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Laura J. Speed and Asifa Majid

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Superior Olfactory Language and Cognition in Odor-Color Synaesthesia

Laura J. Speed
Radboud University

Asifa Majid
Radboud University and Max Planck Institute for Psycholinguistics

Olfaction is often considered a vestigial sense in humans, demoted throughout evolution to make way for the dominant sense of vision. This perspective on olfaction is reflected in how we think and talk about smells in the West, with odor imagery and odor language reported to be difficult. In the present study we demonstrate odor cognition is superior in odor-color synaesthesia, where there are additional sensory connections to odor concepts. Synaesthesia is a neurological phenomenon in which input in 1 modality leads to involuntary perceptual associations. Semantic accounts of synaesthesia posit synaesthetic associations are mediated by activation of inducing concepts. Therefore, synaesthetic associations may strengthen conceptual representations. To test this idea, we ran 6 odor-color synaesthetes and 17 matched controls on a battery of tasks exploring odor and color cognition. We found synaesthetes outperformed controls on tests of both odor and color discrimination, demonstrating for the first time enhanced perception in both the inducer (odor) and concurrent (color) modality. So, not only do synaesthetes have additional perceptual experiences in comparison to controls, their primary perceptual experience is also different. Finally, synaesthetes were more consistent and accurate at naming odors. We propose synaesthetic associations to odors strengthen odor concepts, making them more differentiated (facilitating odor discrimination) and easier to link with lexical representations (facilitating odor naming). In summary, we show for the first time that both odor language and perception is enhanced in people with synaesthetic associations to odors.

Public Significance Statement

This study shows how odor-color synaesthesia can affect the way odors are perceived and named, suggesting synaesthesia plays a role in shaping concepts. Broadly, this highlights the important role of perceptual information in conceptual representations.

Keywords: olfaction, synaesthesia, odor discrimination, odor naming

Olfaction has been considered a vestigial sense for humans across the centuries (Majid, Speed, Croijmans, & Arshamian, 2017). This opinion has biological support, with primates having a proportionally smaller olfactory bulb (Baron, Frahm, Bhatnagar, & Stephan, 1983) and a smaller surface area of olfactory neuroepithelium (Le Gros Clark, 1959) than other mammals. Evolutionarily, olfaction is thought to have been reduced in favor of the development of the visual system, with primate posture becoming more erect (Aiello & Dean, 1990), and the eyes moving to a more central position on the face (Jones, Martin, & Pilbeam, 1992). This view of olfaction as a lesser sense, at least in Western societies, is reflected both culturally and psychologically. Olfaction is undervalued in society. We go to great lengths to eliminate odors. In fact, 55% of youngsters would rather give up their sense of smell than give up technology (McCann Worldgroup, 2011). Psychologically, humans find it difficult to imagine odors (Crowder & Schab, 1995; Herz, 2000), and to correctly identify and name them (e.g., Cain, 1979; Desor & Beauchamp, 1974; Lawless & Engen, 1977; see Yeshurun & Sobel, 2010 and Olofsson & Gottfried, 2015 for recent reviews).

Recent research however suggests that problems with odor may be a culturally specific phenomenon (Majid & Burenhult, 2014; O'Meara & Majid, 2016; Wnuk & Majid, 2014; Majid, 2015). Speakers of a number of languages in the world, such as Jahai in Malaysia (Majid & Burenhult, 2014) and Maniq in Thailand (Wnuk & Majid, 2014), do not show such limitations with odor language. Speakers of these languages belong to hunter-gatherer societies where odor is a prominent part of everyday culture, as reflected in the rituals of the people and in their ideologies (e.g., Burenhult & Majid, 2011; Wnuk & Majid, 2014). The observed

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Laura J. Speed, Centre for Language Studies, Radboud University; Asifa Majid, Centre for Language Studies, Radboud University, and Max Planck Institute for Psycholinguistics.

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Correspondence concerning this article should be addressed to Laura J. Speed, Centre for Language Studies, Radboud University, Erasmusplein 1, Nijmegen 6500HD, Netherlands. E-mail: l.speed@let.ru.nl

odor naming advantage and olfactory cultural preoccupation within these societies suggests olfactory abilities in humans may be more malleable than previously thought. That is, the importance of, and experience with, odor in everyday life may be reflected in language (cf. Malt & Majid, 2013). Similarly, in the West, there is evidence that olfactory experience can improve odor naming. Croijmans and Majid (2016) found wine experts were better able to name the odor of wines compared with novices. This suggests years of dedicated experience smelling and discussing wine odors can lead to improvement in experts' odor naming too (see also Cain, 1979; Desor & Beauchamp, 1974). Odor perception may be similarly malleable, and language may play a role here too. For example, participants are better able to discriminate between odors when given odor labels (de Wijk & Cain, 1994) or when trained with odor labels (Rabin, 1988).

In the present work, we investigate another way in which olfactory language and cognition can be boosted. In particular, we assess how "extra" connections between olfaction and other perceptual modalities, in terms of synaesthetic associations, may affect odor processing. Specifically, we assessed odor language and cognition in individuals with odor-color synaesthesia.

Synaesthesia

Synaesthesia is a neurological phenomenon in which stimulation (inducers) in one sensory modality leads to involuntary sensations (concurrents) within the same or different modality, as when colors are evoked by visually presented letters (same modality) or evoked by sounds (different modality). People can experience days of the weeks and months of the year as having specific colors, shapes, spatial locations, and even personalities (for review see Cohen Kadosh & Henik, 2007; Hubbard & Ramachandran, 2005; Rich & Mattingley, 2002).

Synaesthetic associations may occur via cross-activation of sensory regions in the brain because of reduced synaptic pruning, leaving additional connections not present in nonsynaesthetes (e.g., Hubbard, Arman, Ramachandran, & Boynton, 2005; Maurer & Maurer, 1988; Ramachandran & Hubbard, 2001). Other researchers have proposed synaesthetic experiences are because of disinhibited feedback between regions of the brain (e.g., Grossenbacher, 1997; Grossenbacher & Lovelace, 2001). That is, feedback connections in the brain that are typically inhibited in most people are disinhibited in synaesthetes, such that information from an inducer pathway can propagate down a concurrent pathway, activating a concurrent representation (Grossenbacher & Lovelace, 2001). Combining both accounts to some extent, Smilek, Dixon, Cudahy, and Merikle (2001) propose the reentrant processing model that suggests the cause of synaesthesia as involving both cortical connectivity and inhibition. More important, the model proposes that the inducer activates meaning representations in high-level processing regions, which then activate concurrent sensory information via feedback connections.

Recent models of synaesthesia also emphasize a semantic dimension, proposing semantic activation of an inducer is required before a synaesthetic concurrent is experienced (e.g., Chiou & Rich, 2014; Meier, 2014). For example, in grapheme-color synaesthesia, colors are typically experienced regardless of whether the inducer was seen, heard, or simply thought about (Rich, Bradshaw, & Mattingley, 2005), and synaesthetic colors can be transferred to newly learned graphemes from an ancient alphabet once an association between those graphemes and the familiar Latin alphabet has been made (Mroczko, Metzinger, Singer, & Nikolić, 2009). Nikolić (2009) proposes synaesthesia could more accurately be named "ideasthesia," Greek for "sensing ideas," to reflect that synaesthetic perception-like experiences are associated to certain ideas or concepts, rather than percepts.

Synaesthesia is not merely a curious condition of unusual phenomenology; it can affect multiple aspects of cognition, including perception and memory. Individuals with grapheme-color synaesthesia, where letters or numbers are experienced as having specific colors (e.g., Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Baron-Cohen, Wyke, & Binnie, 1987; Dixon, Smilek, Cudahy, & Merikle, 2000) have been shown to perform better in visual search tasks (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002) and experience higher levels of perceptual grouping for graphemes (Ramachandran & Hubbard, 2001). Similarly, synaesthetes who experience color concurrents have better color discrimination (Banissy et al., 2013; Banissy, Walsh, & Ward, 2009; Yaro & Ward, 2007), and synaesthetes with tactile concurrents have better tactile discrimination (Banissy et al., 2009). Synaesthetes also have better memory for stimuli that induces their synaesthesia (Mills, Innis, Westendorf, Owsianiecki, & McDonald, 2006; Smilek, Dixon, Cudahy, & Merikle, 2002; Yaro & Ward, 2007; but see Rothen & Meier, 2009). For example, 6 months after being given a list of people's names, MLS—a letter-color synaesthete—recalled significantly more names than a control group (Mills et al., 2006).

More impressively still, there is evidence synaesthesia influences other aspects of cognition beyond the specific inducer/concurrent modalities. For example, synaesthesia is related to enhanced creativity, with synaesthetes demonstrating superior ability to generate new ideas, and they more often pursue the arts than nonsynaesthetes (Mulvenna, 2013). Synaesthetes also outperform controls at inferring the meaning of sound-symbolic words, suggesting synaesthesia may exaggerate crossmodal associations more generally (Bankieris & Simner, 2015). In line with this proposal, Brang, Williams, and Ramachandran (2012) found multimodal facilitation was enhanced more in synaesthetes than controls. Participants were presented with either a colored letter, a single tone, or both simultaneously (multimodal condition), and were instructed to respond as soon as they detected a visual or auditory cue (or both). Responses of synaesthetes and controls were faster in the multimodal condition, but this benefit was greater for the synaesthetes than the controls. This was the case even though none of the synaesthetes experienced synaesthesia with sound.

Taken together, the evidence suggests synaesthesia boosts several aspects of cognition, especially within the modalities involved in the synaesthetic experience. Therefore, synaesthesia involving odor presents an excellent test bed to explore the human olfactory potential. Further, if synaesthetic associations are semantically mediated (e.g., Chiou & Rich, 2014; Meier, 2014)—that is, associations are driven by an inducing concept rather than percept—synaesthetic associations may strengthen concepts (Meier, 2014). This is particularly important when considering the olfactory domain, where semantic representations may be weak (Olofsson & Gottfried, 2015). In such a case, synaesthetic associations to odor could help alleviate difficulties in the semantic representation of odor.

To test this idea we explored odor language and cognition in odor-color synaesthesia. Although research in synaesthesia has been prolific in recent years, it has focused heavily on synaesthesia involving the visual modality, more specifically grapheme-to-color synaesthesia. According to Day (2014), around 60% of synaesthetes experience grapheme-to-vision associations. In comparison, synaesthesia involving odor as inducer or concurrent is rare: Day (2014) estimates 6% of synaesthetes experience odor-to-vision associations. Similarly, the Synaesthesia Battery (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007) has over 19,000 participants claiming synaesthesia (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007), but odor-color synaesthesia is experienced by only 18% (Novich, Cheng, & Eagleman, 2011). Thus, the present research also delves into an understudied subpopulation of synaesthetes, and thus potentially sheds new light on the synaesthesia phenomenon more generally.

Individuals with odor-color synaesthesia experience color sensations when they smell odors (Russell, Stevenson, & Rich, 2015; see Figure 1 for some examples). One of the earliest reports of this type of synaesthesia can be found in Cytowic (1989), where a man with odor-color synaesthesia describes his experience:

> I remember at age 2 my father was on a ladder painting the left side of the wall. The paint smelled blue, although he was painting it white. I remember to this day thinking why the paint was white, when it smelled blue (p. 24).

If synaesthetic color associations to odors strengthen their semantic representation, there may be implications for a number of elements of odor cognition. First, more stable semantic representations could improve odor language, which—as mentioned earlier—is impoverished in the West (e.g., Cain, 1979; Desor & Beauchamp, 1974; Lawless & Engen, 1977). Olofsson and Gottfried (2015) propose problems of odor language may be due, in part, to the little opportunity odor representations have to connect to other types of semantic information. Linking odors with color information may, therefore, help resolve this problem. Russell et al. (2015) provided initial evidence for this proposal, by showing odor-color

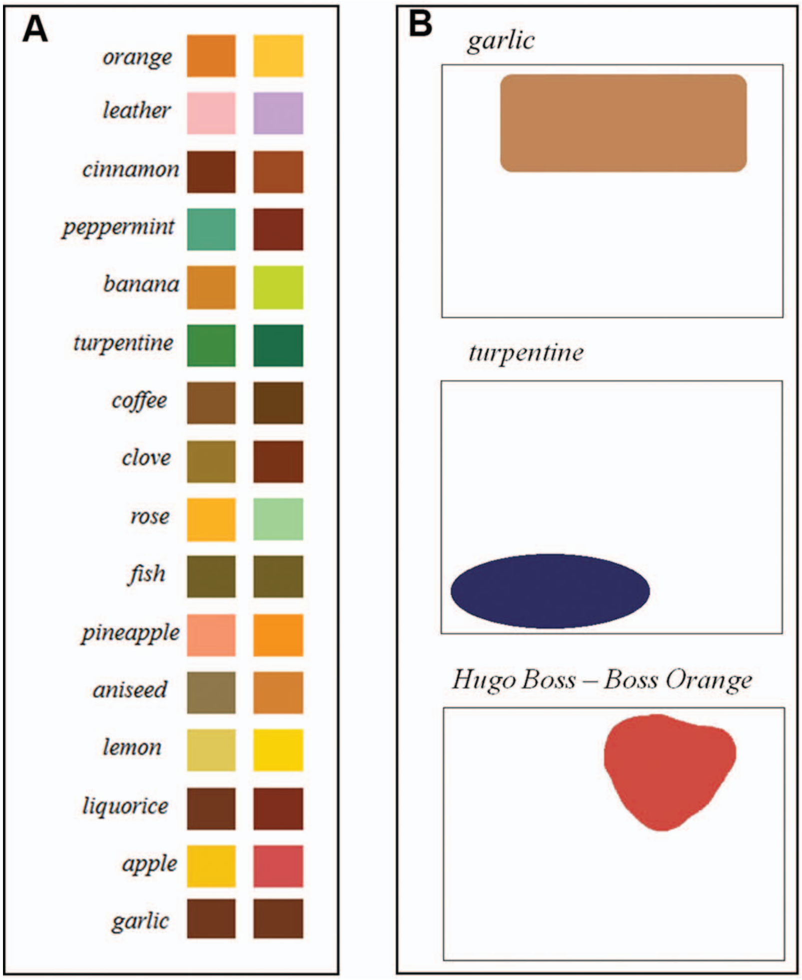

Figure 1. Examples of odor-color associations. Panel A: Selection of colors chosen by Synaesthete D on both testing days to everyday odors. Panel B: Synaesthete E's association to odors combine color and shape, as depicted here. See the online article for the color version of this figure.

synaesthetes were more consistent across time at naming odors than a group of control participants. In this study, we replicate and extend this finding.

Previous research with nonsynaesthetes has also suggested that linking odors with language or semantic information can improve odor memory and odor discrimination. Self-generated labels for odors, or experimenter-generated pairings of odors to a label, improves memory for odors compared with no labels paired with odors (e.g., Batic & Gabassi, 1987; Kärnekull, Jönsson, Willander, Sikström, & Larsson, 2015; Lyman & McDaniel, 1986). Similarly, odor discrimination is better when participants are given odor labels (de Wijk & Cain, 1994) or are trained with odor labels (Rabin, 1988). Visual information may also be important for odor discrimination: Jadauji, Djordjevic, Lundström, and Pack (2012) found odor discrimination was improved after repetitive transcranial magnetic stimulation (rTMS) to the visual cortex. If stimulation of the visual cortex can improve odor perception, then synaesthetic associations between odor and color information could also lead to such improvements.

Another aspect of cognition that could be affected by synaesthesia is mental imagery. Synaesthesia and visual imagery are thought to be intimately related (Karwoski & Odbert, 1938), and individuals with synaesthesia report more vivid visual imagery than controls (Barnett & Newell, 2008). Odor imagery in synaesthesia has not yet been investigated. Odor imagery has been shown to correlate with odor perception (Köster, Stelt, Nixdorf, Linschoten, de Wijk, & Mojet, 2014), and it has also been suggested that greater olfactory experience may enhance odor imagery (Bensafi, Tillman, Poncelet, Przybylski, & Rouby, 2013). This suggests odor-color synaesthetes should also have superior odor imagery, and potentially also visual imagery, compared with nonsynaesthetes.

Current Investigation

Over two separate days we conducted a battery of tests assessing odor language and cognition in odor-color synaesthetes and a group of age-matched controls. Participants were asked to name and match colors to odors, so that we could assess to what extent the consistency of synaesthetic color associations is driven by odor nameability (as observed in Russell et al., 2015, and in nonsynaesthetes, de Valk, Wnuk, Huisman, & Majid, 2016). A semantic account of synaesthesia would predict that odor-color associations would be more consistent for more easily named odors. In addition, odor language can be assessed by looking at odor naming accuracy and consistency across both days.

To assess whether odor-color synaesthesia affects odor perception, we conducted two olfactory tests: odor discrimination and odor threshold. Odor discrimination refers to how well one can discriminate between different odors, and can reflect higher-level, semantic abilities. Odor threshold on the other hand, reflects the ability to detect the presence of an odor, and is therefore a more low-level perceptual ability. If synaesthetic associations to odor strengthen the semantic representation of odor then we would predict enhancements in odor discrimination, but not odor threshold.

Although we were primarily interested in odor cognition, previous findings have shown superior color discrimination in other types of synaesthesia involving color concurrents (Banissy et al., 2013; Banissy et al., 2009; Yaro & Ward, 2007). Therefore, we tested color discrimination in the present odor-color synaesthetes too. This allows us to, first, replicate previous findings and extend to a new form of synaesthesia; and second, use this data as a form of manipulation check of the current participants' synaesthesia.

To investigate further the role of synaesthesia in olfactory cognition, we used established questionnaires to assess visual and olfactory mental imagery (Gilbert, Crouch, & Kemp, 1998; Marks, 1973), as well as the importance of olfaction in everyday life (Croy, Buschhüter, Seo, Negoias, & Hummel, 2010).

Materials and Method

The study received ethical approval from the Radboud University Humanities Ethics Assessment Committee.

Participants

Six participants with odor-color synaesthesia (all female, mean age = 36, *SD* = 14.42) and 17 age-matched controls (all female, mean age = 39.76, *SD* = 13.04) without synaesthesia took part in the study. We tested this number of control participants to cover the age range of the synaesthetes sufficiently. Synaesthetes were recruited in collaboration with the Language and Genetics Department at the Max Plank Institute for Psycholinguistics, Nijmegen. Participants had completed an online synaesthesia questionnaire (www.mpi.nl/synaesthesia) which confirmed the authenticity of one type of synaesthesia (i.e., grapheme-color) with measures of consistency, and participants had indicated they also had synaesthesia involving odor. In addition, one synaesthete who wrote a blog about her synaesthetic experience was invited to participate. Control participants were recruited from the Radboud University participant pool and from the first author's home town in the United Kingdom, where connections with age-matched participants existed.

All synaesthetes had more than one form of synaesthesia, and commented their experiences were difficult to articulate (see Table 1). As well as colors, odor-evoked synaesthetic images sometimes also contained shapes (e.g., "concave shape") and textures (e.g., "flat," "lots of points"), and for some individuals also numbers or emotions. Color experiences also differed between participants, for example, one synaesthete described the smell of people as her strongest inducer of synaesthesia, whereas another found it hard to identify color responses to smells of people. Similarly, one partic-

Table 1
Additional Forms of Synaesthesia Experienced by Participants

Synaesthete	Types of synaesthesia
A	Smell-vivid memories, music-color, music-emotion, time-forms, letter-color
B	Sensory translations move between smell, music, color, texture, and numbers
C	Grapheme-color
D	Grapheme-color, data-color, seasons-color, sound-color, sensitivity for emotions of others
E	Number-color, number-personality, number-gender
F	Number-color, circular calendar

Note. We report types of synaesthesia participants described, and make no claim as to whether or not they are established forms of synaesthesia.

ipant described the colors induced by perfumes as an "overall pleasant experience," even if the perfume was strong or artificial; but a different participant found her experience of colors evoked by strong perfumes as negative and said they "scrambled the brain." Participants reported colors evoked by odors were useful in day-to-day activities. One participant preferred to use shampoos and shower gels that induce a brown/amber color, while another uses the appearance of an unexpected color to indicate states, such as moldy food. Despite these idiosyncrasies, all participants with odor-color synaesthesia experience color sensations to odors.

Before participants with odor-color synaesthesia were invited to take part in the study, phone interviews were conducted, and written questionnaires administered, to learn more about each individuals' synaesthetic experience, and to serve as an additional check of their authenticity as odor-color synaesthetes. Participants were given smell categories gleaned from the anthropological literature (i.e., household smells, food smells, drink smells, outdoor smells, travel smells, smells of people, building smells, medicinal smells, animal smells, perfumes, and other smells), and asked to provide examples of odors within each category for which they have synaesthetic color experiences. Table 2 summarizes various odors participants highlighted as synaesthetic inducers.

Materials

Eight commercial fragrances (four masculine and four feminine) and 16 Sniffin' Sticks (Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997) taken from the Burghart Standard Identification test covering a range of everyday odors were used in an odor-color matching task and an odor naming and rating task (see Appendix). After the preexperiment questionnaire/discussion was conducted with each

Table 2

Odors Identified as Color Inducers by Synaesthetes in a Preexperiment Questionnaire (One Synaesthete Did Not Complete the Questionnaire)

	Synaesthete				
Odor category	A	B	C	D	E
Household smells	Vinegar, bleach, artificial detergents, peppermint salts, washing up liquid	Shampoos, shower gels, washing powder, conditioner, laundry, towels	Ant killing spray, dishwashing soap	Bleach, washing powder	Bleach, ethanol, cleaner
Food smells	Real banana, artificial banana, chocolate, apple, stew		Chocolate, sour candy	Swiss cheese	Warm bread, melting butter from broiling meat, red beet, strawberries
Drink smells	Cola, coffee, juice		Water	Green tea, red wine	Wine
Outdoor smells	Grass, soil, flowers	Flowers, forest	Flowers	Spring, air	Hay, geranium, lily of the valley, wet leaves, wet soil, sea water, side of a ditch
Travel smells	Exhaust, gas, trains			Diesel, kerosene	Petrol, bus, new cars
Smells of people	hair	Children, friends, partner		Boyfriend	Daughter, colleague, passersby, mother's clothes, friend's clothes, new born baby
Building smells	Construction, paint, doctors surgery, school	People's houses, work, doctors, dentist		School	Workshop for car repair, workshop for metal, workshop for wood, church
Medicinal smells	Cough medicine, antacid	Cough syrup			Codfish oil, penicillin, herbal tablets, mouthwash
Animal smells	Puppy, cat boxes, elephant, domestic hay, dog, bear	Gerbils, farms, dogs		Hamster, guinea pig	Wet dogs, pigs, chicken, male goats, sheep, cows, carnivores in zoo, birds
Perfumes	Musky, floral, spicy and cinnamon, sports/masculine, fruity, ocean, grass	Masculine, female, old fashioned, modern	Floral	Floral, freshness, heavy perfume	Ma Vie Hugo Boss, Old Spice
Other smells	Books, paper, leather	New magazine, old book, leather		Old books, leather	Books, paper, leather

participant, it was clear that everyday odors and fragrances were common inducers of color experiences. Further motivation to use Sniffin' Sticks was that they are easy to transport and administer in a controlled manner.

Including the two sets of odors also enabled us to investigate odors with associations to common odor sources (i.e., Sniffin' sticks) versus odor mixtures (i.e., fragrances). Fragrances were prepared by spraying plastic pellets with the scent and placing them inside a squeezy bottle that was refreshed every other day. A book of 1600 Munsell color chips, distributed across 40 pages with one hue on each page, was used to investigate color matches to odors.

Burghart's Odor Discrimination and Odor Threshold tests (Hummel et al., 1997) were used to assess odor perception. Each odor test contained 16 triplets of odors (see Procedure. for more details). Following Banissy et al. (2009), we used the Farnsworth-Munsell 100 Hue Test (FMT; Farnsworth, 1957) to assess color discrimination. This test contained four trays of 21 color chips ordered according to hue.

In addition, we administered two tests of mental imagery: the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973) and the Vividness of Olfactory Imagery Questionnaire (VOIQ; Gilbert et al., 1998). We also administered a questionnaire assessing the importance of olfaction in everyday life (Croy et al., 2010). The questionnaire assesses three subscales: association with olfactory sensations, application of the sense of smell, and readiness to draw consequences from olfactory perception.

Procedure

Participants completed the battery of tests over 2 days with a 1 day gap in between. This was predominantly so that consistency of color associations to odors over time could be established. Furthermore, by assessing consistency of color associations and consistency of odor naming 2 days later, rather than within the same day, we reduce the likelihood that participants memorize their responses. In addition, we split the testing session over 2 days to reduce the duration of a single session and thereby avoid participant fatigue. Each participant was given a response booklet containing instructions and response sheets for all tests in the battery. Testing took place in well-ventilated rooms, and participants were instructed not to wear perfume, and not to eat, drink (except water), or smoke at least 30 min before the session. Table 3 depicts the order of tasks completed across the 2 days. Odor tasks were rotated between nonodor tasks to prevent participant fatigue. Participants gave informed consent and were encouraged to take breaks and drink water if they wished through the sessions.

Table 3
Order of Tasks across the 2 Days of Testing, With a 1 Day Break in Between

Day 1	Day 2
1. Odor-color associations	1. Odor-color associations
2. FMT	2. Color chip rating
3. Odor naming and rating	3. Odor naming and rating
4. VVIQ and VOIQ	4. Importance of olfaction questionnaire
5. Odor discrimination test	5. Odor threshold test

Note. FMT = Farnsworth-Munsell 100 Hue Test; VVIQ = Vividness of Visual Imagery Questionnaire; VOIQ = Vividness of Olfactory Imagery Questionnaire.

Odor-color associations. To explore the consistency of synaesthetic odor-color associations—and whether or not these associations were driven by odor nameablity—participants smelled the odors one at a time and were instructed to pick a color chip most closely matching their synaesthetic association from the Munsell color book. Control participants were instructed to choose the color they thought "goes best" with the odor. Before testing began, participants familiarized themselves with the Munsell color book and the order of hues.

Participants could smell each odor as many times as they wished. A break of at least 30 s between each odor was enforced. Odors were presented to participants in random order. After a color chip was chosen, participants rated how vivid their color experience was and how vivid their overall experience was (if the synaesthetic concurrent included other features such as motion and shape) on a 7-point scale. Control participants were instructed to consider vividness as reflecting the ease with which they could generate an association to the odors. This task was completed on both testing days so we could also assess the consistency of color choices. There was also space for participants to draw any shape or texture associations they had to the odor (see Figure 1); however, only two individuals used this space and only for a small number of odors.

Odor naming and rating. In a separate task, participants were presented with the same set of odors in a different random order and asked to rate the familiarity, pleasantness, and intensity of the odor on a 7-point scale. Finally, they named the odors by writing their answer in response to the prompt question "*What smell is this?*" Again, participants could smell each odor as many times as they wished, and a break of at least 30 s between each odor was enforced. This task was completed on both testing days so we could assess naming consistency.

Odor threshold. Participants were presented with triplets of Sniffin' Sticks, two of which contained just water and one of which contained n-butanol. Across triplets, the concentration of n-butanol varied. Participants wore a blindfold and each pen was held beneath the participants' nose for 5 s. The experimenter informed the participant when to sniff by saying "*Now*." Participants were instructed to indicate which pen contained the odorant. A staircase procedure was utilized to determine each participants' threshold. The task was completed on the second testing day only.

Odor discrimination. Participants were presented with triplets of Sniffin' Sticks, two of which contained the same odor and one a different odor. Pens were presented to participants in the same manner as the odor threshold test. Participants were asked to indicate which of the three pens smelled different. A total score of correct decisions was computed. This task was completed on the first testing day only.

Color discrimination. Participants were presented with the four trays of color chips from the FMT in turn. Two lamps with daylight 860 illumination were placed on either side of the trays to ensure comparable lighting conditions. Participants were instructed to arrange the chips in order of hue so that a smooth continuum of color was formed. Each color chip possessed a code so that an error score for each tray could be computed by inputting the codes into the FMT scoring software. The error score for each color chip is the sum of the differences between the number of that chip and the number of the chips adjacent to it, minus two. This task was completed on the first testing day only.

Questionnaires. The VVIQ contained 16 statements describing visual scenes (e.g., *The sun is rising above the horizon into a hazy sky*), and the VOIQ contained 16 statements describing olfactory scenes (e.g., *The smell of your shirt or blouse when you remove it*). Participants were instructed to imagine each scene and rate the strength of their mental image from 1, for example, "*perfectly clear and vivid as normal vision*" to 5 "*no image at all (only "knowing" that you are thinking of the object)*". They wrote their ratings in a box provided next to each description. For the VVIQ participants were instructed to complete the questionnaire once imagining the described scenes with their eyes open, and once with their eyes closed.

The importance of olfaction questionnaire contains 20 statements (e.g., *Certain smells immediately activate strong feelings*). Participants were instructed to read each statement carefully and place a cross in a box corresponding to how much they agreed with that statement: "totally agree," "mostly agree," "mostly disagree," or "totally disagree."

Results

To assess the role of odor-color synaesthesia in odor cognition and language, we compared synaesthetes' performance with that of the age-matched control participants All results are displayed in Table 5.

Odor-Color Associations and the Role of Naming

If semantic activation of an odor is required for a synaesthetic color experience to occur, then color associations should be more consistent for odors that are easy to name (named accurately and consistently) than those that are difficult to name (named incorrectly and inconsistently Russell et al., 2015). To test this, we assessed the role of naming (both accuracy and consistency) on the consistency of color choices in synaesthetes and control participants. A name was correct if it matched the source of the Sniffin' Stick (e.g., cinnamon, orange). For fragrances, naming was correct if they used terms such as *fragrance*, *perfume*. If participants specifically indicated a gender of fragrance that was incorrect, their response was recorded as incorrect (e.g., saying *male fragrance* for a *female perfume*).

Accuracy of naming was assessed by three researchers, and if any disagreements arose, accuracy was determined by the majority opinion. A score of 1 was given if participants named an odor correctly on either the first day or the second day. For example, if the garlic Sniffin' Stick was correctly named "garlic" on the first day, but then "onion" the second day, it would be scored as 1. If, however, the participant incorrectly said onion on both days they would receive a score of 0. The overall score then reflects the average across odors. For consistency, a score of 1 was given if a participant named the odor the same on Day 1 and Day 2, otherwise a score of 0 was given. If an odor was named consistently but incorrectly on both occasions, it was still scored as consistent. If participants perceived the odor as the same on both days, even if they identified it incorrectly, their colors choices on both occasions should still be more similar than if they had named the odor inconsistently.

Munsell colors were converted to CIE LAB values and the distance between colors chosen on Day 1 and Day 2 was calculated in terms of Delta E.[1] A smaller value of Delta E indicates a smaller distance, and hence more similar colors (i.e., more consistent color choices). Overall, there was no significant difference in Delta E between synaesthetes and controls, $t(21) = .32$, $p = .76$, $d = .16$.

Odor-Color Associations and Naming Accuracy

To assess the effect of naming accuracy on color associations, Delta E values were analyzed with a 2 (naming correct vs. incorrect) × 2 (synaesthetes vs. controls) mixed analysis of variance (ANOVA) separately for Sniffin' Sticks and fragrances. There was a main effect of naming accuracy for Sniffin' Sticks, $F(1, 21) = 7.1$, $p = .014$, $\eta_p^2 = .25$, such that Delta E was smaller (colors more consistent) for odors named correctly compared with odors named incorrectly ($M = 37.00$ vs. 47.68). There was no difference between synaesthetes and controls, $F(1, 21) = 1.73$, $p = .20$, $\eta_p^2 = .08$, ($M = 45.28$ vs. 39.41) and no interaction between group and naming consistency $F(1, 21) = 1.64$, $p = .21$, $\eta_p^2 = .07$. For fragrances no effects were significant: neither the main effect of naming accuracy $F(1, 16) = .17$, $p = .69$, $\eta_p^2 = .01$; group $F(1, 16) = .42$, $p = .53$, $\eta_p^2 = .03$; nor the interaction $F(1, 16) = .04$, $p = .84$, $\eta_p^2 = .003$.[2] Mean Delta E values for Sniffin' Sticks and fragrances named correctly and incorrectly are displayed in Figure 2.

Odor-Color Associations and Naming Consistency

Two further ANOVAs assessing naming consistency, instead of naming accuracy found a main effect for Sniffin' Sticks $F(1, 21) = 6.02$, $p = .023$, $\eta_p^2 = .22$, such that Delta E was smaller (colors more consistent) for odors named consistently compared to odors named inconsistently ($M = 37.38$ vs. 48.8). There was no difference between synaesthetes and controls $F(1, 21) = 1.44$, $p = .24$, $\eta_p^2 = .06$, and no interaction between group and naming consistency $F(1, 21) = .01$, $p = .92$, $\eta_p^2 < .001$. For fragrances, neither main effects of naming consistency $F(1, 17) = .18$, $p = .68$, $\eta_p^2 = .01$, group $F(1, 17) = .11$, $p = .75$, $\eta_p^2 = .01$, nor the interaction were significant $F(1, 17) = .02$, $p = .90$, $\eta_p^2 = .001$; see Figure 3.[3]

To summarize, easier to name everyday odors (i.e., Sniffin' Sticks) were associated with more consistent synaesthetic color experiences for synaesthetes, and more consistent associations for control participants, supporting semantic accounts of synaesthesia (cf., Chiou & Rich, 2014).

Vividness of Associations

Vividness of color association ratings were analyzed with a 2 × 2 mixed ANOVA with odor type (Sniffin' Sticks vs. fragrances) as a within subjects factor and group (synaesthetes vs. controls) as a between subjects factor. There was no difference in vividness ratings between Sniffin' Sticks and fragrances $F(1, 21) = 1.11$,

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[1] One synaesthete occasionally chose more than one color chip to reflect their synaesthetic association. In such instances, we calculated the distance for the most similar colors across the 2 days.

[2] Six control participants were not included in this analysis because their naming accuracy was 0 for fragrances.

[3] Three control participants were not included in this analysis because their naming consistency was 0 for fragrances.

p = .31, η^2_p = .06, nor between synaesthetes and controls, F(1, 21) = .31, p = .58, η^2_p = .02, and no interaction between the two factors, F(1, 21) = 1.14, p = .30, η^2_p = .05. Because control participants were only asked about color associations, ratings of "overall" intensity only applied to the synaesthetes. A pairwise t test found no difference in overall vividness between Sniffin' Sticks and fragrances, t(5) = .3, p = .75, d = .03. Examples of colors chosen by synaesthetes to specific odors are displayed in Figure 1.

Odor Naming and Rating

Two independent t tests were conducted to compare accuracy in naming (whether the odor was correctly named on either day, i.e., they gave the correct name at least once) and consistency in naming responses (i.e., whether the same response was given on both days) between synaesthetes and control participants. Synaesthetes were more accurate at naming both Sniffin' Sticks, (M = 57% vs. 40%), t(21) = 3.28, p = .004, d = 1.43, and fragrances, (M = 44% vs. 20%), t(21) = 2.39, p = .026, d = 1.04. Synaesthetes were also more consistent in their naming across both days than control participants (as Russell et al., 2015 found too), but this was only the case for Sniffin' Sticks (M = 66% vs. 44%), t(21) = 2.52, p = .02, d = 1.10, not fragrances, (M = 31% vs. 24%), t(21) = .79, p = .44, d = .34.

Ratings of odor familiarity, pleasantness, and intensity[4] were submitted to 2 × 2 mixed ANOVAs with odor type (Sniffin' Sticks vs. fragrances) as a within subjects factor and group (synaesthetes vs. controls) as a between subjects factor.

For familiarity ratings there was a marginal effect of odor type, with Sniffin' sticks rated as more familiar than fragrances F(1, 21) = 3.38, p = .08, η^2_p = .14, but there was no difference between synaesthetes and controls F(1, 21) = .89, p = .36, η^2_p, = .04, and no interaction F(1, 21) = .81, p = .38, η^2_p, = .04.

Fragrances were rated as more pleasant than Sniffin' Sticks F(1, 21) = 9.73, p = .005, η^2_p, = .32, but there was also an interaction between odor type and group F(1, 21) = 12.60, $p < .001$, η^2_p = .38. Follow-up t tests showed controls perceived fragrances as more pleasant than Sniffin' Sticks (M = 5.81 vs. 4.24), t(16) = 7.26, $p < .001$, d = 1.91, but there was no difference between fragrances and Sniffin' Sticks for synaesthetes (M = 4.6 vs. 4.71), t(5) = .20, p = .85, d = .10. This is in line with comments from some participants that strong commercial fragrances lead to unpleasant synaesthetic experiences (see Participants). There was no overall difference between synaesthetes and controls F(1, 21) = 1.12, p = .3, η^2_p = .05.

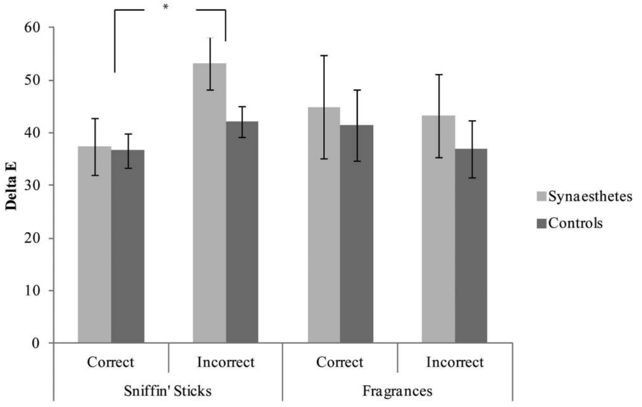

Figure 2. Delta E values for Sniffin' Sticks and fragrances named correctly and incorrectly by synaesthetes and controls. Error bars depict 1 *SE*. An asterisk indicates a significant difference.

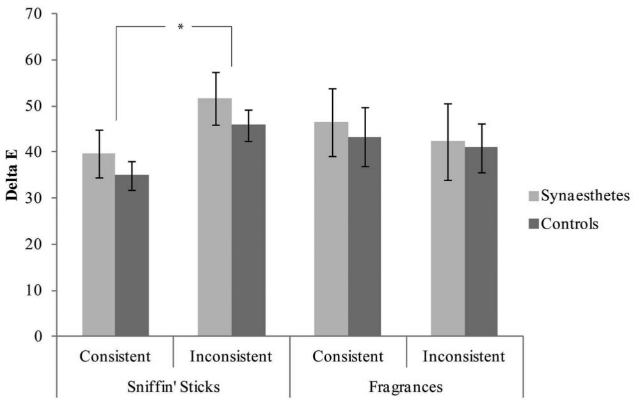

Figure 3. Delta E values for Sniffin' Sticks and fragrances named consistently and inconsistently by synaesthetes and controls. Error bars depict 1 *SE*. An asterisk indicates a significant difference.

Sniffin' Sticks were rated as more intense than fragrances F(1, 21) = 8.08, p = .01, η^2_p = .28, but there was no difference in intensity ratings between synaesthetes and controls F(1, 21) = 0.1, p = .93, $\eta^2_p < .001$, and no interaction F(1, 21) = .48, p = .50, η^2_p = .02.

Perceptual Tasks

Three independent t tests were conducted to compare performance between synaesthetes and control participants on the odor discrimination and odor threshold test, and the FMT.

Odor Threshold. There was no difference between synaesthetes and controls on the odor threshold task (M = 6.59 vs. 6.38) t(21) = −.13, p = .9, d = .05. Mean odor threshold scores are displayed in Table 4.

Odor Discrimination. Synaesthetes outperformed controls on the odor discrimination task (M = 13.83 vs. 11.71 out of 16), t(21) = 2.32, p = .03, d = 1.01. Compared with existing norms for odor discrimination for females in the general population (average score of 12.69, Hummel, Kobal, Gudziol, & Mackay-Sim, 2007), the present synaesthetes also appear to perform higher. Mean odor discrimination scores are displayed in Table 4.

Color Discrimination. Using the FMT test we found synaesthetes (error score 39.33) were better at discriminating between colors than control participants (error score 89.12), t(21) = 2.15, p = .04, d = .94, replicating findings with other forms of synaesthesia involving color concurrents (Banissy et al., 2009). The present results can also be compared to norms for the general population; for example, Verriest's (1963) data for nonsynaesthetes. The range of error scores in that population varies from

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[4] Average ratings of familiarity, pleasantness and intensity of each odor are included in Appendix as a resource for other researchers.

36.3 to 90.4. So, the present synaesthetes are close to the best performing participants of Verriest (1963), while the control group closer to the lowest performing participants. The mean error scores for the synaesthetes and controls are also comparable to those observed in Banissy et al. (2009) who concluded that synaesthetes had superior color discrimination. Mean scores on the FMT are displayed in Table 4.

We further explored whether the superior color discrimination performance of synaesthetes occurred in specific regions of color space. Following Laeng, Brennen, Elden, Gaare Paulsen, Banerjee, and Lipton (2007) we divided the Munsell chips into their 10 step hue subdivisions (red, yellow-red, yellow, green-yellow, green, blue-green, blue, purple-blue, purple, and red-purple) and performed a mixed ANOVA with hue as a within-participants factor and group as a between-participants factor. There was a main effect of hue $F(9, 189) = 7.36$, $p < .001$, $\eta_p^2 = .26$, and group $F(1, 21) = 5.75$, $p = .026$, $\eta_p^2 = .22$, but importantly there was a significant interaction between hue and group $F(9, 189) = 2.43$, $p = .012$, $\eta_p^2 = .10$. Synaesthetes made less errors than controls within the yellow ($d = 0.92$), green-yellow ($d = 1.30$), green ($d = 1.04$), red ($d = 1.01$), and red-purple ($d = 1.26$) subregions (see Figure 4).

Visual and Olfactory Imagery

Ratings on the imagery questionnaires were averaged according to the questionnaire guidelines (Gilbert et al., 1998; Marks, 1973). Cronbach's α was high for the VVIQ eyes open ($\alpha = .95$), VVIQ eyes closed ($\alpha = .94$),[5]and VOIQ ($\alpha = .94$). There was no difference in visual imagery between synaesthetes and controls when the VVIQ was completed with the eyes open ($M = 1.85$ vs. 2.24), $t(21) = 1.10$, $p = .29$, $d = 0.48$, or eyes closed ($M = 1.7$ vs. 2.25), $t(21) = 1.48$, $p = .15$, $d = 0.65$. Similarly, there was no difference between synaesthetes and controls in olfactory imagery ability, that is, VOIQ ($M = 2.05$ vs. 2.69), $t(21) = 1.52$, $p = .14$, $d = 0.66$.

Importance of Olfaction Questionnaire

Again, questionnaire data were treated according to the original guidelines of Croy et al. (2010). Cronbach's α was high for the application ($\alpha = .79$) and association scale ($\alpha = .81$), but it was fairly low for the consequence scale ($\alpha = .56$), suggesting this scale should be interpreted with caution. An overall score with responses summed across the three subscales was calculated. For this measure synaesthetes ($M = 61.17$) were significantly higher than nonsynaesthetes ($M = 52.76$), $t(21) = 2.4$, $p = .026$, $d = 1.05$. Comparing subscales separately, synaesthetes scored higher for measures of application, that is, how much a person uses their sense of smell in everyday life ($M = 21.33$ vs. 16.24), $t(21) = 3.01$, $p = .007$, $d = 1.31$; but not for measures of association (e.g., emotions, memories and evaluations triggered by smell; $M = 20.83$ vs. 18.12), $t(21) = 1.91$, $p = .07$, $d = .083$, or measures of consequence (i.e., conclusions drawn from olfactory impressions; $M = 19$ vs. 18.41), $t(21) = .42$, $p = .68$, $d = .18$.

Table 4
Odor Threshold (Concentration Level), Odor Discrimination (Total Number of Correct Responses), and Color Discrimination (FMT Error Scores) Scores for Individual Synaesthete and Controls (Mean; Error Bars in Brackets)

Participant	Odor threshold	Odor discrimination	Color discrimination (FMT error score)
Controls	6.59 (.90)	11.71 (.48)	82.12 (10.90)
Synaesthete A	6	15	32
Synaesthete B	6.5	13	44
Synaesthete C	4.5	12	96
Synaesthete D	2	12	20
Synaesthete E	9.5	16	8
Synaesthete F	9.75	15	36

Note. FMT = Farnsworth-Munsell 100 Hue Test.

Table 5
Means and SD for Each Task Administered

Task	Synaesthetes	Controls
Color distance (Delta E)	44.17 (12.98)	40.78 (7.27)
Naming consistency*	.54 (.11)	.38 (.17)
Naming accuracy*	.53 (.14)	.33 (.10)
Odor threshold	6.38 (2.97)	6.59 (3.73)
Odor discrimination*	13.83 (1.72)	11.71 (1.99)
FMT*	39.33 (30.51)	82.12 (44.92)
Visual imagery (open eyes)	1.85 (.54)	2.24 (.82)
Visual imagery (closed eyes)	1.70 (.55)	2.25 (.84)
Olfactory imagery	2.05 (.53)	2.69 (.96)
Olfactory importance (total)*	61.17 (7.14)	52.76 (7.44)
Olfactory application*	21.33 (2.34)	16.24 (3.87)
Olfactory association	20.83 (3.43)	18.12 (2.85)
Olfactory consequence	19.00 (3.29)	18.41 (2.83)

Note. Asterisk indicates a significant difference between synaesthetes and controls. FMT = Farnsworth-Munsell 100 Hue Test.

Discussion

We investigated odor perception and language in odor-color synaesthetes, individuals who have involuntary color experiences to odors. Overall, synaesthetes were more accurate and consistent in naming odors, and better able to discriminate between odors than age-matched control participants. In addition, synaesthetes were better than controls at discriminating between colors, demonstrating synaesthetes can have superior perception in both the inducer and concurrent modality; to our knowledge, a finding not previously reported.

Everyday odors that were easier to name were associated with more consistent synaesthetic color experiences, and more consistent color choices in control participants. This suggests synaesthetic associations to odors, and cross-modal associations between odor and color demonstrated in nonsynaesthetes (e.g., Gilbert, Martin, & Kemp, 1996; Stevenson, Rich, & Russell, 2012), can be explained by semantic factors; that is, color information is more accessible for odor concepts that are more accessible.

Why were color choices equally consistent in controls and synaesthetes? Although this finding appears problematic for a study of synaesthesia, where consistency is a defining characteristic, we be-

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[5] Data from two participants was excluded in the reliability analysis of the VVIQ because participants did not provide responses for the first question in the questionnaire.

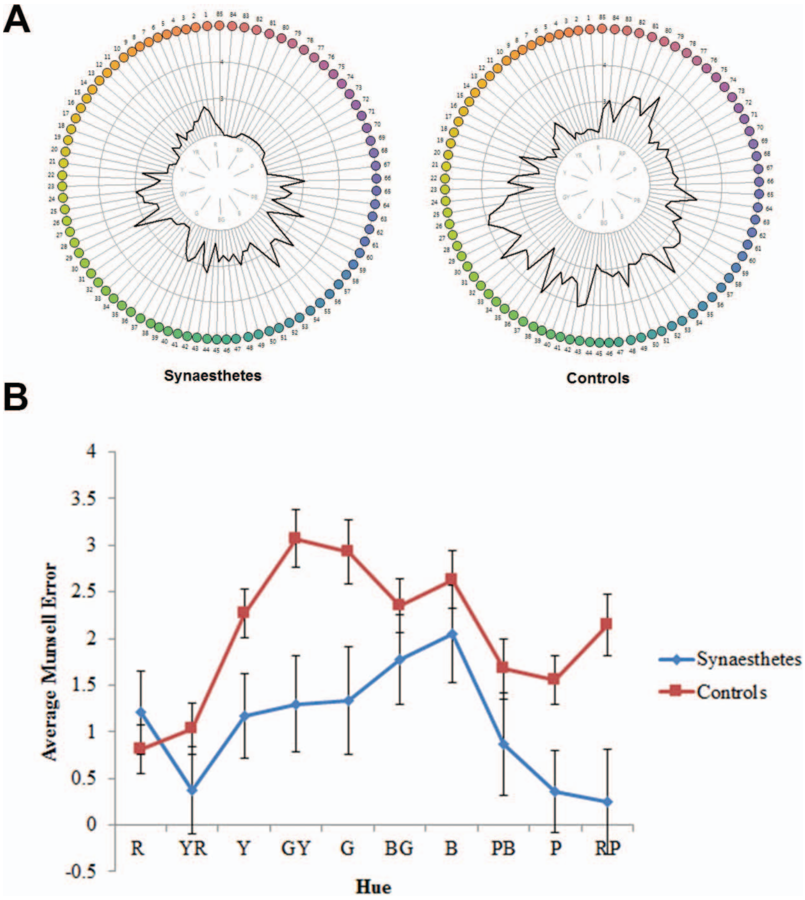

Figure 4. Synaesthetes' and controls' average FMT error score across all 85 color chips (A) and across 10 step hue subregions (B). Error bars reflect 1 *SE*. See the online article for the color version of this figure.

lieve this finding is expected. Previous studies have demonstrated that nonsynaesthetes can easily and consistently match colors to odors (e.g., de Valk et al., 2016; Gilbert et al., 1996; Levitan et al., 2014). Colors matched to odors often match the color of the source object (de Valk et al., 2016; Gilbert et al., 1996); for example, caramel with brown. Because odor sources typically have specific colors, it is not surprising that people can easily place a color with an odor. The lack of an additional advantage for odor-color synaesthetes could be because of competition between real-world odor-color associations and synaesthetic odor-color associations. Figure 1 shows the synaesthetic colors to leather and rose odors, for example, do not match the typical color of the odor source (pink instead of brown, and yellow instead of pink/red). So synaesthetic odor-color associations do not necessarily mirror real-world odor-color associations. In fact, one participant described her color concurrent to the odor of banana as beginning with yellow, because she knows bananas are yellow, but then changing to her synaesthetic experience of pink.

It is possible that color choices in synaesthetes are a mixture of real-world and synaesthetic associations. If correct, this might even lead to the prediction that color choices in synaesthetes would be less consistent than in controls, if they respond using real-world associations on one day, but synaesthetic associations on the other day. As noted in the introduction, odors are difficult to name, and can often be named differently by the same person on different days (e.g., Cain, 1979; Desor & Beauchamp, 1974; Lawless & Engen, 1977). Taken together, it is possible odors are being perceived, or identified, differently on Day 1 and Day 2, leading to variable color concurrents. Previously, Simner (2012) has suggested that using consistency as a "gold standard" of synaesthesia is questionable, and may lead to a selection bias, potentially ruling out cases of genuine synaesthesia that do not display this feature. In line with this objection, one synaesthete in the present study commented in the prestudy interview that her synaesthetic colors can be modified over time. Because there are of over 60 different forms of synaesthesia, sometimes with very different phenomenologies, it might be time to reconsider what are merely operational characteristics applicable to only some sorts of synaesthesia and what are core characteristics common to all. For example, consistency may be particularly relevant for grapheme-color synaesthesia because graphemes have fixed labels and stable concepts. In comparison, odor naming is poor and the same odor can be perceived differently from one occasion to the next, suggesting odor concepts are more unstable.

Odor-color synaesthesia has benefits for olfactory language, with odor naming both more consistent and accurate than among control participants. This finding is in line with recent work suggesting odor naming difficulties are not universal, and may be overcome by experience. In cultures, such as the Jahai in the Malay Peninsula, people are just as good at naming odors as naming colors, and better at naming odors than English speakers (Majid & Burenhult, 2014). For the Jahai, odors are a significant part of their everyday life, featuring in their communication, everyday actions, and belief system (Burenhult & Majid, 2011). Here we provide evidence of another way, aside from cultural factors, olfactory naming can be boosted. Connections between odor concepts and other sensory areas of the brain, such as vision, can similarly improve odor naming ability. A recent study found greater semantic richness (i.e., more semantic features) can lead to enhanced conceptual activation, facilitating access to lexical representations, and subsequent faster lexical selection and naming (Rabovsky, Schad, & Abdel Rahman, 2016). We propose synaesthetic associations to odors act as additional semantic features, increasing the semantic richness of the odor concept, and thereby facilitating odor naming.

Odor-color synaesthetes were better than controls at discriminating between odors, but not at detecting odors. Odor discrimination is considered a higher-level process than odor detection. Supporting this, lesions to the temporal lobes cause deficits in discrimination but not detection (Zatorre & Jones-Gotman, 1991). In addition, cognitive variables (measures of executive function and semantic memory) predict individual odor discrimination scores, but not odor threshold scores (Hedner, Larsson, Arnold, Zucco, & Hummel, 2010). Odor discrimination is also improved with the availability of (de Wijk & Cain, 1994) or training with (Rabin, 1988) odor labels. Synaesthetic associations to odor, therefore, do not aid processing of low-level sensory properties of an odor, but rather enhance discriminatory properties, making odors more distinct from each other. Could the lack of difference in the threshold task be because of more mundane reasons? For example, it was the final task on the final day, so participants were susceptible to olfactory fatigue. We think this is unlikely because participants were given a one day break between testing days. In addition, the odor discrimination task and odor threshold task were completed with equal amounts of odor exposure on each test day (see Table 1). Finally, the attested results fit the previously reported findings of a conceptual, not perceptual, effect.

That odor-color synaesthesia improves both odor discrimination and odor naming is consistent with models of synaesthesia in which synaesthetic concurrents are seen as extra connections in a semantic network, enriching conceptual representations (Meier, 2014). According to some models of semantics (e.g., Barsalou, 1999; Rogers, Lambon Ralph, Garrard, Bozeat, McClelland, Hodges, & Patterson, 2004) meaning is distributed across modality-specific regions of the brain. So, synaesthetic color activation to odors may have become integrated with the concept of the odor, along with its olfactory features. We suggest this conceptual enrichment strengthens odor concepts so they become more differentiated (leading to improved odor discrimination) and facilitate access to lexical information (leading to improved odor naming). It is possible, however, that the results could be explained by another underlying mechanism that affects both olfactory cognition and the propensity to develop odor synaesthesia. Such an explanation could be explored by tracking the development of synaesthesia and related cognition from an early age.

We also found synaesthetes were better at discriminating between colors than controls. This replicates previous findings of improved color discrimination (Banissy et al., 2009, 2013; Yaro & Ward, 2007), and observed differences in early components of visual-evoked potentials (Barnett et al., 2008; Goller, Otten, & Ward, 2009), to another form of synaesthesia involving color concurrents. However, because all participants additionally experience other forms of synaesthesia involving color concurrents (see Table 1), we cannot conclude that this superior performance is because of the presence of odor-color synaesthesia specifically. Previous studies have also found that texture discrimination is improved in mirror-touch synaesthesia (Banissy et al., 2009) suggesting enhanced perceptual processing is "a core property of synaesthesia." Such advantages observed within the concurrent domain could be related to differences in brain development, such as enhanced cortical connections within the concurrent modality, or enriched perceptual experience as a result of experience with the concurrents (Banissy et al., 2009, 2013). Banissy et al. (2009) describe synaesthesia as involving an "oversensitive concurrent perceptual system."

The FMT revealed synaesthetes' superior color discrimination was specific to the hue subregions yellow, green-yellow, green, purple, and red-purple. Although we did not predict differences within specific regions, previous research has shown that 2-month-olds fail in a color discrimination task specifically in the yellow/green and mid-purple ranges (Teller, Peeples, & Sekel, 1978), but not other color ranges. Making a link between this finding and the present result may be premature, but, if synaesthesia is a developmental phenomenon (Maurer & Maurer, 1988), then early experiences with color will be of great importance to the development of synaesthetic associations. On the other hand, there is evidence suggesting that although synaesthetic associations can be observed early in development, they may take several years to fully emerge (Simner & Bain, 2013). Furthermore, the trajectory of development may differ across perceptual modalities: for example, lexical-gustatory synaesthesia may develop only later through associations with food-related words (Simner & Haywood, 2009). This is the first time color discrimination in synaesthesia has been addressed in such detail, and it clearly requires further investigation.

Using two mental imagery questionnaires assessing visual and odor imagery, we did not find any differences between synaesthetes and controls, although there was a numerical suggestion that synaesthetes found both types of imagery easier. It is possible, then, that the perceptual and conceptual enhancements observed here do not overlap with systems utilized in visual and olfactory imagery. On the other hand, the current study may be underpowered to detect such effects, with only six odor-color synaesthetes. Finally, a questionnaire assessing the importance of olfaction found synaesthetes scored higher on the application scale than controls; that is, synaesthetes were more likely to intentionally use their sense of smell in everyday life. So, synaesthesia involving odors also has implications for how the sense of smell is used from day to day.

Conclusion

Human olfaction has been underestimated for centuries, but the feats our sense of smell can accomplish are, in fact, quite astounding (e.g., Bushdid, Magnasco, Vosshall, & Keller, 2014; Laska, Seibt, & Weber, 2000; Majid et al., 2017; Porter et al., 2007). In this study, we show olfactory language and cognition is further enhanced in people with olfactory synaesthesia. We suggest synaesthetic associations strengthen semantic links with odor concepts, leading to stronger conceptual representations and subsequently better discrimination and naming. This study is also the first, to our knowledge, to demonstrate improved perceptual abilities in both the inducer and concurrent modality simultaneously in synaesthesia. So not only do synaesthetes have additional perceptual experiences (i.e., experience colors), but their primary perceptual experience (i.e., their experience of smells) is also different to nonsynaesthetes. In sum, synaesthetic associations for olfaction may not be epiphenomenal, but instead play a critical role in shaping concepts.

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Appendix

List of Odors

Odor	Familiarity	Pleasantness	Intensity
Fragrances			
Hugo Boss - Orange	4.67	5.54	4.48
Calvin Klein - Eternity	4.71	5.67	4.93
Armani Si	4.78	5.22	4.86
Dior - Jádore	5.22	5.58	4.96
Chanel - Bleu de Chanel	4.43	5.46	4.72
Davidoff - Cool Waters	4.65	5.70	4.98
Joop!	4.70	5.39	5.46
Hugo Boss - Boss Bottled	4.48	5.40	4.65
Sniffin' Sticks			
Orange	5.57	5.87	5.40
Coffee	4.98	4.85	5.63
Apple	4.07	5.00	5.65
Clove	3.59	3.39	6.29
Pineapple	3.97	4.79	5.53
Rose	4.33	5.30	5.37
Aniseed	4.11	4.72	5.02
Fish	3.70	1.84	6.41
Leather	3.33	3.85	4.35
Cinnamon	3.85	4.35	4.72
Peppermint	5.53	5.58	5.96
Banana	4.96	5.38	5.84
Lemon	3.43	4.34	4.88
Licorice	4.07	4.61	4.96
Turpentine	3.33	3.50	5.89
Garlic	3.96	2.37	6.46

Note. Odors used for odor-color associations and naming, with their average ratings of familiarity (1 = *very unfamiliar*, 7 = *very familiar*), pleasantness (1 = *very unpleasant*, 7 = *very pleasant*), and intensity (1 = *low intensity*, 7 = *high intensity*).

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