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ODORS IN COGNITIVE RESEARCH

A Commentary on 'Scented Colours' and an evaluation study on odor quality, with the example of human wayfinding

ABSTRACT: In his target article on "Scented Colours", Charles Spence highlights the importance of crossmodal connections by focusing on the interaction between odors and colors. In this commentary and our presentation of own empirical work in this research context, we want to reach out further by emphasizing this importance not only on a perceptual and representational level, but also highlight it as an example for spatial cognition research. We provide an evaluation study on emotional effects of odors that could be used in future interdisciplinary research. While the meaning of odors in spatial wayfinding is, thus far, not well investigated, we want to briefly introduce the current research state, focus on new and valuable research strains in this area as an example for the importance of odors in cognitive research.

1. PREFACE

This commentary article will be fourfold. We start with a commentary on the work "Scented Colours: Artistic Interest in the Crossmodal Connection Between Colour and Odor" by Charles Spence (2020a). In this first part, we focus on different contexts of crossmodal connections in human life besides visual or artistic aspects where the olfactory sense plays a significant role. Then, we highlight the lack of scientific studies in the field of multimodal connections including the olfactory sense and therefore the need to find a common agreement on how to best categorize odors. This leads to the second section, where we present some of our own empirical work. Here, we added an evaluation study on emotional quality of odors to the commentary in order to support and stimulate further research on this topic. In the third section, we will demonstrate the necessity of such a categorization system for research in human wayfinding, a field in which the role of odors and the sense of smell thus far has mainly been neglected. This example research field serves as a representative for other research topics, which will be discussed in the final section, concerned with crossmodal correspondences between the olfactory and other senses in order to diminish the gap between the arts and (psychological/ neuroscientific) sciences.

2. INTRODUCTION

Alinea is a different word for paragraph mark and means “the beginning of a new train of thought”. But it is not just a feature you can use in Microsoft Word. It is the meaning and the name of one of the (probably) best restaurants in the world. It was awarded three Michelin stars and represents a modern and rather unusual cuisine in Chicago, Illinois. But it is not just the dishes that are unusual. It starts with the restaurant itself and how it plays with the human senses. To get to the table, the guests have to follow a hallway, which is full of visual illusions. Next, Alinea’s chef, Grant Achatz, presents his Sci-Fi cooking. His dishes do not look like normal dishes. Some look like and are inspired by artworks, physical or chemical natural laws like an edible balloon that floats over the table. He plays not just with the guest’s visual and gustatory senses, he also stimulates the olfactory system. One of the dishes named “Bean, many Garnishes, Pillow of nutmeg air” (on the menu in 2006) is the best example of it. Every time a piece of the dish is cut off, a smell of nutmeg escapes. Taken together, the dishes are a whole new experience and demonstrate crossmodal correspondences between the visual, gustatory and olfactory senses (McGinn 2016).

Now, what is the connection between this high-class restaurant and our commentary on the target article "Scented Colours: Artistic Interest in the Crossmodal Connection Between Colour and Odor" by Charles Spence (2020a)? Charles Spence highlights the importance and urgency of the topic crossmodal connections between color and odors in his article. The general research focus is, thus far, rather on crossmodal connections between the visual and auditory system, in comparison to vision and olfaction. He discusses the former assumption that only individuals with synaesthesia are able to experience these connections between senses and demonstrates studies which show these crossmodal correspondences for non-synaesthetic individuals. This assumption is important to address, because it may be the reason why many scientists feel unable to do research on it, due to the selective and hard-to-reach sample of people with synaesthesia. A different, but also important point he refers to is the lacking universal agreement on how crossmodal connections arise (e.g., associative learning, crossmodal mapping, synaesthesia). Besides this, the major focus in his article is the artistic interest on crossmodal connections. However, it seems as if Charles Spence leaves out other important crossmodal connections we are confronted with in everyday life. Space, for instance, is one of the most elementary things in our lives. Humans need to locate the position of their body in the environment which is essential for orientation and navigation. We will address this topic in more detail in the third section.

Another aspect that is required and consumed on a daily basis is food. It stimulates different modalities to make certain decisions or to gather experiences. Every meal that is prepared stimulates our color perception as well as our receptors in the sense of smell and depending on how the combination fits together, an expectation arises due to the appearance and our mental representations based on experiences (e.g., disgusting, tasty, weird). One study suggests that a congruent color of a product (i.e. yellow for a banana instead of purple) increases the identification of a flavor (Garber Jr et al. 2000). But what is a flavor? Flavors are experienced through chemical sensations of taste and smell, which shows the close connection between these senses. In the study of Garber Jr et al. (2000) the color of a fruit beverage was manipulated, but the flavor was the same for all fruit drinks. Results showed that in addition to the identification performance, the perception of the flavor was also influenced by the food color. In this case the color determined different flavor profiles for the product, even if the flavors were the same except for the color (Garber Jr et al. 2000). Food industries make use of this knowledge and, for instance, add annatto and beta-carotene to products like cheese in order to make it look more attractive and appetizing, but also nitrate to keep its typical cheesy shape (Cordes 2017). Such techniques do not only account for the food industries. A whole new marketing category has been established over the past years: odor marketing (Emsenhuber 2009; Orvis 2016). Product companies already understood the huge impact of odors on emotions and now systematically make use of it. In a study of Porcherot et al. (2013) scents and colors of a fabric softener were systematically varied in order to explore the feelings of participants that occurred when smelling it. It turned out that diverse perfumes and colors induced different reports of participants' feelings. The perfume "Lagoon" (fresh, marine) for example, received stronger reports on the category of well-being than the perfume named "Cotton" (almondy, powdery). The scores of how much the participants liked the perfumed fabric softener were also influenced by a variation of the colors.

Odor marketing strategies are not limited directly to products. Supermarkets locate the bakeries close to the entrance to create an appetizing odor and a feel-good atmosphere. Or, odor dispensers are integrated into air conditioning systems to affect the shopping behavior of customers (Fründt 2010). The crossmodal influence of color and odor in the food area and product companies is important to be addressed scientifically, because it is something humans are confronted with and unconsciously manipulated by every day. Thus, we should also understand what is going on in the human brain in such settings. A rather different, but interesting crossmodal experience is the idea of watching movies with all senses. New techniques make it possible to bring this adventure into movie theaters as in the cineplex in Bayreuth, Germany. On the usual cinema program visitors are able to choose the 4DX version of movies. The seats are able to lift, vibrate, shake, to balance sideways and to exude scents (Cineplex n.d.). This shows that even leisure activities of humans start to be addressed and crossmodal effects are integrated.

In the following, however, it is important for us to refrain from everyday situations and turn towards the scientific side of crossmodal connections. The fact that there is a large gap in the area of multimodal connections between the olfactory and other senses in the scientific field must be pointed out. Charles Spence already summarized a number of scientific studies on crossmodal correspondence of color and odor, but with a focus on the artistic side (Spence 2020a). That is why we are going to introduce a different field besides the food area and leisure activities, but at least equally important for crossmodal connections between color and odor. A significant scientific and underestimated research field is, from our point of view, human wayfinding and navigation. Unfortunately, especially this area of cognitive research has largely been neglected in the past, especially with regards to olfaction. When thinking about navigation, orientation or human wayfinding (as the cognitive component of navigation in contrast to locomotion; Montello 2005), the first sense that comes to mind is the visual sense. Even the auditory sense is being considered in case of providing audio cues or listening to a route description (Lokki & Grohn 2005; Massiceti et al. 2018). Objects and buildings are typically perceived and analyzed visually (i.e. size, shape, color, contrast to the environment; e.g., Lynch 1960). Thus far, the meaning of our olfactory system has mainly been neglected but may also contribute to spatial orientation and navigation. The reason for this underestimation of the olfactory system could be the mostly unconscious usage of the sense of smell.

Another explanation for this "ignorance" may be the assumption that humans have a bad sense of smell. McGann reveals this claim to be a 19th-century myth which could be traced back to the reductionist view of the olfactory bulbs by neuroanatomist Paul Broca (McGann 2017). Thus, research on olfaction in the field of human wayfinding is rare. A literature research on "vision [and] human wayfinding" on Google Scholar, currently reveals about 19,100 matches. In contrast, for "olfaction [and] human wayfinding" just about 1,660 matches are provided and even decreases to 809 hits by searching "odor [and] wayfinding" (last search executed on January 26, 2021). However, surprisingly, research has to date mainly been addressed in visually impaired people (e.g., Koutsoklenis & Papadopoulos 2011), but rarely in visually unimpaired people (e.g., Hamburger & Karimpur 2017; Hamburger & Knauff 2019). We therefore want to bridge the gap between the often-neglected multimodal connections between the visual and olfactory senses in human wayfinding. In order to do this another basic problem must first be addressed. Charles Spence asked at the beginning of his article for a universal agreement for best matching colors for odors. This raises the question whether, in order to find a universal agreement, why not first reach a common agreement on how to categorize odors or even a universal classification system of odors? Without a classification system of odors (e.g., on the basis of triggering emotions through odors) scientific research between different modalities as well as within the modalities will be difficult to execute, since odors are most often accompanied with emotions (i.e. episodic memory). Likewise, crossmodal correspondences and brain processes will be more difficult to investigate. This is the challenge we are about to address in this current work, in order to provide first evidence (i.e. evaluation data) to be used in systematic future studies on odor perception and cognition (here especially on the cognitive process of human wayfinding with connections to spatial memory and the like).

3. ODOR CLASSIFICATION

3.1. Present research on odor categorization and classification

Important for further research and to comprehensively understand the olfactory system (from a cognitive perspective), is to have a common categorization system for odors at hand. So far, only a few researchers have addressed this topic and offered various classification systems. As early as in the epoch of ancient Greece the philosopher Plato (428-348 BCE) was searching for a categorization system of odors. He divided odors into two categories: pleasant and unpleasant (Legrum 2015). With these two categories Plato already showed in which direct way odors are able to affect human mood. Aristotle (384-322 BCE) on the other hand was convinced of a close connection between olfaction and the gustatory sense. Therefore, he assumed six basic qualities for both senses (Legrum 2015):

(1) bitter

(2) sweet

(3) spicy (hot)

(4) sour

(5) oily

(6) foul

A new idea for categorization arose with the Swedish naturalist Carolus Linnaeus (1707-1778). His categories were inspired by the observation of plants and animals. Yet, his seven classes are almost unknown (Legrum 2015):

(1) odores aromatici (aromatic)

(2) fragrantes (fragrant)

(3) ambrosiaci (amber-like)

(4) alliacei (leeky)

(5) hircini (goatish)

(6) tetri (foul)

(7) nausea (nauseating)

A hundred years later, the physiologist Hendrik Zwaardemaker (1857-1930) extended the categorization system of Carolus Linnaeus with two additional categories, odores aetherii (ethereal, essential) and empyreumatici (gob, smokey; Legrum 2015).

But, what exactly do these categorization systems listed above lack? They all include only a unidimensional way to categorize odors. A first approach to demonstrating a multidimensional categorization system is offered by the Hennig Prism. Hans Hennig (1885-1946) created a prism with six corners that form the basic odors flowery, fruity, resinous, spicy, foul and gob. Combinations of two basic odors produce an odor quality that can be arranged on the edges between the basic odors. For instance, the odor quality “ginger” can be placed on the edge between the basic odors spicy and resinous (figure 1; Legrum 2015). However, it is questionable whether these basic odors are sufficient to describe every olfactory impression.

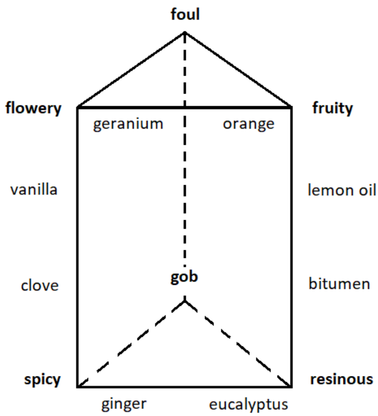

Figure 1: The Hennig prism includes six corners, which demonstrate the basic odors spicy, resinous, gob, fruity, foul and flowery. Different odor qualities are produced through combinations of the basic odors. Examples for odor qualities can be found on the edges of the prism.

If we take a brief look at the visual system, we immediately see that multidimensional approaches are used for different characteristics. We identify and see objects not just based on single features. Humans analyze them based on the size, depth, edges, lines, experiences, and many more (Marr 1982; Gegenfurtner 2015). So, why shouldn't the olfactory system work in a similar way? Zald & Pardo (1997), for example, explored the regional cerebral blood flow (rCBF) in the amygdala and orbitofrontal cortex of participants, while being exposed to aversive or less aversive odors. The results indicated a strong connection between the human amygdala and the emotional processing of olfactory stimuli (Zald & Pardo 1997). This offers the possibility to classify odors based on emotions. However, the connection to the limbic system is not limited to the amygdala, a strong bond to the hippocampus exists as well.

Marcel Proust explains that magical moment where he feels triggered back into his childhood only by the taste and smell of a madeleine cake dipped into lime-flower tea (Van Campen 2014). This experience is known as "the Proust phenomenon" and suggests influences of odors on the hippocampal region, which is mainly responsible for memories (Milner et al. 1968; Cohen & Eichenbaum 1993). The phenomenon is based on the hypothesis that memories evoked by odors are experienced more emotionally than memories evoked by the other senses. Many studies have so far investigated this assumption. Herz and colleagues, in particular, have examined the hypothesis of the Proust phenomenon (Herz et al. 2004). In a fMRI study they compared the emotional responses of the visual and the olfactory system triggered by individual perfumes whose sight and scent induce pleasant and personal memories. Evidence came from a higher activation of the amygdala during the odor presentation in comparison to the visual condition (Herz et al. 2004). In addition, neural interactions were shown between the hippocampus and the amygdala with greater activation in the parahippocampal gyrus. In a different study (Herz 1998) tested whether odors really represent the best memory cues. Her results suggested that the performance of recalling an odor-associated, arousing picture was equivalent to other modalities (visual, tactile, acoustic). However, the odor stimuli evoked memories that were more emotional than memories generated by any other modality. This indicates that in this study the odors were not superior memory cues, but the emotional salience of odor cues was higher (Herz 1998).

For now, let us go back to our initial example. In 2007 Alinea's chef Grant Achatz was diagnosed with stage 4 tongue cancer. Through a treatment of radiation and chemotherapy he lost his ability of taste. He asked himself how he should work as a chef or create new dishes without being able to taste anything? Thus, he started to draw his inspirations and created flavor-dimensions for his crew that helped to communicate with each other. They used dimension-scales to figure out how sour or salty a dish should be or how it is already. After the treatment his taste ability came back gradually and finally recovered completely (McGinn 2016).

The dimensions he created helped him and his crew to estimate the degree of a desired flavor or quality for the dishes. This raises the question whether such dimensions are able to assess the degree of odor qualities and how the dimensions may help in categorizing them? As already pointed out, a strong connection between the olfactory and the human emotional processing system exists (Zald & Pardo 1997). This leads to the idea that classifying odors based on emotional dimensions could represent a possible solution for the lack of a universal categorization system for odors. With a pictorial, non-verbal assessment test [Self-Assessment Manikin (Bradley & Lang 1994)], Bestgen et al. (2015) evaluated 26 odors on the dimension valence, arousal, and dominance in terms of the identification performance of participants. In this study, the dominance and valence dimensions especially predicted the subjects' ability to identify the odors. The same dimensions were used in our evaluation study to investigate whether these dimensions serve as a good categorization system. However, the identification performance of odors was not taken into account for the purpose of our experiment. Cain (1979) already showed that odors are rather associated than identified, because it is difficult to label the correct odor name. Additionally, the results of Hamburger & Knauff (2019) revealed that odors only need to be differentiable and not identifiable for successful recognition. Therefore, we did not focus on the identification performance, but rather on the emotional assessment of odor qualities.

3.2. Evaluation Study: emotional quality of odors

For our evaluation study 55 odors (Table 1) were estimated based on emotions. The aim is to provide a large sample of odor material for systematic future research (i.e. for basic research as well as for applied research). Another objective of the study was to compare the three dimensions valence, arousal, and dominance to examine any kind of relationship between them. Overall, forty subjects (31 female; 9 male) participated with a mean age of 26.52 years (SD= 12.40) in our study on the emotional quality of the odors. The odors were presented with small (2 cubic millimeter) brown pharmacy bottles in order to prevent subjects from seeing the content and to protect the odors from light. To evaluate the odors, the Self- Assessment Manikin questionnaire (Bradley & Lang 1994) was used. The study included a 5-point Likert-scale for the dimensions valence, arousal, and dominance. The dimension valence reached from pleasant (5) to unpleasant (1) and the dimension arousal ranged from disturbing (5) to soothing (1). The third dimension, dominance, presented manikins from no-control[1] (5; dominant) to in control (1; not dominant at all). The highest average score for the dimension valence was achieved by cinnamon (M = 4.50; SD = 0.88) and the lowest by perm liquid (M = 1.55; SD = 0.78). For the dimension arousal the highest rating was reached by butyric acid (M = 4.43; SD = 0.68) and the lowest by cinnamon (M = 1.78; SD = 0.95). The highest average score for the dominance scale was assessed for perm liquid (M = 4.15; SD = 1.21) and the lowest for rose (M = 1.78; SD = 1.05). The full scores are provided in Table 2. To estimate the relationship between the emotional qualities the Pearson correlation coefficient was calculated. The correlation between valence and arousal showed a negative relationship with high significance ($r = -0.950$; $p < 0.001$), indicating that pleasant odors are less arousing than unpleasant odors. This effect can also be observed by the diverging lines in Figure 3. Interestingly, the correlation between valence and dominance ($r = -0.913$; $p < 0.001$) also turned out to be negative and highly significant. Thus, pleasant odors are rather evaluated as less dominant than unpleasant odors. In contrast to these results a significant positive correlation was observed between the dimension arousal and dominance ($r = 0.962$; $p < 0.001$). The positive correlation is clearly visible in the almost overlapping scores in Figure 3 and the similar bar lengths of arousal and dominance in Figure 2. A closer look at the mean values reveals that, especially in the valence category, certain odors could be assigned to subcategories like pleasant, neutral or unpleasant for a closer and more specific classification. For example, the odor cinnamon (M = 4.50; SD = 0.88) obtained the highest rating in the dimension valence and would therefore be a good representative for the subcategory pleasant. The odor nail-polish (M = 3.03; SD = 0.89) could then be assigned to the subcategory neutral and the odor perm liquid (M = 1.55; SD = 0.78) to the subcategory unpleasant.

[1]Having no control over an odor implies that it cannot be ignored and to endure the odor, because of its intrusive kind.

Table 1: Overall 55 odors that were used in the evaluation study and the references where the odors were purchased.[†]

Odors	Reference	Odors	Reference
Rose	Rose oil ordered by Amazon	Fish	Dried; Pet shop
Lavender	Oil ordered by Primavera	Salami pizza	Syntheric
Basil	Dried; Supermarket	Cola	Synthetic
Cardomom	Supermarket	Melon	Synthetic
Peppermint	Synthetic	Frakníncense	Synthetic
Black tea	Dried; Supermarket	Apple	Synthetic
Orange	Synthetic	Gras	Synthetic
Thyme	Dried; Supermarket	Vinegar essence	Diluted; Supermarket
Vanilla	Dr. Oetker Vanilla paste; Supermarket	Alcohol	Isopropyl alcohol 70%; Pharmacy
Aftershave	Supermarket	Peanut	Peanut butter; Health food store
Nail polish	Transparent; Supermarket	Eucalyptus	Synthetic
Nutmeg	Supermarket	Fresh laundry	Synthetic
Chlorine cleaner	DanKlorix; Supermarket	Leather	Synthetic
Curry	Supermarket	Spruce Needle	Synthetic
Pepper	Synthetic	CBD-oil	5%; ordered by InnoNature
Tangerine	Synthetic	Pineapple	Supermarket
Cinnamon	Synthetic	Strawberry	Synthetic
Sage	Dried; Supermarket	Coconut	Synthetic
Aniseed	Supermarket	Banana	Synthetic
Close	Supermarket	Perm liquid	Bottled by a hair salon
Olive oil	Supermarket	Sulfur powder	Pharmacy
Rosemary	Dried; Garden	Bulls pizzle	Dried; Supermarket
Garlic	Freshly squeezed	Licorice	Supermarket
Cabbage juice	Health food store	Fishpaste	Fishing shop; Powerbait
Oregano	Dried; garden	Caraway seed	Supermarket
Cocoa	Supermarket	Cigarette	Cigarette butts; Marlboro
Lemon	Synthetic	Butyric Acid	Ordered by Amazon
Cedarwood	Synthetic		

[†]The essential synthetic oils were ordered from Raima AirConcept (http://www.duftmarketing.de/de/) and Dragonspice (https://www.dragonspice.de/).

Table 2: Odors used in the experiment with the average scores and standard deviation of valence, arousal and dominance based on the participants emotional evaluations of the Self- Assessment Manikin questionnaire

Odors	**Valence, mean**	**(S.D.)**	**Arousal, mean**	**(S.D.)**	**Dominance, mean**	**(S.D.)**
Perm liquid	1.55	(0.78)	4.38	(0.68)	4.15	(1.21)
Butyric Acid	1.58	(0.93)	4.43	(0.68)	4.13	(1.16)
Cigarette	1.63	(0.54)	3.95	(0.85)	3.80	(1.24)
Bull's pizzle	1.73	(0.72)	3.85	(0.86)	3.63	(1.31)
Fish paste	1.78	(0.80)	3.88	(1.07)	3.78	(1.21)
Cabbage juice	1.98	(0.92)	3.98	(0.95)	3.80	(1.29)
Fish	2.03	(0.77)	3.55	(0.85)	3.43	(1.26)
Sulfur	2.10	(0.74)	3.35	(0.92)	3.33	(1.10)
Vinegar	2.13	(0.82)	3.68	(0.92)	3.68	(1.29)
Garlic	2.30	(1.22)	3.80	(1.02)	3.55	(1.38)
Salami pizza	2.53	(1.24)	3.45	(1.06)	3.53	(1.30)
Leather	2.68	(1.10)	3.18	(1.03)	3.20	(1.14)
Licorice	2.93	(0.86)	2.83	(0.81)	2.63	(1.14)
Nail polish	3.03	(0.86)	3.28	(1.11)	3.18	(1.50)
Spruce needle	3.05	(1.13)	2.80	(1.29)	2.80	(1.42)
Alcohol	3.08	(0.89)	3.05	(0.93)	2.60	(1.17)
Cedarwood	3.08	(1.00)	2.70	(1.02)	2.65	(1.23)
Basil	3.15	(0.98)	2.60	(0.96)	2.13	(1.16)
Chlorine cleaner	3.18	(1.30)	2.75	(1.30)	2.45	(1.24)
Caraway seed	3.18	(1.01)	2.65	(1.00)	2.30	(1.26)
Peanut	3.20	(1.11)	2.70	(0.97)	2.43	(1.28)
Black tea	3.23	(0.77)	2.50	(0.93)	2.15	(1.17)
CBD oil	3.25	(1.01)	2.65	(1.12)	2.63	(1.39)
Nutmeg	3.25	(0.98)	2.73	(0.96)	2.10	(0.98)
Pineapple	3.28	(1.20)	2.95	(1.11)	2.78	(1.27)
Sage	3.30	(0.88)	2.30	(0.88)	2.20	(1.22)
Frankincense	3.30	(0.97)	2.65	(1.03)	2.75	(1.19)
Gras	3.35	(1.10)	2.80	(1.24)	2.80	(1.34)
Rosemary	3.35	(0.80)	2.25	(0.93)	2.13	(1.26)
Thyme	3.38	(1.05)	2.33	(1.02)	2.43	(1.22)
Aniseed	3.40	(1.22)	2.35	(1.14)	2.28	(1.32)
Cocoa	3.40	(1.19)	2.45	(1.18)	2.33	(1.25)
Oregano	3.40	(0.90)	2.48	(0.99)	2.23	(1.00)
Cola	3.48	(1.06)	2.73	(1.06)	2.63	(1.35)
Fresh laundry	3.50	(1.13)	2.50	(1.11)	2.55	(1.34)

Table 2 continued on next page

Table 2 continued						
Odors	**Valence, mean**	**(S.D.)**	**Arousal, mean**	**(S.D.)**	**Dominance, mean**	**(S.D.)**
Lavender	3.50	(1.19)	2.55	(1.41)	2.80	(1.38)
Eucalyptus	3.60	(1.17)	2.43	(1.34)	2.70	(1.32)
Cardamom	3.65	(0.80)	2.20	(0.91)	2.13	(1.20)
Melon	3.65	(1.10)	2.38	(1.03)	2.48	(1.32)
Clove	3.73	(1.20)	2.48	(1.24)	2.43	(1.32)
Pepper	3.73	(0.99)	2.28	(1.20)	2.08	(1.02)
Curry	3.78	(0.95)	2.80	(1.07)	2.63	(1.17)
Peppermint	3.80	(0.91)	2.38	(1.10)	2.23	(1.14)
Olive oil	3.83	(0.90)	2.20	(1.04)	2.18	(1.28)
Coconut	3.95	(1.04)	2.05	(1.04)	2.20	(1.18)
Banana	3.98	(0.97)	2.35	(1.08)	2.15	(1.14)
Citron	3.98	(1.19)	2.28	(1.09)	2.38	(1.33)
Vanilla	4.10	(0.93)	1.90	(0.90)	1.85	(1.14)
Orange	4.13	(0.91)	2.30	(1.18)	2.33	(1.33)
Apple	4.15	(0.86)	2.08	(1.00)	2.20	(1.32)
Aftershave	4.18	(1.01)	1.90	(0.96)	2.03	(0.95)
Tangerine	4.25	(0.90)	2.10	(0.98)	2.03	(1.19)
Rose	4.30	(0.94)	1.83	(0.98)	1.78	(1.05)
Strawberry	4.40	(0.84)	2.25	(1.13)	2.00	(1.28)
Cinnamon	4.50	(0.88)	1.78	(0.95)	1.90	(1.15)

4. ODORS IN HUMAN WAYFINDING

Since there is, as we already pointed out, a general need for research on odors in human brain processing, we want to highlight this by now using human wayfinding as a more detailed example alongside those given by Charles Spence in his article. Only a few studies have so far integrated odor cues in their experiments to provide information about their use in olfactory wayfinding. However, odors are not only helpful as orientation cues, they may also be implemented as landmarks in the environment. Odors as landmark information can serve as a reference point and thus increase the wayfinding performance. Hamburger & Knauff (2019) exhibited an experiment revealing that humans can use odors for wayfinding even if the odor is hard to identify (i.e. the odors just needed to be differentiated and recognized by the partici-

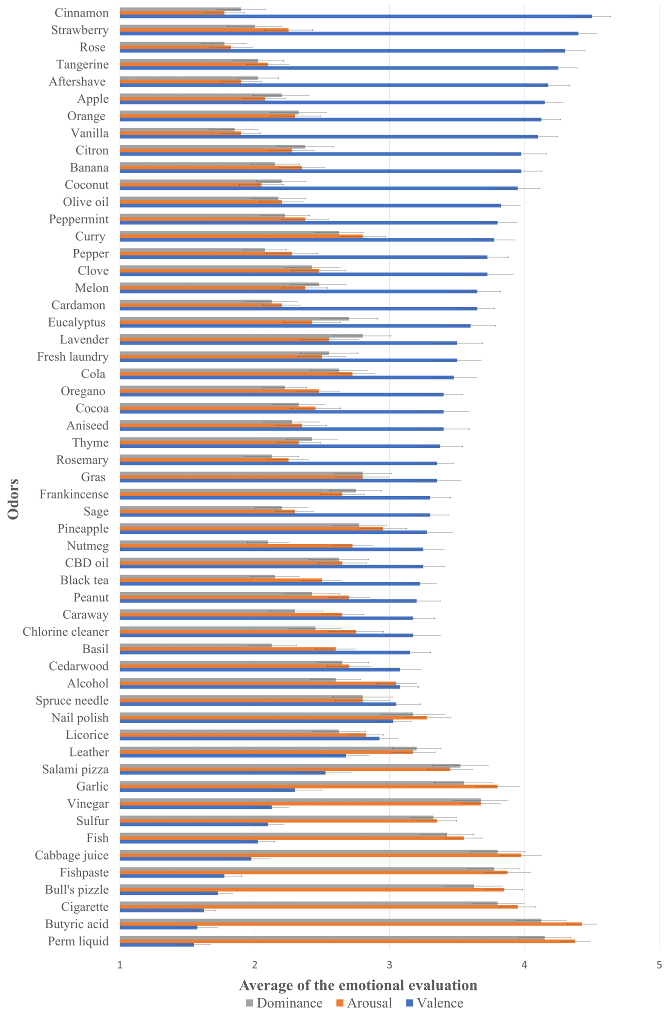

Figure 2: Evaluation of the emotional quality for 55 odors on the dimensions valence, arousal and dominance

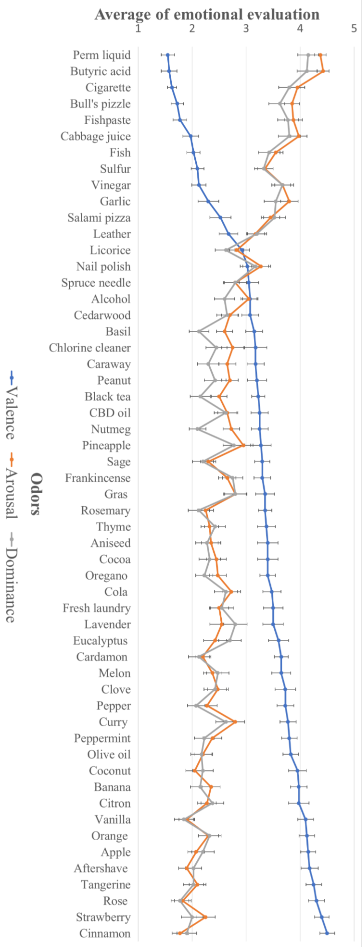

Figure 3: Emotional evaluations of the odors on the dimension valence, arousal and dominance

pants). Participants in the wayfinding experiment performed significantly better than chance which suggests that humans are able to build cognitive maps based on olfactory cues (Hamburger & Knauff 2019).

One of the few studies available on this topic was presented by Porter et al. (2007). In their experiment, participants had to scent track an approximately 10-meter-long chocolate trail by crawling on their knees and using their nose. Here, two-third of the participants were able to follow the right path like dogs do. Further investigation showed that the participants were even able to increase their performance through practice. Especially when vision is lacking, information from the remaining senses is important for avoiding obstacles and potential danger (e.g., garbage can, bad food; Chebat et al. 2011), and thus, the other senses besides vision may be elementary for wayfinding and navigation as well (Koutsoklenis & Papadopoulos 2011). Furthermore, the other senses are also important for social interaction in space (e.g., verbal descriptions of paths; e.g., Bradley & Dunlop 2005) and for social interaction in general (Belin et al. 2004). A recent study demonstrated that individuals with visual impairments use certain odors more often and estimate different odors as more useful than others for wayfinding in urban environments (Koutsoklenis & Papadopoulos 2011). An attached interview gave information that the olfactory cues were used for different purposes. Some were important as reference points, or to locate objects and buildings and some to ensure the right path (i.e. landmark information). To examine in which ways odors and olfaction influence our perception, orientation and wayfinding, it is important to carry out further systematic studies, but also to expand the research field (e.g., clinical research). Therefore, a common categorization system of odors is needed. With our evaluation study we want to provide odor material with assignments on three emotional dimensions. Especially in the wayfinding context, visual cues (such as images) are often divided into emotional classes in advance to examine their effect on the wayfinding performance (e.g. Balaban et al. 2017, Palmiero & Piccardi 2017). The odor categories could thus enable us to systematically compare the different modalities such as vision, audition, and olfaction. One step further, a comparison on a neural level using functional Magnetic Resonance Imaging (fMRI) could provide valuable information about the underlying brain processes. Investigations could, for example, be made whether positively sensed landmarks (e.g., strawberry fields) that are communicated verbally would lead to a higher wayfinding performance than landmarks that are provided in the olfactory sense. The areas for which these findings could be relevant and where they can be used and integrated will be explained in the following discussion. Our example on wayfinding is only a small excerpt on what could be investigated with the help of a common classification system and useful odor material.

5. DISCUSSION

5.1. General discussion on crossmodal correspondences including the olfactory system

Charles Spence (2020a) pointed out that the interest of crossmodal correspondences experienced a rapid growth, even in the non-synaesthetic area. What has previously been called synesthesia, nowadays rather seems to be a multimodal view on our senses. His articles on the crossmodal relationships in the fields of food, arts, movies and many more are very important to demonstrate that such connections arise not only through the auditory and visual senses, but also through our gustatory sense and the sense of smell (Spence et al. 2010; Spence 2020a,b). Thus, he also highlights the difficulties and challenges that arise with multidimensional investigations (e.g., confounding variables, technical issues). It seems as if humans generally long for multidimensional and multimodal activity, because it is the way we experience our different environments in everyday life. This is also evident in the cinema industry. It hadn't taken long before it was possible to watch 3D movies not only in the movie theaters but also at home. Shortly after 3D movies came to the cinemas, electronic stores offered televisions with a 3D function for the private household (as a side note: this was already the case for surround sound). However, it was not only the 3D movies that were supposed to lure the guests into the cinema halls. Ideas to bring odors into the movies also existed (Spence 2020b). The main reason for including odors was the stench that accumulated with a large number of guests in the cinema. This recurring problem, however, was technically difficult to solve. Over time, it was no longer about covering up the stench, but more and more about creating a multidimensional attraction for the guests to get closer to a multisensory and holistic experience (Spence 2020b). The upcoming years will reveal whether we experience the same as with surround sound and 3D television: Maybe one day in the future it will be possible to buy an odor-releasing television.

With his articles on the crossmodal relationship between color and odors, Charles Spence sets the often-neglected olfactory sense into focus. However, it is important to consider the artistic side of the underestimated or even forgotten olfactory sense but also to encourage and strengthen scientific research (McGann 2017). To understand how human cognition really works, we need to move away from a unimodal understanding of the senses and start to examine more realistic multimodal investigations (especially in human spatial cognition and orientation; e.g., Hamburger 2020), because this is the way the human organism processes information. With our evaluation study we took a first step into this direction.

5.2. Discussion of the evaluation study with regards to wayfinding based on olfactory information

The correlations of our evaluation study demonstrate a highly positive relationship between arousal and dominance. In contrast, the correlations between valence and arousal as well as between valence and dominance turned out to be highly negative. Past studies already found similarities between the dimensions arousal and intensity as well as between arousal and dominance (Bensafi et al. 2002; Bestgen et al. 2015). Therefore, both dimensions could possibly cover the same odor quality, but as we have demonstrated here, only one of them is required to measure emotional values for odor categorization. Thus, the categorization of odors could be limited to two dimensions: valence and arousal (or valence and dominance). Based on the results, it is also possible to subdivide the dimensions in sub-categories and to assign odors to each sub-category for an even more specific odor classification and odor description. See Table 3 for an example on the dimension valence with the subcategories pleasant, unpleasant and neutral. This is important because, in case of odors, most of the time humans are only able to describe odors as “it smells like”, but no more specific information can be given (Cain 1979; Hamburger & Knauff 2019). In order to compare features of objects that are perceived on different modalities this finding could be of particular relevance (e.g., emotions that arise through the sound of traffic vs. the smell of car exhaust).

Table 3: Eight selected odors that could be classified into the categories pleasant, neutral, and unpleasant

Pleasant odors	**Neutral odors**	**Unpleasant odors**
Vanilla	Licorice	Perm liquid
Orange	Nail polish	Butyric acid
Apple	Spruce needle	Cigarette
Aftershave	Alcohol	Bull's pizzle
Tangerine	Cedarwood	Fish paste
Rose	Basil	Cabbage juice
Strawberry	Chlorine cleaner	Fish
Cinnamon	Caraway seed	Sulfur

With our evaluation study we hope to encourage and support systematic research on multimodal processing and representation. Our proposed categorization system based on emotions is surely not comprehensive, which has never been our aim, but rather an initial spark on how to possibly categorize odors for research.

Especially when it comes to diseases like Alzheimer's, the olfactory system and crossmodal correspondences need more exploration and therefore a good classification system. Odors show beneficial effects on the ability to produce past and future events in patients with Alzheimer's disease (Glachet & El Haj 2020). Particularly odors activate memories that are more emotional than memories triggered by any other modality (Herz 1998). This, and the knowledge about the successful use of odor cues as landmarks in wayfinding and navigation, could possibly be integrated in retirement homes (e.g., Van Campen 2014) as well as in clinical settings to support residents' orientation skills and to prevent their getting lost (Koutsoklenis & Papadopoulos 2011). For example, individual odor cues that trigger strong emotions could also be incorporated in retirement homes for elderly people to recognize their personal room. In landmark-based wayfinding research the effect of emotionally-laden landmarks has already been demonstrated for the visual sense (e.g., Balaban et al. 2017; Palmiero & Piccardi 2017). Thus, it is important to also transfer this research strain into the odor-processing domain.

Our study may therefore serve as a basis to find out whether certain emotional dimensions of smells can increase such cognitive abilities. Nonetheless, in addition to subjective assessments, objective ones should be used and included in future studies to further evaluate the emotional quality of odors. Psychophysical methods can, for instance, show connections between the pleasantness of odors and heart rate variations as well as between skin conductance and arousal (Bensafi et al. 2002).

On the basis of the target article by Charles Spence (2020a), we again would like to emphasize the importance of multimodal and cross-modal research (here mainly from a spatial cognition perspective) in order to reach a better understanding of the human brain, the nature of human decisions and behavior, and to further develop our different societies.

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