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Olfactory categorization: A developmental study

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ABSTRACT

This study examined the ability of children to classify fruit and flower odors. We asked four groups of children (4–11 years of age) and a group of adults to identify, categorize, and evaluate the edibility, liking, and typicality of 12 fruit and flower odors. Results showed an increase in interindividual agreement with age for the taxonomic (fruit/flower) and function-based (edible/nonedible) categories but not for the hedonic component. So, it seems that this hedonic component is not the explicit basis for this increase in interindividual agreement when categorizing an odor as a fruit/flower odor or as being edible or nonedible. An age-related trend was also observed on the typicality scores: The youngest group of children did not show a typicality gradient, but all of the other groups did. Blackcurrant and lemon were rated as the most typical fruit odors, whereas raspberry and peach were rated as the least typical. For flower odorants, results were not as clear, yet it seems that for all groups lavender was considered as quite typical.

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Introduction

The ability to acquire categorical knowledge is a fundamental aspect of human cognition and perception. When we identify a newly encountered stimulus as a category member, we use our knowledge of the category for understanding and predicting the properties of the stimulus. Categories are particularly useful during childhood when many new stimuli (e.g., objects, events, people) are encountered (e.g., Markman & Jaswal, 2003). As a consequence, understanding how categorization develops is crucial for understanding children's cognition and, therefore, has generated considerable interest

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focused mostly on the visual modality (Markman, 1991; but see also Fabes & Filsinger, 1986). The main questions are these: How do children acquire categories, and what is the role of language in category acquisition? The role of linguistic information in visual perception has been debated for more than half a century. Central to this debate is the notion of categorical perception (i.e., the partitioning of continuously varying stimuli into categories).

In a recent review, Regier and Kay (2009) modulated the initial Whorfian view (Kay & Kempton, 1984) that language affects our apprehension of the world by filtering our perceptions. For example, Gilbert, Regier, Kay, and Ivry (2006) found categorical perception effects (i.e., faster or more accurate discrimination of stimuli crossing the boundaries between two categories) for color categories only in the right visual field (left hemisphere), but these effects disappeared when a concurrent verbal interference task was used. Similar results have been found in children. For example, Daoutis, Franklin, Riddett, Clifford, and Davies (2006) showed that children who had not yet acquired color terms displayed categorical perception effects (i.e., better visual search performance when a target color belonged to a different category than the distracters) in the left visual field, whereas children who had acquired color terms displayed such effects in the right visual field.

Although research on categorical perception has traditionally focused on visual object processing, many researchers agree that other senses (e.g., touch, smell, taste) might show forms of categorical perception. An evolution of categorical perception was demonstrated, for instance, in speech sounds (e.g., synthesized speech sounds continuum between /ba/ and /pa/) between 2 and 6 years of age (Burnham, Earnshaw, & Clark, 1991) and in other sorts of sounds. Lange-Küttner (2010) showed that both infants (from 5–7 months to 10–12 months) and adults were able to distinguish between two types of bird sounds (i.e., seabirds vs. garden birds) and that whereas infants preferred seabird sounds to garden bird sounds, adults showed the reverse preference.

On a daily basis, people categorize sounds or smells in their environment as belonging to everyday life events such as the sound of flowing water and the *smell* of freshly baked bread. The correct categorization of sounds (e.g., the honking of a car) and smells (e.g., rotten food) can even be of critical importance. Yet, much of the systems-level organization for these other senses remains unexplored. A key issue, therefore, is to know whether categorical processing observed for visible stimuli can be transferred to nonvisible and transient stimuli. Despite the fact that the sense of smell seems to differ from visual or auditory senses as having more affective loading (Wrzesniewski, McCauley, & Rozin, 1999), the incredibly large number of discriminable odorous substances offered in nature suggests that we do respond to odors in terms of their class membership rather than as unique wholes linked to very specific contexts, as initially hypothesized (Engen, 1982). For instance, we do not need to univocally identify the smell of rotten food to know that we should not eat this food.

From an evolution standpoint, accurate odor categorization is crucial for survival because the olfactory system is critically involved in recognition of food and mates (Schaal, 1988; see also Gottfried, 2009). Despite this ecological relevance, research on odor categorization has been limited for a long time to the understanding of the physiological and neural mechanisms underlying odor encoding, and so little is known about how odor categories are processed. A recent high-resolution functional magnetic resonance imaging (fMRI) study by Howard, Plailly, Grueschow, Haynes, and Gottfried (2009) suggested that in humans, odor categories are encoded as distributed spatial ensembles in the posterior piriform cortex (olfactory primary cortex); odorants belonging to the same perceptual category exhibited similar pattern topography. According to the authors, “olfactory codes of odor object categories are arranged much in the same way that visual object categories (houses, cows, chairs) are organized in inferotemporal cortex” (p. 937). From a cognitive point of view, the existence of odor categories has been confirmed for citrus and woody odors (Lawless, 1989; Lawless & Glatter, 1991), floral and fruity odors (Chrea et al., 2004), and everyday odors (Chrea, Valentin, Sulmont-Rossé, Nguyen, & Abdi, 2005; Chrea et al., 2004; Dubois, 2000; Dubois & Rouby, 2002; Ueno, 1993).

Most research on odor categorization had been performed with adults. Yet, Ferdenzi, Camos, and Schaal (2008) showed that children tend to use olfactory stimuli in numerous everyday life situations. According to Bensafi, Rinck, Schaal, and Rouby (2007), odors are part of children's semantic knowledge of objects, contexts, and people because children can name objects or persons after being presented only with their odor. These observations suggest that for children, odors constitute a source of information about the world that is far from negligible. However, although infant olfactory perception has

been widely documented (for reviews, see Delaunay-El Allam, Soussignan, Patris, Marlier, & Schaal, 2010; Schaal, 1988), research on children is much more scarce. Therefore, it is important to further examine olfactory responsiveness in children. Accordingly, the main goal of this study was to assess children's odor categorization abilities within a developmental perspective.

Whereas a number of studies compared children's and adults' ability to detect and identify odors, very few are those concerned the development of olfactory functions in young children. Indeed, in most life span developmental studies, children are considered as a single group opposed to adult and elderly groups (e.g., Cain et al., 1995; de Wijk & Cain, 1994; Hummel et al., 2007; Lehrner, Glueck, & Laska, 1999). The interest in the development of olfactory functions in young children is not recent, as testified by the pioneering work of Petó (1936). This author, in a study analyzing the language and gestures/behavior of children from 1 month to 16 years of age presented with basic smells, showed that only children 5 years of age and older distinguished between agreeable and disagreeable odors. Petó concluded that 5 and 6 years were "years of transition" that could be explained in terms of education. More than 20 years later, Stein, Ottenberg, and Roulet (1958) compared the patterns of liking response of children from 3 to 12 years of age, adolescents (12–14 years of age), and adult participants to synthetic feces, synthetic sweat, and amyl acetate (a substance that smells somewhat like banana). Nearly all of the 3- and 4-year-olds rated all of the odors as pleasant. A marked decrease in the "like" responses for feces and sweat was observed in the 5- and 6-year-olds up to the adult group. A reverse pattern was observed for the amyl acetate odorant. According to Stein and colleagues, this developmental pattern could be explained in terms of psychosexual development.

However, according to Schmidt and Beauchamp (1988), Petó's (1936) and Stein and colleagues' (1958) results might be due to inadequate questioning procedures. Engen (1974) already reported that younger children's responses varied more with the nature of the question than with the odors. To verify this interpretation, Schmidt and Beauchamp (1988) used two puppets from the well-known *Sesame Street* children's show. Young children and adults were asked to give pleasant odorants to the nice puppet ("Big Bird") and unpleasant ones to the mean puppet ("Oscar the Grouch"). The data of 3-year-olds correlated well with those of adults, although children were generally more likely to consider odors as pleasant than adults and, as noted by Engen and Engen (1997), children and adults did not agree on the most pleasant and most unpleasant odors. In a recent longitudinal study, Rinck and colleagues (2011) asked 3-year-olds to evaluate their liking of 12 odorants once a year over a period of 3 years. A shift was observed between 3 and 5 years of age. Whereas 3-year-olds categorized the same number of odorants as liked or disliked, 5-year-olds liked more odors (a pattern closer to that of adults). This shift from dislike to like was significant only for food odors and not for toxic odors and only in children who exhibited higher language production skills.

Taken together, these data suggest that young children, by 3 to 5 years of age, would have acquired the ability to categorize odors according to their hedonic value. To evaluate whether the hedonic dimension is the only dimension structuring children's odor representations, Rouby, Chevalier, Gautier, and Dubois (1997) asked 5- and 6-year-olds to categorize 12 everyday life odors into familiarity, taxonomic (indoor vs. outdoor, natural vs. artificial, vegetable vs. animal), and functional (edible vs. nonedible, wearable vs. nonwearable) categories. Results showed that 5- and 6-year-olds were able to categorize odors according to functional dimensions such as edibility, and to a lesser extent wearability, but not according to taxonomic categories such as indoor/outdoor and natural/artificial odors. Among the taxonomic categories, only the vegetable/animal categories seemed to be meaningful to children. A superiority of edibility judgments over odor naming was already found by de Wijk and Cain (1994) in 8- to 14-year-olds.

In the current investigation, we were interested in examining at what age functional and taxonomic odor categories are acquired. We used fruit and flower odor categories. Previous work carried out with adults showed that fruit and flower odors seem to be organized along a continuum going from very fruity odors to very floral odors (Chrea, Valentin, & Abdi, 2009) and, as such, are somewhat comparable to the stimuli used in color perceptual categorization studies. These categories also have the advantage of functioning as each other's contrast categories at both the taxonomic and functional levels (Chrea et al., 2004). Finally, a pretest carried out with a small group of children showed that these odors were familiar to children globally.

We designed three categorization tasks. In the first task, participants needed to categorize odors into fruit and flower odors. This task aimed at evaluating participants' ability to produce a taxonomic sort (i.e., one that is based on shared perceptual properties). In the second task, participants were asked to categorize odors into edible and nonedible odors. This task aimed at evaluating participants' ability to produce a functional sort (i.e., one that is based on shared actions). The third task was a liking rating task in which participants were asked to indicate whether they liked or disliked the odors.

The three tasks were performed by four groups of children (4–11 years of age) and a group of adults. One of the difficulties in working with odors is that the notion of correctness of the answer is quite subjective and, thus, difficult to establish. Indeed, the odor of some fruits such as litchi and mango might be perceived as more floral than fruity (Chrea et al., 2004). Thus, to evaluate the categorization performance of the child groups, we did not compute the number of correct responses, as is classically done in developmental studies, but instead computed the degree of interindividual agreement within each group of participants.

Previous work in the vision domain showed that children do have several ways of categorizing objects and that their categorization evolves with age (Blaye, Paour, Bernard-Peyron, & Bonthoux, 2006). We expected this result to be extended to the olfactory domain. More specifically, we expected that the degree of agreement between participants would increase with age for both taxonomic and functional tasks. Although the current literature on the developmental course of the different forms of categorization is far from clear, based on Rouby and colleagues' (1997) work, we expected interindividual agreement to increase faster for the edible versus nonedible task than for the fruit versus flower task.

Because the hedonic value is often reported as the predominant dimension in odor categorization, we could suspect the results of Tasks 1 and 2 to be partially driven by this dimension. We asked participants to indicate whether they like or dislike the odors. Because fruit and flower odors are not much contrasted, we used a simple yes/no task rather than the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) that was previously used to assess odor liking in children (Bensafi et al., 2007; Stagnetto, Rouby, & Bensafi, 2006). The SAM scale includes five response categories illustrated by manikins with different facial expressions. Although this scale is more precise than the binary questions we used, it might have been too complex for the youngest children with the specific set of odors we exploited.

To gain some insight into the processes underlying the three categorization tasks, we designed two additional tasks: a typicality task and an identification task. Previous work carried out with adults showed that fruit and flower odor categories are organized along a typicality gradient (Chrea et al., 2009). The goal of the typicality task was to evaluate at which age this typicality gradient emerged. Typicality is generally evaluated using 7-point scales that are probably too complex for preschoolers. To avoid this problem, we designed a visual scale that should facilitate preschoolers' ability to perform the task.

Research on categorical perception showed that language partially underlines our perception of the world (Gilbert et al., 2006). In the domain of olfaction, Bensafi and colleagues (2007) exposed 5- and 6-year-olds to pleasant, neutral, and unpleasant odors with or without verbal cues. Results showed that making an odorant name available increased the hedonic value of neutral odors but had no effect on pleasant or unpleasant odors. According to the authors, this result suggests that providing an odorant name may help to categorize neutral odors into a more clearly defined hedonic category. To evaluate whether language can also facilitate categorizations other than hedonic categorization, we asked participants to indicate whether they knew the odors from the experimental set and, if so, to tell us what it was for them. We were interested in evaluating whether the increase in interindividual agreement we expected to find in the taxonomic and functional tasks would be concomitant with a better odor identification performance.

Method

Participants

A total of 87 children (47 girls and 40 boys) and 20 adults participated in the study. The children were recruited, with parental authorization, at the preschool and primary schools "La Pinède" near

Nice, France. They sample of children came from four different grades: 21 from the first year of kindergarten (mean age = 4.7 years, range = 4 years 1 month to 4 years 10 months [4;1–4;10]), 24 from a second year of kindergarten (mean age = 5.5 years, range = 4;11–6;5), 22 from third grade (mean age = 8.3 years, range = 7;10–9;1), and 20 from the fifth-grade level (mean age = 10.5 years, range = 9;11–11;11). The sample of adults (13 women and 7 men, mean age = 36.5 years, range = 17–66) were graduate students in psychology from the University of Nice. These five groups are labeled as 4 years, 5 years, 8 years, 10 years, and adults in this article.

Materials

Six fruit (banana, blackcurrant, lemon, peach, raspberry, and strawberry) and six flower (dianthine, jasmine, lavender, lily of the valley, rose, and mimosa) artificial odors were used in the experiment. These fruit and flower odors were chosen from the set previously used by Chrea and colleagues (2009) based on their familiarity for French participants. All odorants were supplied by Firmenich (Geneva, Switzerland) except for mimosa, peach, and rose, which were purchased locally (Extraits de Parfum, Grasse, France). They were chosen for their “naturalness” (i.e., they were not single molecules like amyl acetate for banana but rather complex mixtures designed to resemble, as much as possible, the actual fruit or flower odors). Although these chemical instantiations certainly diverge from actual fruit or flower odors, they have the advantage of being stable over time and to be at iso-intensity (which cannot easily be reached using natural products).

Mimosa, peach, and rose odorants were used as 100% solutions; the other odorants were diluted in odorless mineral oil to obtain roughly a similar average intensity for all odorants. Ten drops of the odorants or diluted odorants were applied to a piece of odorless cotton in capped 60-ml amber glass jars.

Procedure

Children participated in the protocol during regular class time in kindergarten or primary school. Each child was tested individually in a quiet area outside the classroom. All instructions and answers were given orally. To accommodate the youngest children's limited attention spans, testing was divided into two sessions separated by a few days. The first session started with a familiarization step followed by a fruit/flower categorization task and a typicality task. The second session consisted of familiarity, liking, and edibility categorization tasks. Adults were tested individually, during one unique session, in a quiet room of a research laboratory located at the University of Nice.

The experimenter started by asking children to answer the question, “Do you know what an odor is?” If the response was negative, the experimenter provided them with a short explanation. Children were then asked, “Do you know what a flower is? A fruit?” All children answered positively to these questions. After children were made comfortable enough with the experimental setup, the experimenter familiarized them with the testing procedure.

Familiarization step

Children were tested individually. The experimenter showed the odorant flasks to the child participant and explained how to smell them. Then the experimenter gave the child two flasks: a fruit (grapefruit) and a flower (lilac) odor. For each flask, the experimenter asked, “Can you smell this odor?” Then she asked, “Do you think it is the odor of a fruit or a flower?” If the child answered that it is a flower, the experimenter showed the flower box (Fig. 1A) and helped the child in putting the flask in the flower box. If the child answered that it is a fruit, the experimenter showed the fruit box (Fig. 1A) and helped the child in putting the flask in the fruit box. If the child did not immediately understand, a further explanation was provided. The child then needed to do the same thing with the second flask. For all tasks, the flasks were presented in a random order, different for each participant and each task, and the experimenter helped the younger children in handling the flasks.

Fruit/Flower categorization task

Participants were asked to smell each of the 12 flasks and to put them in the fruit box if they thought the odor was that of a fruit or in the flower box if they thought the odor was that of a flower.



Fig. 1. (A) Fruit and flower boxes. (B) Edible and inedible boxes.

Typicality task

Participants were asked to again smell the flasks they put in the fruit and flower boxes. For the fruit box, they were asked to indicate how much each flask smelled like a fruit. For the flower box, they were asked to indicate how much each flask smelled like a flower. Participants answered by pointing to the appropriate box on the scales shown in Fig. 2. The experimenter explained how to use the scale with the two training odors (grapefruit and lilac) and made sure that children understood the task.

Identification, liking, and edibility tasks

Participants were asked to smell the 12 flasks in the order that they were presented and to answer the following questions.

Identification. Participants were asked, “Do you know this odor?” If participants answered *yes*, the experimenter continued with the next question: “Can you tell me what it is?” If participants did not know, the experimenter insisted, “Are you sure you don’t know this odor? Do you want to smell it again?”

Liking. Participants were asked, “Do you like this odor?” Participants needed to answer *yes* or *no* rather than by using a box for “bad” odors (or those they disliked) and a box for “good” odors (or those they liked) to avoid lassitude effects that could emerge from repetitive tasks.

Edibility. Participants were asked, “Do you think that this is the odor of something edible? If you think it is edible, put it in this box [the experimenter showed the edible box presented in Fig. 1B], and if you think it is not edible, put it in this box [the experimenter showed the inedible box presented in Fig. 1B].” The presence of an apple image on the edible and nonedible boxes might have somehow influenced children in their choices. However, because (a) the goal of the study was to evaluate olfactory categorization and not object categorization and (b) we supposed that children had already acquired the concept that fruits are mostly edible and flowers are mostly nonedible, this should not have a strong impact on the results.

Results

Categorization tasks

To analyze the categorization tasks, we computed three indexes for each odorant and each age group. First, a *taxonomic index* was obtained as the number of participants who put the odorant in

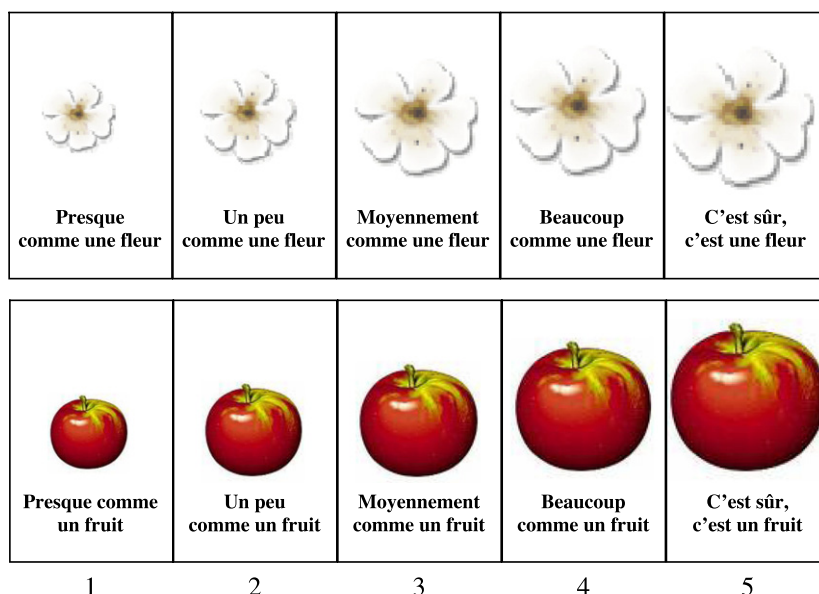


Fig. 2. Scales used to evaluate the typicality of the flower and fruit odors. The levels of the scale were (1) *almost like a fruit (flower)*, (2) *a little like a fruit (flower)*, (3) *somewhat like a fruit (flower)*, (4) *a lot like a fruit (flower)*, and (5) *that's sure, this is a fruit (flower)*.

the fruit box. Second, an *edibility index* was obtained as the number of participants who put the odorant in the edible box. Third, a *liking index* was obtained as the number of participants who answered that they liked the odorant. Then we carried out a chi-square analysis for each index in each age group with an alpha (α) level of .05 to highlight the odorants with an answer distribution significantly different from chance. The three indexes, along with the results of the chi-square test, are presented in Fig. 3A, B, and C, respectively, for each age group.

A clear age evolution in the agreement among participants can be noted in Fig. 3A and B for the taxonomic and the edibility indexes. Whereas indexes of younger participants were near 50%, those of older participants were close to 100 or 0%. For fruit odors, the evolution appears to be mainly for banana, lemon, and strawberry, for which the degree of agreement among participants increased with age, whereas it decreased for peach and remained stable for blackcurrant and raspberry. Blackcurrant was clearly categorized as a fruit odor since 4 years of age and considered as edible as early as 5 years of age, whereas for raspberry the answers remained randomly distributed. For the flower odors, an evolution was observed for all odorants. No such evolution appeared for the liking index. Blackcurrant and lemon were clearly liked since 4 years of age, whereas no clear agreement emerged for the other odorants. A last point worth noting is that interparticipant agreement seemed to be larger for the odorants corresponding a priori to the flower category than to the fruit category even for adults.

To quantify these visual observations, we averaged the three indexes across odors (Fig. 4) and carried out three regression analyses with age as an independent variable and taxonomic, edibility, and liking indexes as dependent variables. A slope significantly different from 0 was obtained only for the taxonomic index (slope = 2.20), $t(4) = 4.16$, $p < .05$, and the edibility index (slope = 1.60), $t(4) = 1.60$, $p < .01$. For the hedonic index, the regression was not significant. An R^2 comparison showed that the linear model ($R^2 = .95$) fitted the edibility index slightly better than the taxonomic model ($R^2 = .85$). This difference can be explained by a larger change between the youngest children (4 years) and third graders (8 years) for the taxonomic index than for the edibility index. Indeed, for the youngest children, only one odorant (blackcurrant) was preferentially attributed to the fruit category. The other odorants were attributed as often to the fruit category as to the flower category. At the same age,

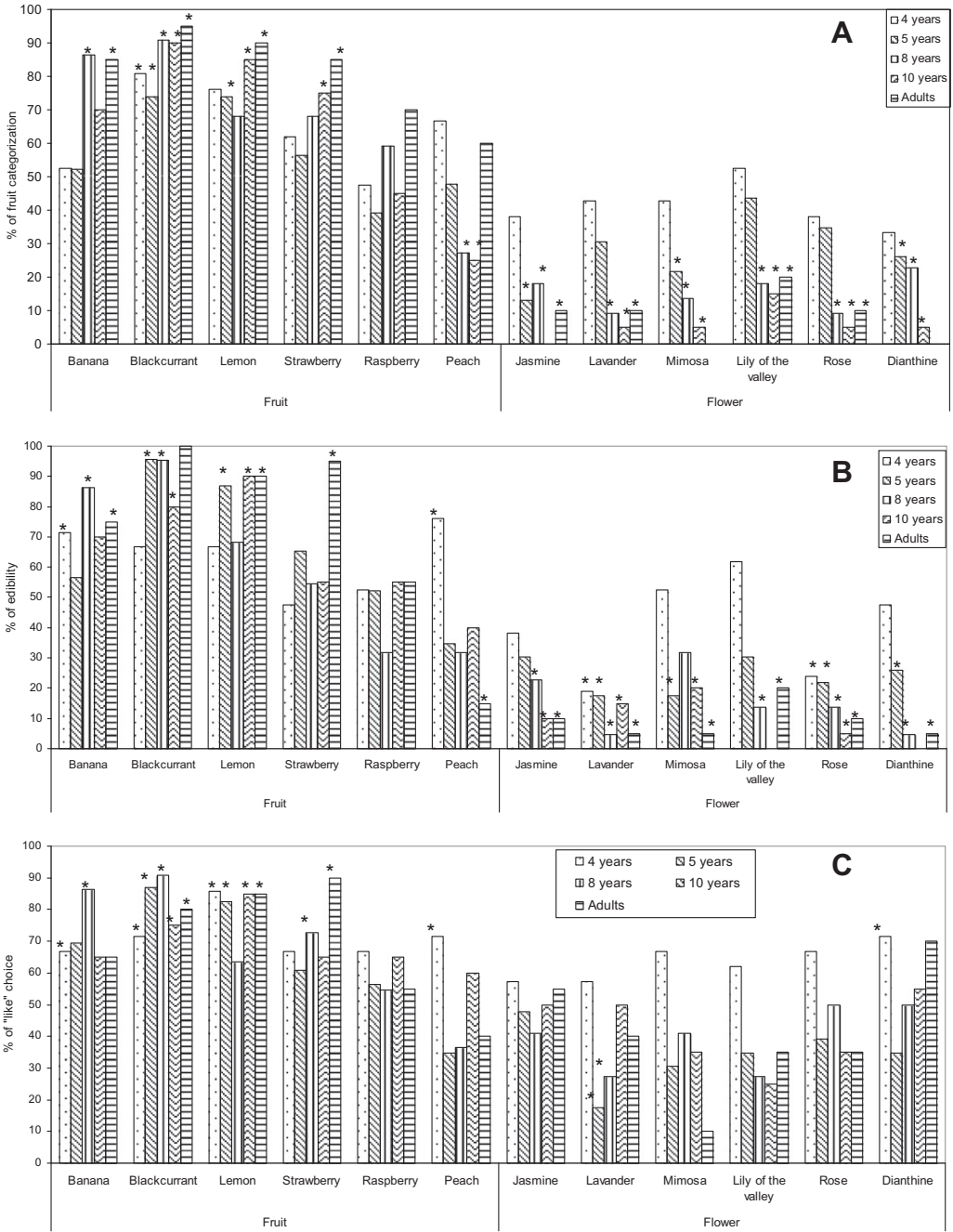


Fig. 3. (A) Percentages of fruit and flower items categorized as fruit for all of the participants. (B) Percentages of edibility of fruits and flowers. (C) Hedonic choices for the 10 odorants for each age level. Odorants with a distribution significantly different from chance are marked by an asterisk.

four odorants were preferentially considered as edible (banana and peach) or nonedible (lavender and rose).

Typicality task

For each odorant, following Chrea and colleagues (2009), we first compiled individual scores by attributing a positive score going from +1 to +5 if the odorant was classified in the expected category (fruit for a fruit odorant and flower for a flower odorant) and attributing a negative score going from –1 to –5 if the odorant was classified in the contrasting category. We then averaged the scores across participants in each age group to obtain a unique typicality index by odor for each age group. This unique typicality index reflects, for a given age group, the typicality of an odorant for its expected category minus its typicality for the contrasting category.

An analysis of the typicality score coefficients of variation (CVs) revealed a larger interindividual difference for the first two groups than for the others (median CVs = 456, 213, 98, 60, and 69 for 4-, 5-, 8-, and 10-year-olds and adults, respectively). This effect was stronger for the flower odorants (median CVs = 63, 52, 98, 312, and 1170, respectively) than for the fruit odorants (median CVs = 101, 96, 17, 209, and 204, respectively). In this last category, two odorants (peach and raspberry) led to large interindividual differences in all groups, and for a third odorant (strawberry) the interindividual difference decreased only in the adult group. To verify the observation that interindividual differences in typicality scores decreased with age, we computed a Cronbach's α coefficient on the raw data. As expected, the obtained values increased from 4-year-olds to 10-year-olds (Cronbach's α s = .14, .34, .84, and .90 for 4-, 5-, 8-, and 10-year-olds, respectively) but decreased in adults (Cronbach's α = .73).

The average typicality scores for flower and fruit odorants are shown in Table 1. A two-way analysis of variance (ANOVA) with age as a between-participant independent variable and odor as a within-participant independent variable was carried out on typicality scores. Age and odor were considered as fixed factors. Results showed a significant effect of age, $F(4, 100) = 18.67$, $p < .0001$, $MSe = 11.62$. The Bonferroni test showed no difference between 4- and 5-year-olds or between 8- and 10-year-olds. The effect of odor was significant, $F(11, 1100) = 13.07$, $p < .0001$, $MSe = 8.52$. The Bonferroni test showed that the odor of blackcurrant was significantly more typical of a fruit odor than the odor of strawberry, raspberry, or peach. However, no significant difference was observed among flower odors. The

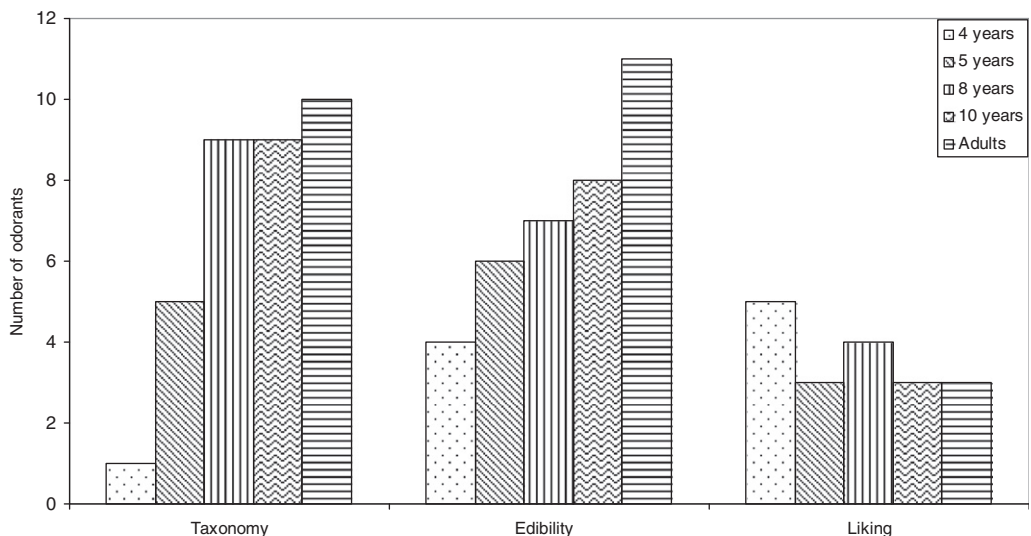


Fig. 4. Numbers of odorants with an answer distribution significantly different from chance (chi-square test, $\alpha = .05$) as a function of age level for all odors confounded.

interaction between age and odor was also significant, $F(44, 1100) = 1.93, p < .001, MSe = 8.52$. A sub-design analysis conditional on age showed a significant effect of odors only for the two older groups of children (8 and 10 years) and adults, but not for the two younger groups of children (4 and 5 years). For the fruit odorants, the typicality gradient was quite similar in all groups, with blackcurrant and lemon being the most typical fruit odors and raspberry and peach being the least typical fruit odors. This similarity in the typicality gradient for fruit odors was confirmed by Pearson's correlation coefficients computed on individual data (adults vs. 10 years: $r = .53, p < .0001$; adults vs. 8 years: $r = .52, p < .0001$; 8 years vs. 10 years: $r = .80, p < .0001$). For the flower odorants, the typicality gradient was less clear. Yet, lavender seemed to emerge as the more typical flower odor. Pearson's correlation coefficients computed on individual data showed the same level of correlation between the adults and the two older groups of children (adults vs. 10 years: $r = .62, p < .0001$; adults vs. 8 years: $r = .45, p < .0001$) but showed a smaller correlation between the two older groups of children (8 years vs. 10 years: $r = .52, p < .0001$) as for fruit odorants.

Finally, we computed Pearson's correlation coefficients between the proportion of categorization as fruit/flower and typicality score for each age. All coefficients were significant at the $\alpha = .05$ level, but the magnitude of the coefficients increased with participants' age ($r_s = .61, .61, .74, .74$, and $.94$ for 4-, 5-, 8-, and 10-year-olds and adults, respectively).

Identification task

We computed four indexes to evaluate participants' identification performance. The first one, which we called *expected label*, was the proportion of responses corresponding to the name of the object source (e.g., "lavender" for the lavender odorant). The second one, which we called *fluency index*, was the proportion of responses given by the participants of each age group. The third one, which we called *consensual index*, evaluated the consistency among participants of an age group in labeling odors; it was computed as the highest frequency of consistent answers among participants of an age group regardless of the status of the label as expected or not. The fourth one, which we called *precise index*, was the frequency of specific nouns given by participants of an age group to each odor (e.g., strawberry, rose).

Several points can be noted regarding Fig. 5. For both fruit and flower odors, the fluency index decreased from 4-year-olds to 8-year-olds and then increased from 8-year-olds to 10-year-olds up to adults, where it reached its highest value. This pattern of responses was closely paralleled by that of the precise index. The U shape of the fluency and precise indexes was not observed for the expected and consensual indexes. For these last two indexes, a slow and progressive increase was observed from 4-year-olds to adults.

To look at the nature of the vocabulary, we first separated the terms given by the five groups of participants into fruit terms (e.g., strawberry, red fruit, fruit), flower terms (e.g., jasmine, white flower,

Table 1

Average typicality scores of flower and fruit odorants along with Bonferroni test results.

Odor	4 years	5 years	8 years	10 years	Adults
Banana	0.50 _a	0.52 _a	2.59 _a	1.85 _{a,b}	3.10 _{a,b}
Blackcurrant	2.15 _a	1.69 _a	3.18 _a	3.25 _a	4.20 _a
Lemon	1.95 _a	1.69 _a	1.40 _a	3.25 _a	3.75 _a
Strawberry	0.85 _a	0.30 _a	0.54 _{a,b}	1.60 _{a,b}	2.95 _{a,b}
Raspberry	−0.30 _a	−0.26 _a	0.45 _{a,b}	−0.65 _{b,c}	1.40 _{a,b}
Peach	1.05 _a	−0.13 _a	−1.59 _b	−2.50 _c	0.20 _b
Jasmine	0.20 _a	2.47 _a	2.31 _a	3.55 _a	3.50 _a
Lavender	0.20 _a	0.78 _a	3.04 _a	3.95 _a	4.00 _a
Mimosa	0.35 _a	1.82 _a	2.68 _a	2.95 _a	4.15 _a
Lily of the valley	0.20 _a	0.65 _a	2.59 _a	2.75 _a	2.20 _{a,b}
Rose	0.70 _a	0.87 _a	2.40 _a	3.10 _a	3.50 _a
Dianthine	0.70 _a	1.52 _a	1.09 _{a,b}	3.75 _a	3.50 _a

Note. Two odorants with the same subscript letter are not significantly different at $p = .05$. When several letters are attributed to the odors, the letter "a" represents the first more typical odor, the letter "b" represents the second more typical odor, and so on.

flower), and other terms. We then computed the proportion of each type of terms for all groups. The results for fruit and flower terms are shown in Table 2.

The proportion of fruit and flower terms seemed to depend on age level. The youngest children tended to give more fruit terms than flower or other terms regardless of the types of odor. This tendency started to decrease in 5-year-olds, who provided slightly more flower terms than fruit terms for flower odors and provided more fruit terms than flower terms for fruit odors. A clear separation between fruit and flower terms appeared in 8-year-olds and remained stable up to the adult group. Globally, the other terms were scarcely used, and their frequency of use did not seem to depend on age level.

Discussion

This study addressed the general question of the developmental trajectory of odor categorization and identification. Globally, our results showed a clear age-dependent increase in interindividual agreement for taxonomic and edibility categorization but not for liking judgment. For the taxonomic categories, a typicality gradient emerged at around 8 years of age and remained stable up to adult age for the fruit category but not for the flower category. The age-dependent increase in interindividual agreement for taxonomic and edibility categorization was paralleled by a slight increase in individual agreement for odor identification and a U-shape progression of the fluency and preciseness of the identification.

In response to the first question raised in the Introduction (At what age do children perform functional and taxonomic odor categorization?), our data support the idea that such an acquisition might occur between 5 and 6 years of age. Traces of agreement among children appeared during the last year of kindergarten (5 years). Before this age, children's categorization performance was near 50%, suggesting random answers. A steep increase in interagreement was then observed up to the first year of primary school (~7 years of age) followed by a slow increase up to adult age. This developmental trajectory in the ability to categorize the odors of fruits and flowers might be explained in terms of frequency of exposition; as children grow up, they acquire more experience with odors. Yet, this acquisition seems relatively late when considering the general literature about object categorization (e.g., animals, vehicles).

Although studies on object categorization diverge in child age, stimuli, and method, it seems that traces of taxonomic categorization are present in 3-year-olds or even earlier, depending on the

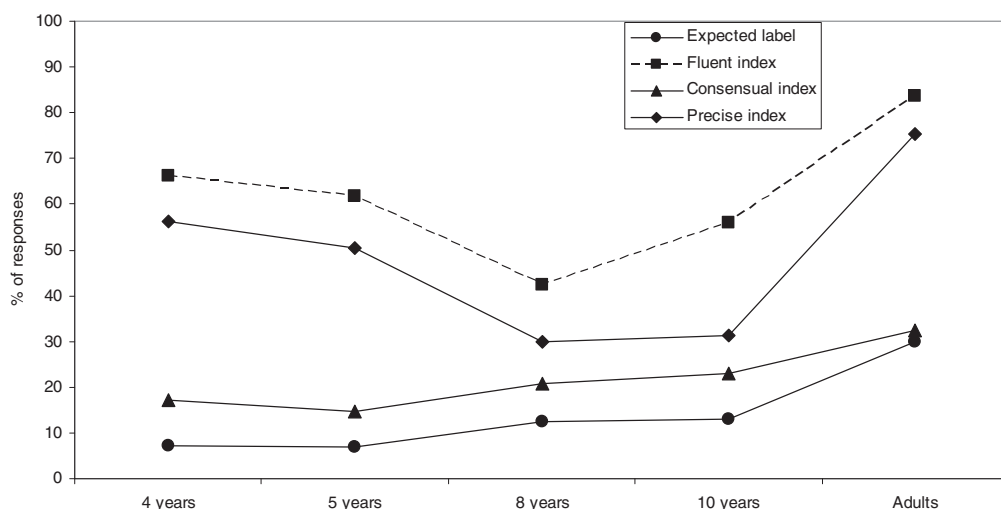


Fig. 5. Odor identification indexes as a function of age level.

Table 2

Percentages of fruit and flower terms as a function of odor type and age level.

	4 years		5 years		8 years		10 years		Adults	
	Fruit	Flower	Fruit	Flower	Fruit	Flower	Fruit	Flower	Fruit	Flower
Fruit	75.42	53.67	63.89	32.50	71.85	15.83	67.07	6.83	67.31	6.33
Flower	12.46	34.00	13.13	45.33	20.56	80.33	27.29	74.50	11.46	85.67

inclusiveness level. Children would first categorize objects at more inclusive levels and later at less inclusive levels (for a review, see [Bornstein & Arterberry, 2010](#)). For example, using an examination task, [Mandler and McDonough \(1993\)](#) showed that during the first 2 years, children differentiate categories of animals and vehicles (e.g., birds and airplanes) but not less inclusive categories such as dogs and rabbits. With fruit and flower distinction being an intermediate-level categorization, we could expect children to be able to categorize them from visual information within their first 2 years. Why is it not the case from olfactory cues?

Two alternative explanations might account for this time lag between odor and visual cues. First, whereas our perceptual world is interwoven with sensory cues from various modalities, vision is commonly believed to dominate human perception. Indeed, when visual and olfactory cues conflict with each other, olfaction tends to be overridden by vision. For example, [DuBose, Cardello, and Maller \(1980\)](#) showed that it was easier to identify the correct aroma of a drink when the drink had the expected color. Participants made errors toward the aromas that were expected for a particular color. [Oram and colleagues \(1995\)](#) showed that this effect is age dependent. Children relied more on the color of a drink than older participants to make a decision about its aroma. According to the authors, this result can be explained in terms of an increase in the ability of children to focus on aroma as their perceptual–attentional skills mature. Moreover, not all things have identifiable odors, but all things have more or less visual characteristics, and thus visual cues might be more readily available for categorization. In this view, visual information should provide better cues for fast and efficient categorization. However, for some objects that come in very different shapes and colors, such as fruits and flowers, smell might be a better categorical cue than vision. Further work is needed to verify this hypothesis.

The second explanation is related to the methodology we used. We presented odors to children in an opaque jar—a standard practice in the field—but what does an odor in a jar represent for a child? In everyday life, odors are generally perceived together with visual cues, and both types of sensation interact to modulate the subjective experience of the stimuli from which they emanate. This is a very different experience from when the same odor is smelled from a jar. Do children “understand” that the odors from the jars represent odors of real objects? If we make a parallel with vision, [Younger and Johnson \(2004\)](#) observed that 14-month-olds begin to understand the representational relation between miniature toy replicas and their real object counterparts. Toy animals appear to activate stored mental representations of real-world animals that have corresponding perceptual and/or conceptual attributes. It seems that early on, children have the capacity to use information about color, shape, texture, and sound to access the properties of real-world objects ([Mandler, 1997](#)).

The second question we raised in this study concerned the prevalence of the functional category over the taxonomic category. Based on previous work showing the importance of the edibility dimension in children’s odor categorization ([Rouby et al., 1997](#)), we expected edibility categorization to be acquired earlier than taxonomic categorization. From an evolutionist standpoint, this would make sense because odors help in identifying foods as well as preventing danger (e.g., spoiled food, chemical dangers). Although we did not observe a strong difference in edibility and taxonomic categorization, the youngest children were, to some extent, better at categorizing odors according to edibility than according to the fruit/flower dimension. Whereas they agreed only on the fact that blackcurrant belongs to the fruit category, they agreed that banana and peach were edible but lavender and rose were not. Interestingly, children did not seem to make the connection between the two types of categorization because most children of this age thought that blackcurrant was a fruit but that it was not edible. This raises the question of the information that children use to perform these types of task.

Our third hypothesis was that children might rely on hedonic information to categorize odors. Indeed, hedonic value seems to play a major role in the organization of odor categorization (for a recent review, see Zarzo, 2011), and we hypothesized that the increase in taxonomic and edibility interindividual agreement might be parallel to an increase in interindividual agreement for hedonic categorization. Contrary to this hypothesis, we observed that the hedonic interindividual agreement remained low across all age groups. They are two points of view on the origin of odor preference that are not mutually exclusive. According to the first evolutionist point of view, humans are predisposed to liking or disliking some odors (Mandairon, Poncelet, Bensafi, & Didier, 2009). Through evolution, humans would have learned to reject some odors such as decomposition odors because these odors might signal dangerous food or to like some odors that signal energy-loaded food (Schaal, Rouby, Marlier, Soussignan, & Trambly, 1998). So far, scientific evidence in favor of this hypothesis is rather scarce. According to the second standpoint, hedonic values of odors are culturally determined and depend on individuals' experience with the odorants (Hertz, Schankler, & Beland, 2004; Poncelet et al., 2011). Our results are more in line with the second point of view because no agreement was observed among individuals. They should, however, be interpreted with caution because they might also be due to both the lack of hedonic contrast between the odors we used and the binary nature of the categorization task. Nevertheless, whatever the cause of the lack of agreement on the hedonic task, our results suggest that the increase in agreement in taxonomic and functional categorization is not based on a hedonic dimension.

Our fourth hypothesis was that odor identification abilities might also play a role in odor categorization. According to Engen and Engen (1997) and Rinck and colleagues (2011), language and semantic representations of objects should constitute key organizers in the development of odor perception (see also Monnery-Patris, Rouby, Nicklaus, & Issanchou, 2009). In line with this hypothesis, we observed a progressive increase in the ability to identify the odorants in a normative and consensual way from 4-year-olds to adults. This phenomenon could partly explain the increase we observed in interparticipant agreement for both the edibility and taxonomic categorizations. Children might become more and more able to identify the object source of the odors and then categorize the objects rather than the odors, as suggested by Rinck and colleagues (2011) in a longitudinal study that revealed an increase in olfactory verbalizations from 3-year-olds to 4- and 5-year-olds. Yet, odor identification ability is probably not the only factor underlying the evolution we observed from 4-year-olds to adults. First, the rate of identification remained relatively low. Second, the fluency and precise indexes followed a U-shaped curve, with a decrease from 4- to 8-year-olds and an increase from 8-year-olds to adults.

U-shaped curves have been well documented in the development literature. According to Karmiloff-Smith (1992), development is a set of "representational redescription," going from implicit to explicit knowledge and from unconscious to conscious knowledge. The main interest of her representational redescription model is to account for the U-shaped developmental path during learning in very large domains such as physics, math, and language (Karmiloff-Smith, 1992) as well as in narrow ones such as the acquisition of language spelling (Critten, Pine, & Steffler, 2007) and spatial knowledge (Courrèges & Troadec, 2009). Although no previous research has been carried out in the olfactory domain, the U-shaped odor identification curve obtained in our study could be interpreted in the light of Karmiloff-Smith's (1992) model. As for each domain of knowledge, it is necessary for children to go through several levels of representation via the process of redescription. Thus, it could be argued that the decrease in performance for fluent and precise indexes is due to a developmental level change, between 5 and 8 years of age, concerning the reorganization of vocabulary. This decrease could be explained by the acquisition of reading and the consecutive development of lexical knowledge. However, this conclusion must be considered with caution given that we did not use a longitudinal design. Another alternative explanation could be cast in terms of Case's (1985) neo-Piagetian theory of working memory. According to this theory, 5- and 8-year-olds simply might not have enough available cognitive resources to both activate lexical items in working memory and perform an identification task. However, here again, a longitudinal design would be needed to evaluate this interpretation.

The last issue we raised concerned children's ability to organize fruit and flower odors along a typicality gradient. Previous work had shown that adults organized perceptual categories for fruit and

flower odors according to a graded structure that is implicated in cognitive tasks such as typicality judgment, similarity judgment, membership verification, and recognition memory. The mechanisms underlying such a graded structure seem to be universal, but the organization of odor categories resulting from these processes reflects both universal and cultural constraints (Chrea et al., 2009). The question that logically follows from these results was this: At what age did this graded structure emerge? To address this question, we adapted the typicality task used with adults to children. Our findings revealed a clear graded structure in third graders, fifth graders, and adults for fruit odors. For these three groups, blackcurrant and lemon odors were the most typical ones. Interestingly, on average, these two odorants obtained the highest interindividual agreement scores and were the first odorants to be preferentially categorized as fruit odors by kindergarten children. For flower odors, the data are fuzzier and no shared typicality gradient emerged. For the youngest children, no difference was observed between either fruit or flower odors. This result suggests that these children have not yet developed a typicality representation for fruit and flower odors and that all fruit and flower odors are equally good examples of the fruit and flower odor categories. However, this interpretation should be viewed with caution because another potential explanation is that the scale we designed to adapt the typicality task to young children was difficult to use. Although children did not show many difficulties in performing the task, this explanation cannot be ruled out and further work is needed to clarify this point, perhaps using other types of scales (e.g., grading the clearness of the drawings).

An interesting aspect of the typicality effect found in this study is that odor typicality seems to differ from object typicality; blackcurrant is not the first fruit that comes to mind in a free association task. This observation is in line with Chrea, Valentin, Bourry, Brochard, and Abdi (2002), who previously reported such a dissociation between odor and object typicality with adult participants. These authors asked participants to rate the typicality of fruit and flower when prompted by either names or odors. In the name condition the three more typical fruits were strawberry, banana, and apricot, whereas in the odor condition the three more typical fruits were coconut, blackcurrant, and melon. For the flower categories, the difference was less striking than for the fruit categories because it concerned only lavender; in the odor condition the three more typical flowers were lavender, lily of the valley, and rose, whereas in the name condition the three more typical flowers were rose, lily of the valley, and violet. This pattern of results suggests that the processes used for determining the typicality of an odor differ from those used to determine the typicality of an object for both children and adults. Yet, the mechanisms underlying odor typicality judgments remain to be explored.

In conclusion, this study is a first step toward understanding the development of odor categorization. Follow-up studies using longitudinal design would help in decreasing intra- and interindividual variances; it would be interesting to have some age levels between the oldest primary school children we tested and the adults in order to have more precise developmental cues.

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