cognitive performances, could have influenced the increase in odor liking. It is indeed likely that a high cognitive development is associated with good language performances and because only language production level was assessed in our study design, this possibility cannot be excluded. Second, as familiarity with various odorants and objects increases over 3 years and because mere exposure is known to influence sensory preference (Zajonc 1968), simple perceptual learning could also explain the increase in odor liking. Third, besides perceptual learning, emotional encoding of smells can be considered to be a basic emotional experience that does not imply much cognitive mediation as compared with other modalities (Ehrlichman and Bastone 1990). In 5- to 8-year-old children (Mennella and Garcia 2000; Forestell and Mennella 2005), Menella and colleagues showed that affective responses to some odorants (alcohol and tobacco smoke) reflected the emotional context in which their parents used them. Thus emotional encoding of smells could occur

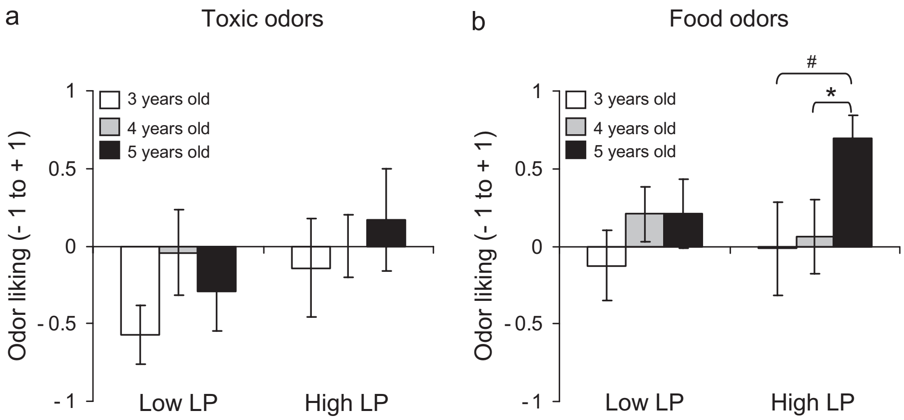

Figure 6 Evolution of odor liking as a function of language production level ("Low LP" corresponds to children with a low level of language production, "High LP" to children with a high level of language production) and odor type (food odors vs. toxic odors). **(a)** No significant increase in odor liking for toxic odors was observed neither in Low LP nor in High LP. **(b)** For food odors, the increase in odor liking was significant only in High LP but not in Low LP. #, trend with a statistical probability between 0.10 and 0.05; *, significant difference at the statistical threshold of 0.05.

with little cognitive involvement and should not vary while language develops. Fourth, a nonspecific cognitive trend that could explain the present results is the decline of neophobia, documented in respect to the acceptance of foods: food neophobia increases during the second year of life and declines gradually between 4 and 22 years of age (Nicklaus et al. 2005).

Although we cannot discard totally the involvement of the second and the third factors in the shift in odor liking, there is no reason to suppose that children with a high level of lexical knowledge would have encountered the 12 odors more often in their environment or in a more emotional context than their schoolmates: it seems more likely that language skills are responsible for this change.

As regards the fourth factor, although odor neophobia has not yet been studied in children, it could be a trend explaining the shift in odor liking observed here. However, food neophobia is high between 4 and 8 years and was not found to change between 2 and 6 years of age (Cooke et al. 2003), thus it seems unlikely that a decrease in neophobic attitudes toward odors could underlie the children's responses observed in the present study. Furthermore, the same age range corresponds to the emergence of disgust responses to foods; these reactions appear between 3 and 5 years of age (Fallon et al. 1984), and the shift toward pleasantness observed here is parallel to cognitive progresses in the categorization of nonacceptable foods and an increasing reluctance to ingest them. Thus, although our study design as such could not specify the respective roles of perceptual learning, emotional learning and neophobia (because it was not possible in the framework of this study to carry out individual inquiries to measure these parameters through each child's actual context and frequency of encounter with such and such an odorant), future investigations could address this question by developing methodologies adapted for children. Nevertheless, according to what is known about language development, it would have been interesting to retest the low-level language producers at the age of 6, to see if the foreseeable improvement in their language skills had, 1 year later, produced a corresponding enhancement in odor liking.

Another question that may be raised here is whether the increase in odor liking may be due to the fact that younger children may be more sensitive to odors which therefore render the smells more disliked. Although our study design cannot discard this possibility, the issue of odor threshold in young children is not completely resolved, both higher and unchanged sensitivity in younger children seem possible: previous empirical studies of sensitivity showed thresholds in children and adolescents to be either lower than (Wysocki and Gilbert 1989; Solbu et al. 1990) or the same as in adults (Cain et al. 1995; Lehrner et al. 1999; Chalouhi et al. 2005). Moreover, to the best of our knowledge, there is no study that allows expecting a short-term raise in thresholds between 3 and 4–5 years of age.

In conclusion, the present data support the hypothesis that, beyond predisposed hedonic reactivity (Soussignan et al. 1997; Khan et al. 2007; Mandairon et al. 2009), odor hedonics is highly plastic during childhood. Odor hedonics changes between 3 and 5 years of age, 5 year olds rating fewer odorants as disliked than they did at 3 and 4 years of age. Moreover, this shift toward odor liking is correlated with language skills but not with age itself as it is seen only in children with higher scores in language production.

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