SMELLS, WELL-BEING, AND THE BUILT ENVIRONMENT

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SMELLS, WELL-BEING, AND THE BUILT ENVIRONMENT

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EDITORIAL
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Editorial: Smells, Well-Being, and the Built Environment

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Editorial of the Research Topic

Smells, Well-Being, and the Built Environment

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INTRODUCTION

From the pungent smells of Khari Baoli Spice Market in New Delhi to soothing smells of Mayfair Lavender Farm in south London, smells bring distinct identities to places and can connect people emotionally to the surroundings (Porteous, 1985). Smells are powerful to influence our feelings and recall memories of the past. Experiences of smells enrich our understanding of places and behavioral responses in places (Classen et al., 1994; Henshaw, 2014; Xiao, 2018) (**Figure 1**). In light of aromatherapies, spaces with therapeutic smells can potentially bring positive impacts on human wellbeing. In service spaces, smells are important environmental cues to delight people. In artistic practice, smells are curated to create an immersive experience to connect the audience and artists' inner worlds. Conversely smells in the form of odor pollution deriving from waste, traffic, plants, and food districts can compromise the quality of life of residents, and negatively affect our experience of places and lead to behavior changes (Henshaw et al., 2018).

In this Research Topic, we aimed to collect a range of contributions to understand the emotional and wellbeing responses resulting from smells in different public spaces (museums, highstreets, heritage buildings, food districts, neighborhoods, squares, etc.) to inform future spatial design and management. The articles in this Research Topic are presented according to three types of contributions: reviews and conceptual analyses, empirical research in fieldwork, in laboratory studies and technological applications.

REVIEWS AND CONCEPTUAL ANALYSES

Xiao et al. reviewed smellscape research studies conducted in the past 10 years to identify the challenges and related areas of future research, namely smell archives and databases, social justice within odor control and management, and research into advanced building materials. Spence reviewed the changing role of smells in the built environment from negative associations with sanitation to meaningful personal and cultural associations with memories and experiences which led to an evaluation of different approaches in examining the impact of smells on people's mood or wellbeing and the challenges of researching smells in the multi-sensory environment.

FIGURE 1 | Reading the smells in various sites in the Digbeth area in the city of Birmingham, UK.

Moving from the sick building sydrome to sick transport sydrome, Spence further reviewed the smells in transport environments as aesthetic and functional, and suggests challenges for future transportation to produce a more tangible vision to integrate smells in the design process to achieve the right balance of olfactory stimulation. Looking backwards to scented past, Bembibre and Strlič make the case for the need of knowledge exchange and interdisciplinary interpretation of findings in the field of olfactory heritage, providing an overview of methodological and museal studies as well as challenges associated with historical scent reconstruction.

EMPIRICAL RESEARCH - FIELDWORK

Pálsdóttir et al. carried out a field study with participants suffering from stress-related mental disorders and explored how they would describe their smellscape perception of a garden in the context of a nature-based rehabilitation intervention. In a different field study, de Groot investigated whether ambient scents could affect customers' subjective experience and spending behavior in an experiment with customers of a second-hand clothing store. The author concluded that for that to happen, the smellscape should have a meaningful link to the physical context. Masaoka et al. present the results of a study conducted to examine whether continuous odor stimuli associated with autobiographical memories could activate olfactory areas in the brain of older adults and assess whether this odor stimulation could have a protective effect against age-related cognitive decline.

EMPIRICAL RESEARCH - LABORATORY STUDIES AND TECHNOLOGICAL APPLICATIONS

Masaoka et al. investigated the potential protective effect from age-related cognitive decline of continuous odor stimuli associated with autobiographical memories and whether those could activate the above olfactory areas in older adults. Jiang et al. used blood pressure, pulse rate, EEG, POMS, and SD data to examine the odor-visual effects of the *Primula forbesii Franch* compared with the non-fragrant Primula malacoides Franch on the physiological and psychological state of Chinese female college students in the indoor environment. Courrèges et al. examined the correlations between odor and texture in users' perceptions of cosmetic creams cross-culturally, in laboratory conditions, using questionnaires, minimizing the impacts of branded messages from the packing and retail spaces. Amores et al. discussed the design and technical implementation of Essence- a smartphone-controlled wearable device that monitors users' EEG and real-time sleep staging algorithm to release scents to interact with users- in home-based sleep environments.

The articles included in this Research Topic represent a nice balance between the theoretical reviews, empirical studies and laboratory research, showing the vibrance and dynamic in this research field as well as new technological developments such as extended reality, emotional sensors (i.e. EEG, GSR) and odor monitoring devices. New insights are drawn into the theoretical frameworks to understand relationships between smells, wellbeing and emotions, behaviors and physiological aspects; methodological approaches to measure smell triggered emotions, experiences, and quality of life; practical explorations on the process and challenges of using smells to influence user experiences in the built environment.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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REVIEW
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Using Ambient Scent to Enhance Well-Being in the Multisensory Built Environment

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The majority of the world's population now lives an urban existence, spending as much as 95% of their lives indoors. The olfactory atmosphere in the built environment has been shown to exert a profound, if often unrecognized, influence over our mood and well-being. While the traditionally malodorous stench to be found indoors (i.e., prior to the invention of modern sanitation) has largely been eliminated in recent centuries, many of the outbreaks of sick-building syndrome that have been reported over the last half century have been linked to the presence of a strange smell in the environment. At the same time, however, there is also growing evidence that consumer behavior can be manipulated by the presence of pleasant ambient odors, while various aromatherapy scents are said to improve our mood and well-being. This Anglophone review focuses primarily on indoor western urban developed spaces. Importantly, the olfactory ambience constitutes but one component of the multisensory atmosphere and ambient odors interact with the visual, auditory, and haptic aspects of the built environment. Surprisingly, the majority of published studies that have deliberately chosen to combine ambient scent with other sensory interventions, such as, for example, music, have failed to increase store sales, or to enhance people's mood and/or well-being, as might have been expected. Such negative findings therefore stress the importance of considering multisensory congruency while, at the same time, also highlighting the potential dangers that may be associated with sensory overload when thinking about the effect of ambient smell on our well-being.

Keywords: smell, scent, built environment, multisensory, malodor, well-being, sensehacking

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INTRODUCTION

The proportion of the world's population living an urban existence continues to grow year-on-year. In fact, as of 2010, more people around the globe lived in cities than in rural areas, and by 2050, it has been estimated that 60% of the world's population will be urban (see UN-Habitat, 2010; United Nations Department of Economic and Social Affairs, 2018). Given that city dwellers spend something like 90–95% of their lives indoors (Ott and Roberts, 1998; Klepeis et al., 2001; Wargocki, 2001; Velux YouGov Report, 2018), the diet of multisensory stimulation that the majority of us are exposed to on a daily basis is likely very different and, most probably, much more monotonous (see Draycott, 2015, p. 60), than that we may have once evolved to deal with. Indeed, of America, Hall (1966, p. 45) once complained that the *"extensive use of deodorants and suppression of odors in public spaces results in an olfactory blandness and sameness that would be difficult to duplicate anywhere else in the world."* Louv (2005), meanwhile, has written of 'Nature Deficit Disorder.' Nevertheless, a growing body of empirical evidence now shows that the ambient smells of the built environment can still have a profound effect on us, no matter whether we are aware of them or not (see Sobel et al., 1999; Hummel et al., 2006), and very often the evidence suggests that we are not. While unpleasant, and often unidentified, odors can undoubtedly have a negative impact, a range of pleasant scents have also been shown to exert a positive effect on people's mood, their well-being, and their behavior/performance across a wide range of everyday situations (Spence, 2002, 2020e, 2021).

One of the problems, though, with olfactory perception is that we are visually dominant (see Hutmacher, 2019, for a recent review), and hence tend to give little consideration to the ambient smells that surround us (Jiang et al., 2016). Our tendency to focus our attention on what we see and hear means that we can often exhibit 'olfactory anosmia' to the presence of ambient scents (Forster and Spence, 2018; see also Sela and Sobel, 2010; and Spence, 2019, for a review). We also adapt rapidly to constant ambient odors, such as the smell of our own homes, only becoming aware of the distinctive building odor (or BO; McCooey, 2008) ourselves, as others presumably normally experience it, when, for instance, returning after a long trip away (Dalton and Wysocki, 1996; though see also Hummel et al., 2004). Here, though, it should be noted that while we adapt to ambient odors just as long as they are pleasant or neutral. We typically fail to adapt to constant unpleasant ambient odors though (Matheny and Honoré, 2011; Anon, 2018). We are very suggestible as far as the presence and/or pleasantness of ambient odors are concerned. For instance, Slosson (1899) conducted a now-classic demonstration in which the students in a university lecture theater were instructed to raise their hands on detecting an odor in the air that the professor had apparently released from a bottle at the front of the auditorium. Slosson (1899) reports how a slow wave of raised hands could be seen moving from the from to the back of the lecture theater, despite the fact that the professor had not actually released any scent at all (see also Knasko et al., 1990; van den Bergh et al., 2004).

The Ambient Smell of the Multisensory Environment

As we will see later, one cannot simply focus solely on the olfactory ambience, and ignore the visual, auditory, and even tactile aspects of the built environment. This is because the senses combine to influence our overall experience of, and response to, the multisensory atmosphere of the spaces in which we live, work, play, and sleep (Spence, 2002, 2021). And while a number of architectural theorists have, in recent decades, increasingly started to stress the importance of going beyond the purely visual aspects of design (e.g., Anderton, 1991; Pallasmaa, 1994, 1996, 2000; McCarthy, 1996; Malnar and Vodvarka, 2004; Eberhard, 2007; see also de Vries, 1997), they have not, as yet, fully recognized the multisensory interactions that drive our holistic response to the built environments in which we spend so much of our lives (see Spence, 2020e, for a recent review).

At the same time, however, a growing body of cognitive neuroscience research has revealed the various rules the brain uses in order to combine sensory inputs, sometimes doing so in what may at first appear to be surprising ways (Spence, 2021). Sometimes, for example, one sense dominates over the others in terms of determining our behavioral/perceptual response. Typically, vision tends to be the dominant sense (Hutmacher, 2019, for a review). At other times, though, weak unisensory cues (such as faint scents and sounds) can combine to give rise to a multisensory response that appears to be bigger than the sum of the parts (see Stein and Meredith, 1993; Lwin et al., 2010). However, should the senses provide conflicting, or incongruent, information, then the resulting gestalt can be hard for people to process, thus leading to a loss of processing fluency that is normally negatively valenced (e.g., Reber et al., 1998, 2004; Winkielman et al., 2003, 2015; Reber, 2012; Herrmann et al., 2013).

ELIMINATING MALODOR

It is widely accepted that the built environment would traditionally have smelled terrible (e.g., Bradley, 2015). Indeed, it has long been suggested that prior to the widespread introduction of flushing toilets (invented at the end of the 16th century, but only in widespread use in the latter-half of the 19th century; Stamp, 2014), there would have been unpleasant odors both within and without the home (e.g., Jütte, 2005; see Engen, 1982, pp. 135–136; and Corbett, 2006, on the universal Western dislike of toilet smells). Or, as Potter (1999, p. 169) once succinctly put it: *"There can be no question but that the urban air of the Roman empire stank."* The interesting thing to note, though, is how those living under what were presumably extremely smelly conditions (e.g., in Roman times) never appeared to comment on the stench, instead choosing to complain about the goaty/garlicky smell of those living in the countryside instead (Morley, 2015, p. 117). That said, the richest residents of Ancient Rome were known to pride themselves on spraying their toilets with perfume, and, on notable occasions, releasing perfumed doves to try and scent the air while feasting/dining, suggesting that they were at least aware that the normal smell of their homes was undesirable (see Bradley, 2015; Koloski-Ostrow, 2015).

Moving forward in time, Corbin (1986) has also highlighted the deodorization of everyday life that occurred in France during the 18th century (see also Payer, 1997; Jenner, 2000, 2011; Jütte, 2005, pp. 207–211; el-Khoury, 2006; Cockayne, 2007; Chiang, 2008, for a description of the similar changes that were taking place elsewhere in Europe and North America). Here, I should stress that this Anglophone review will focus primarily on indoor western urban developed spaces, as this is where the majority of the literature can be found. There has long been a belief in the connection between unhealthy foul odors and pestilence/disease (Jenner, 2011), with many people using nosegays and other fragrant handheld objects (e.g., pomanders) in order to try and help mask unpleasant environmental smells (Classen et al., 1994;

Brant, 2004). Early reports of the use of nosegays can be traced back at least as far as Ancient Roman times (Morley, 2015, p. 117). Meanwhile, according to Corbett (2006, p. 224), *"Regulation of air flows was crucial to Enlightenment architects. Buildings were designed so as to separate putrid exhalations from currents of fresh air, in the same way that fresh water had to be divided from used water. The degree of stench became the measure of the architect's efficiency."* Improvements in sanitation and personal hygiene gradually helped to reduce the malodor in city streets as well as in the home. Furthermore, the use of perfume also became cheaper and hence more widespread in Europe during the 19th century (see Jenner, 2011, p. 340).

Complaints and concerns about the malodor of the masses continued, especially in those locations where the great unwashed would sometimes congregate. So, for example, moving into the opening decades of the 20th century, there were various attempts to deal with the sweaty stench of unwashed bodies crammed together in the poorly ventilated early cinemas (see Spence, 2020d, for a review). In this case, the smell became so unbearable that regular 10 min airing breaks were introduced (Payer, 2001). On occasion, deodorant (Perolin, which had a naphthalene-like smell) was even sprayed out over the audience (Berg-Ganschow and Jacobsen, 1987). The widespread introduction of air-conditioning in cinemas in the 1930s would, though, presumably have helped address the problem of bodily malodor in warmer climates (see Arce, 1979, p. 104; Heschong, 1979).

Similar problems with malodor were likely to have affected early music hall, vaudeville, and possibly also theater/opera venues as well. Fragranced fountains were, on occasion, introduced into the lobbies of London theaters in the latter decades of the 19th century (Rimmel, 1865; Anon, 2020), presumably to help mask the smell of the audience. The underlying problem of malodor may not have been as bad in the theater as it was in the cinema, where multiple daily screenings would also have been the norm. What is more, cinemagoers were more likely to go straight from work, whereas those going to the single theater performance of the day would have been more likely to get changed (and possibly also washed) beforehand. Adding to the disparity between the cinema and theater at the start of the 20th century, one German engineer calculated that the latter had as much as three or four times more air to breathe per person (Richter, 1926).

Intriguingly, researchers in Germany recently assessed the composition of the 'audience emitted chemicals,' comprising various volatile organic compounds (VOCs), such as carbon dioxide and isoprene (C_5H_8), from cinemagoers' sweat and breathing, while watching a range of movies in a 250-seater cinema in Mainz (Williams et al., 2016). Data were collected from more than 9,500 people while watching one of 108 screenings of 16 different films. Changes in the chemical composition of the atmosphere given off by the audience could be linked to the on-screen action, with a significant increase in chemicals being associated with thrill and comedy scenes. Such results therefore hint at the possibility that volatile human chemosignals from the rest of the audience might actually contribute to the viewer's multisensory experience. The authors themselves go on to suggest that: "the chemical accompaniment generated by the audience has the potential to alter the viewer's perception of a film" (Williams et al., 2016, p. 7; see also de Groot et al., 2015). Rather more worryingly, though, thirdhand exposure to smoke has also been documented in cinemagoers when those who have been smoking enter the auditorium (Sheu et al., 2020).

Moving forward to the end of the 1930s, concern about the detrimental effects of so-called 'store odor' (SO) started to appear in trade publications directed at the owners of North American food stores (Anderson, 1939; see Mack, 2010, for a review). In this case, the smells that store managers were told to avoid were those associated with stale, rotten, or spoiled produce. Fresh smelling and deodorized is what the store owners were told to aim for instead (Cline, 1941). More recently, following the widespread ban on smoking, many venues, such as nightclubs, started to smell rather unpleasant – or rather, the unpleasant stale odor was no longer masked by the smoke (see Schifferstein et al., 2011). Recognizing the widespread problem of malodor in such enclosed spaces, Schifferstein et al. (2011) reported how the dance club experience could be enhanced simply by introducing a pleasant scent. They reported that the scents of orange, seawater, and peppermint were all equally efficacious, compared to a no scent baseline, in terms of enhancing dancing activity, people's evaluation of both the music and the evening, and the latter's mood (based on almost 850 completed questionnaires). Interesting in this regard, according to press reports (see White, 2011), the China White nightclub in London started using ambient scent to improve the ambience at around the same time. Four years earlier, in 2007, there were also press reports circulating that the Luminar chain of nightclubs and venues was pumping a rose scent through the air-conditioning to counteract the stale smell of sweat and beer (Anon, 2007).

While the problem of malodor in the built environment has seemingly been largely eliminated in the modern era (though see Schiffman et al., 1995; Rinck et al., 2011), one nevertheless still comes across occasional reports of problematic ambient smells. For example, a citrus scent was introduced onto the underground carriages in Vienna recently in order to address growing complaints concerning the sweaty malodor associated with passengers traveling during the summertime (Walker, 2019). It is unclear whether the deliberate scenting of other public spaces, such as the much commented on Barclays Center arena in Brooklyn, NY, United States, home of the Brooklyn Nets, on its opening in 2013, might not also have been introduced in order to cover up the sweaty smell of the fans (Albrecht, 2013; Doll, 2013; Martinez, 2013). At the same time, however, it is worth noting that problems have sometimes resulted from the synthetic scenting of enclosed spaces, such as the underground in the United Kingdom (Jury, 2002).

On the rare occasions nowadays where malodor intrudes into our olfactory experience in the built environment, it can exert a significant impact on both our well-being and behavior. For example, writing in The New York Times, Pacelle (1992) noted how many people refuse to check in, if they detect a strange smell in the hotel lobby. The growing awareness of such olfactory problems presumably helping to explain the rise of signature scents that are nowadays often to be experienced in the lobbies of many hotel chains (Goodwin, 2006; Stellin, 2007; Kaufman, 2017). Meanwhile, in 2016, Virgin Australia had a problem when some of its passengers started falling sick at what they interpreted as the smell of sweaty socks, but which was actually the parmesan cheese sandwiches that they had started selling (Buaya, 2016). Note that the same chemical isovaleric acid is found in both, hence explaining why this is such a popular compound for research into the cognitive modulation of olfactory perception (e.g., Herz and von Clef, 2001; De Araujo et al., 2005). Laboratory research by Rotton (1983) has demonstrated the affective and cognitive impact of ambient malodor released into a testing room (see also Rotton et al., 1978; Weber and Heuberger, 2008, Experiment 5).

Interim Summary

While efforts to deodorize, or else mask, unpleasant ambient odors in the built environment have been largely successful (Stenslund, 2015), the ensuing total absence of smell in many contemporary environments, such as the art gallery, and other cultural institutions, has led some commentators to complain. For example, Drobnick (2005) has criticized the 'anosmic cube'[1] mentality that has taken hold in many public spaces (see also Byatt, 2003). Oftentimes, it would appear that it is people's beliefs about the environmental source of an ambient odor that is key to determining their responses, rather than necessarily the nature of the physical stimulus itself (Dalton, 1996).

While the built environment was likely much smellier in former times than it is today, people may simply have either adapted, or else habituated, to the ever-present malodor, meaning that it may not have smelled as bad to them as it would to us today if we were exposed to the same stench. As Engen (1982, p. 169) notes: *"Odor preferences are acquired by learning to adapt to the environment."* What is more, he also argues that people would once presumably have habituated to what now we would consider a terrible smell (see Engen, 1982, pp. 63–77).

SICK-BUILDING SYNDROME

Sick-building syndrome (SBS) is the name given to illness caused by air pollution in the built environment (Rothman and Weintraub, 1995; Joshi, 2008; Sahlberg, 2012), possibly caused by the build-up of VOCs (Love, 2018). According to Joshi, the symptoms include: Headache, dizziness, nausea, eye, nose or throat irritation, dry cough, dry or itching skin, difficulty in concentrating, fatigue, enhanced sensitivity to odors, hoarseness of voice, allergies, cold, flu-like symptoms, increased incidence of asthma attacks and even personality changes (see also Anon, 2000). In the context of the present special issue (*Smell, Well-Being, and the Built Environment*), it is interesting to note how many of the large outbreaks of SBS in the 1980s were linked to the presence of an unfamiliar smell in closed office buildings with little natural ventilation (see also Wargocki et al., 2000).

For instance, back in June 1986, more that 12% of the workforce of 2,500 people working at the Harry S. Truman State Office Building in Missouri came down with the symptoms of SBS over a 3-day period (Donnell et al., 1989). The symptoms presented by a number of the office workers, including headaches, mucosal irritation, fatigue, dizziness and an odd taste, were so severe they had to be taken to the local hospital for emergency treatment. While a thorough examination of the building itself subsequently failed to uncover any particular toxic airborne pollutants that might have triggered the outbreak, the symptoms of SBS were, in the majority of cases, preceded by the perception of unusual odors and inadequate airflow in the building. It has also been suggested that the energy crisis in the 1970s may also have been partly to blame, as that tended to result in lower ventilation standards. According to Donnell et al. (1989), these complaints regarding the presence of a strange odors may well have heightened the building employees' perception of poor air quality. This, in turn, may then have led to an epidemic anxiety state (mass hysteria) resulting in the outbreak itself (Faust and Brilliant, 1981; Rothman and Weintraub, 1995). Those workers suffering from SBS were more than twice as likely to have noticed a particular odor in the office before the onset of their symptoms than those who were unaffected by the outbreak.

To give a sense of the potential scale of the problem, Woods (1989) estimated that 30–70 million people in the United States alone are exposed to offices that manifest SBS. As such, anything (and everything) that can be done to reduce the symptoms associated with this reaction to the indoor environment will likely have a beneficial effect on the health and well-being of many office workers (Finnegan et al., 1984). Those who believe that it is the neglect of the olfactory aspects of the interior environments that may be at least partly responsibly for SBS, have argued that improving indoor air quality might therefore provide an effective means of helping to alleviate the symptoms (e.g., Guieysse et al., 2008). Consistent with such a view, researchers have demonstrated that both increased ventilation rates, and reduced air pollution, can exert a significant influence over the subjective well-being, SBS symptoms, and performance (e.g., typing speed) of female office workers (Wargocki et al., 1999, 2000).

At the same time, however, it is perhaps also worth bearing in mind here that reports of SBS in the office environment would appear to have declined somewhat in recent decades, perhaps suggesting (at least according to certain commentators) that commercial building design/ventilation has improved as a result of the earlier outbreaks. The indoor smoking bans introduced in many countries are also likely to have resulted in improved indoor air quality (though see Sheu et al., 2020). A more pessimistic take, though, would instead be to suggest that many of the symptoms of SBS (which is not, it should be noted, a recognized illness; Anon, 2000) are now so ubiquitous in society today that they no longer merit any special mention (see also Magnavita, 2015; Higham, 2019; Kim et al., 2019).

Over the years, there have been a number of reports suggesting that indoor plants might provide an effective means of helping to absorb the VOCs (Wolkoff et al., 2006) that tend to build up indoors (e.g., Brown et al., 1994; Guieysse et al., 2008), as well as possibly providing a range of other

[1] This referencing Brian O'Doherty's (1999, 2009) earlier discussion of the 'white cube' mentality in art galleries.

psychological benefits to the occupants of office buildings (Bringslimark et al., 2009; Nieuwenhuis et al., 2014). However, the latest research suggests that the number of plants that would be needed to exert a significant effect on VOCs is realistically too large for all but the Amazon HQs of this world to achieve (Walker, 2000; Cummings and Waring, 2020). Amazon HQ, known as The Spheres, and situated in downtown Seattle, consists of a biome of three huge plant-filled domes (Hartmans, 2018), housing an estimated 40,000 plants, encompassing more than 400 different species (see also Everett, 2019).

At the same time, however, there continue to be many reports of Sick Home Syndrome (SHS), especially amongst those living in cooler Northern climates, such as in Scandinavian countries (e.g., Finland; Runeson-Broberg and Norbäck, 2013; Love, 2018). In the latter case, it is the damp/mold in the home environment that is thought to be responsible. That said, there continues to be some uncertainty as to whether the symptoms of SBS should be attributed to airborne pollutants, or may instead be better understood as a psychosomatic response to a particular environmental atmosphere (see Redlich et al., 1997; Shusterman, 2001; Fletcher, 2005; Love, 2018). Indeed, one of the psychological factors that has been suggested to be relevant here concerns the feeling of a lack of control over one's multisensory environment that many of those working in ventilated buildings experience, especially when the windows cannot be opened manually (Faust and Brilliant, 1981).

A number of researchers now prefer to use the less pejorative term building-related symptoms (BRS) instead of SBS (Niemelä et al., 2006). At the same time, however, it should be recognized that some people also suffer from multiple chemical sensitivity (MCS), otherwise known as idiopathic environmental intolerance (IEI) that may well be triggered by the presence of ambient volatiles chemicals (Shusterman, 1992; IPCS, 1996; Van den Bergh et al., 2001; Bornschein et al., 2002; Fletcher, 2005). Though, as Fletcher (2005, p. 380) notes, while the majority of adverse reactions do indeed appear to be triggered by the presence of ambient smells, some episodes may also be triggered by foods and/or by physical contact with synthetic materials as well (see also Dager et al., 1987). MCS is characterized by the presence of a wide range of non-specific symptoms, such as fatigue and weakness, cognitive difficulties (concentration and memory), dizziness, pounding heart, shortness of breath, anxiety, headache, and muscle tension (notice here the overlap with the symptoms of SBS), in response to the presence of (often odorous) chemical substances present at concentrations below those known to cause harmful effects in the population.

Interim Summary

Sick-building syndrome and SHS (not to mention BRS, MCS, and IEI) are amongst the most noticeable negative influences of poor indoor air quality on our well-being. Several of these conditions are often preceded by the inhabitants' awareness of a strange smell in the environment. While the levels of certain carcinogenic chemicals in buildings may well be higher than is desirable (Nazaroff and Weschler, 2004), more often than not the deleterious effects of ambient smell on people's well-being tend to result from a process of associative learning with an arbitrary odorant. Indeed, associative learning has often been documented for olfactory stimuli, whereby an ambient smell takes on negative associations (Herz, 2007), possibly due to unconscious odor conditioning (Kirk-Smith et al., 1983; though see Black and Smith, 1994; Epple and Herz, 1999; Zucco et al., 2009). This is where a scent can be conditioned (after being paired with an emotionally meaningful task, say) through exposure to be either positive or negative, despite the fact that the person is unaware of the odor having been presented. Subsequent exposure to the odor can then elicit a conditioned effect on a person's mood. Evaluative olfactory conditioning is, by now, a well-studied phenomenon (Engen, 1988; Zucco, 2012). The negative consequences of exposure to certain ambient volatile stimuli that has been linked to cases of MCS is also thought to reflect learning (i.e., Pavlovian conditioning; Van den Bergh et al., 2001). It is precisely this kind of odor conditioning that has led some to suggest that workers should make sure to change the ambient odor after a stressful meeting in order to try and avoid such negative ambient smell-related effects (Spence, 2002). In some extreme cases, specific odors have even been shown to trigger post-traumatic stress disorder (e.g., Kline and Rausch, 1985; Vermetten and Bremner, 2003).

STRESSFUL SMELLS

The associative nature of the emotions that are attached by people to scent means that those smells that we tend to link to stressful/unpleasant healthcare situations, such as the eugenol (i.e., clove) smell of a visit to the dentist's surgery, can all too easily end-up making us stressed (Robin et al., 1998, 1999). Back in the 1960s, one commentator was already recommending that hospitals experiment with 'odor therapy' by blowing pleasant scents into the wards so as to promote feelings of security and well-being amongst the patients (Hamilton, 1966; Stenslund, 2015, for a contemporary take on hospitals and ambient smell). There has also been a suggestion that certain ambient scents can also facilitate wound healing (Busse et al., 2014).

The research shows that simply changing the ambient aroma (e.g., replacing the clove smell with a citrus scent instead), can sometimes help to reduce the physiological signs of stress (Lehrner et al., 2000, 2005). Note, though, that not everyone has found the smell of citrus (or apple) to reduce anticipatory stress in patients waiting for treatment in the dental surgery (Toet et al., 2010). Here, though, it is worth noting that the citrus scent would itself eventually presumably also come to elicit stress should that become the standard smell that a person associates with a trip to the dentist. As such, it might be argued that healthcare establishments really ought to change their scent on a regular basis, say once every year or so, to avoid too many of their customers from building up an undesirable association between the stress of a visit and a particular ambient smell (Spence, 2021). At the same time, however, such a dynamic approach to scenting the healthcare environment does not leave much scope for establishing a healthcare brand's signature scent, this is something that is becoming increasingly important to private healthcare providers working in what has become an increasingly competitive marketplace in a number of countries (see Goldkuhl and Styvén, 2007; Naja et al., 2014).

Over the years, researchers have also investigated the use of fragrance to help reduce stress during other anxiety-inducing medical procedures (e.g., Graham et al., 2003; Braden et al., 2009; Redd et al., 2009; Kritsidima et al., 2010; Ghiasi et al., 2019). There is also a growing body of research to suggest that 'sweet-smelling' ambient scents can help people deal a little better with pain (e.g., Prescott and Wilkie, 2007; though see also Marchand and Arsenault, 2002; Martin, 2006).[2] Researchers have also demonstrated how the pleasantness of interpersonal touch can be modulated by the presence of either a pleasant or disgusting ambient scent (e.g., Croy et al., 2015, 2016).

Perhaps hinting at the potential for well-being interventions in this area, at least one patent has been awarded relating to the stress-relieving properties of certain essential oils either when inhaled or else applied transdermally (Warren et al., 1987). Summarizing almost a decade of research on the mood benefits of fragrance for IFF (the latter, one of the world's largest fragrance houses), Warren and Warrenburg (1993, p. 9) arrived at the following surprisingly modest conclusions: *"1. Fragrance-evoked mood changes are small, but beneficial to our well-being. 2. Fragrance can be used to reduce the stress response in humans, but its physiological effects on a non-stressed subject are minimal and difficult to measure. 3. Measurement of fragrance-evoked mood change by psychological methods is feasible, and yields intriguing results."* Warren and Warrenburg ended-up concluding their review by suggesting that: *"We believe that further improvements in our measurement techniques, and a better understanding of the mood changes evoked by specific perfumery ingredients will allow for the development of more impactful mood-altering fragrances"* (Warren and Warrenburg, 1993, p. 16).

USING AMBIENT SCENT TO ENHANCE WELL-BEING

It has long been recognized that ambient odors can influence our well-being (e.g., Montaigne, 1993; Hosey, 2013). While, as we have just seen, undesirable, and negatively valenced, malodors tend to be associated with negative outcomes on the health, well-being, and mood of those who are exposed to them, it is important to note that pleasant ambient scents can also be used to help improve our mood and well-being (e.g., Spence, 2003; Glass et al., 2014; Glass and Heuberger, 2016; Haehner et al., 2017). Here, one can think of everything from the use of aromatherapy scents (see Spence, 2003; Herz, 2009; Perry and Perry, 2018, for reviews) through to the recent trend to deliver well-being flower bouquets (Carlyle, 2020). The latter supposedly not only looking beautiful but also exerting a positive influence over the olfactory environment. Scented candles have also become increasingly popular (Rose, 2019), though they may not be without their own risks in terms of the release of pollutants into the atmosphere (e.g., Lau et al., 1997; Lambert, 2012; though see also Petry et al., 2014, for the suggestion that concerns may, in fact, be unwarranted). Relevant here, the Human Ecology Action League reported that one in five people in the United States are adversely affected by exposure to synthetic fragrances in perfumes and cleaning products (Kosta, 1998). It is interesting to note how many of the scents that have been reported to improve our well-being are related to nature (e.g., plants and flowers; Warren and Warrenburg, 1993; Weber and Heuberger, 2008; Chen, 2009; Jo et al., 2013; Glass et al., 2014; Darabia and Mirabi, 2018). The latter observation, then, might link to evolutionary psychology, i.e., the biophilic account that has been put forward in order to help explain our attraction to green scenes of nature that incorporate water (cf. Wilson, 1984; Grinde and Patil, 2009; Steinwald et al., 2014; Gillis and Gatersleben, 2015; McMahan and Estes, 2015).

Researchers have shown that ambient urban odors are capable of evoking basic emotions in people of different ages (Weber and Heuberger, 2011; Glass et al., 2014; Glass and Heuberger, 2016). For instance, in one study, Glass et al. (2014) demonstrated that exposure to a range of typical ambient urban odors (synthetic mixtures representing the odors of disinfectant, candles/bees wax, summer air, burnt smell, vomit, and a musty smell) gave rise to significant changes in autonomic activity (e.g., in the electrodermal response). And, in one of the larger of the more recent studies of the impact of pleasant ambient fragrance, Haehner et al. (2017) conducted a single-blinded between-participants experimental study assessing the effect of short-term exposure to room fragrance on people's attention, anxiety, and mood.

The 200 Germans who took part in the latter study spent around 30 min completing a number of standardized psychological tests (of attention, anxiety, and mood) in a room that had a grapefruit aroma, a combined lemon-lime-orange aroma, a nature-identical synthetic rose aroma, or else had been left unfragranced. The scents consisted of essential oils for the fruit aromas and nature-identical synthetic rose odor dispensed by a commercially available room-fragrancing device. The results revealed no main effect of room fragrance on any of the measures. That said, separating the results by sex revealed that the grapefruit scent appeared to have a slightly more positive effect on the male participants. Normally, it is women who tend to be more influenced by ambient odors than men (e.g., see Marchand and Arsenault, 2002). The latter showed something of a negative response (i.e., lower attention, higher anxiety, and impaired mood) to the rose-scented room. At the same time, however, it should be noted that the effects on mood, anxiety, and attention in men in this study were only marginally significant, and, what is more, failed to survive the correction for multiple comparisons.

Furthermore, the between-participants nature of Haehner et al.'s (2017) experimental design makes interpretation of the results of this particular study somewhat more challenging, because of the possibility of underlying between-groups

[2]Of course, associative learning is likely also responsible for certain odors being rated as smelling sweet in the first place (Stevenson and Boakes, 2004).

differences. Unfortunately, the participants were not asked what they thought about the fragrance, nor even whether they had detected it (cf. Forster and Spence, 2018), nor how intense they found it to be. Moreover, no calculation was reported to assess whether the researchers in question had themselves collected a sufficiently large sample size in order to detect any significant between-group differences should they have been present. On the other hand, as Haehner et al. (2017) themselves noted, many of the earlier studies that have reported a significant effect of aromatherapy fragrance on people's mood, well-being, and performance have tended to be statistically underpowered (by contemporary standards) and were often not blinded, hence raising a different set of concerns about the robustness of the results reported.

Interim Summary

Taken together, the most parsimonious conclusion to draw on the basis of the literature that has been published to date is that while a significant (and typically positive) impact of ambient fragrancing on human well-being has often been reported, it is by no means guaranteed to occur. Furthermore, as yet, there isn't a clear sense of what the key factors determining whether an effect of ambient scent will be demonstrated or not (see also Warren and Warrenburg, 1993; Goel and Grasso, 2004). Potentially relevant here is the fact that our response to an ambient fragrance is likely to depend on its intensity, whether we personally happen to like it, not to mention our perception, or belief, about it being synthetic/artificial versus natural (e.g., Herz, 2000; Wilkins et al., 2007; Baccarani et al., 2020). People's belief about the efficacy of ambient scent, and its likely effect(s), also seems to play a role too (Torii et al., 1988; Lorig and Roberts, 1990; Campenni et al., 2004; Moss et al., 2006). This observation has led some researchers to suggest that the effect of pleasant ambient scents may be a kind of placebo effect. At the same time, however, it is clear that conditioned associations resulting from prior exposure also represent an important factor determining the effect of specific odorants (Robin et al., 1999). The duration of people's exposure to ambient fragrance may also be relevant, varying between 30 min in Haehner et al.'s (2017) study (essentially reporting null results) and 2 h made up of 30 min exposure periods spread out over the course of a day in Sakamoto et al.'s (2005) study, where significant effects of scent were reported. And finally, it is perhaps also worth bearing in mind Warren and Warrenburg's (1993, p. 12) earlier observation that: *"When a normal subject is at rest, the effects of odors on the peripheral nervous system appear to be minimal and difficult to measure."*

HOME AND OFFICE SMELLS

Two of the locations in the built environment where we spend most of our time are the home and work, and it is to these that we will turn next. As will become clear in this section, the type of odorant that might be most appropriate in terms of enhancing our well-being depends on the particular circumstances and state of mind that we find ourselves in. What is more, a number of the odorants that we are exposed to on a regular basis are not necessarily related to ambient fragrances (such as air fresheners) but are perhaps better classified as incidental building odors. Baudelaire once described the smell of a room as 'the soul of the apartment' (Corbin, 1986, p. 169, and there is certainly no shortage of advice out there concerning the best scents to sell a (new) home; Demetros, 1997; Anon, 2014; Ebert, 2018). At the same time, however, the smell of cigarette smoke and pets, and here we are talking about dogs not goldfish, can be particularly off-putting, potentially reducing sale prices by as much as 10% according to the CEO of one Florida estate agency (McCooey, 2008; Anon, 2014). At the very upper end of the housing market, the lucky owners of one high-end apartment commissioned synesthetic scent-designer Dawn Goldsworthy to create a bespoke scent especially for the $29 million new Miami condo back in 2018. The idea was for this fragrance to be dispersed through the air conditioning, thus giving their property a truly unique olfactory identity (Schroeder, 2018).

At the same time, however, there is little doubting that specific incidental ambient odors associated with place can be incredibly evocative too, as anecdotally noted by Pallasmaa (1994, p. 32) when he wrote that: *"The strongest memory of a space is often its odor; I cannot remember the appearance of the door to my grandfather's farm-house from my early childhood, but I do remember the resistance of its weight, the patina of its wood surface scarred by a half century of use, and I recall especially the scent of home that hit my face as an invisible wall behind the door."* Once again, though, note how it is the personal associations that are formed with the smell, rather than the particular smell itself, that are key to understanding ambient smell's emotional impact on someone (Reid et al., 2015; see also Herz, 2016, for a review).

Traditionally, the home would have been the place where the majority of us would have been exposed to food and cooking aromas. The basement kitchens that were such a common feature of Victorian-era homes in the United Kingdom released food cooking aromas throughout the house. Concerned by the regular exposure to cooking smells, the architect J. J. Stevenson wrote in 1888 that: *"unless the kitchen itself is ventilated so that all smells and vapors pass immediately away, they are sure to get into the house, greeting us with their sickly odor in the halls and passages, and finding their way to the topmost bedroom, notwithstanding all contrivances of swing doors and crooked passages"* (Stevenson, 1888). The famous Swiss architect Le Corbusier tackled this particular problem in the house he designed in Poissy, just outside Paris by deliberately placing the kitchen on the roof to avoid scents from the kitchen from permeating the rest of the house (Steel, 2008).

One of the most frequently studied effects of ambient fragrance is in terms of its alerting/relaxing function. There has been growing interest in the influence of fragrance on the performance of workers. In one Japanese car factory, for example, a significant increase in productivity (together with a concomitant reduction in accidents) was reported when a lemon scent was introduced onto the factory floor (see Shimuzu Corporation, 1988; Knasko, 1992; Barker et al., 2003; Zoladz and Raudenbush, 2005; Herz, 2007; Shepherd, 2010). Positive results of odor administration on people's performance have not always been reported though (e.g., see Marx, 1990; Gaygen and Hedge, 2009). An increase in positive affect is one of the mechanisms by which ambient scent affects us (Baron and Thomley, 1994), though it is by no means the only one.

A number of researchers have argued that lavender can sometimes be used to enhance productivity by reducing stress (Ludvigson and Rottman, 1989; Motomura et al., 2001; Sakamoto et al., 2005). At the same time, however, lavender has long been mentioned in plays and literature as a scent that is commonly associated with sleep (Kirk-Smith, 2003). In fact, there is now a broad range of research demonstrating beneficial effect on sleep quality of exposure to ambient lavender scent across the lifespan (e.g., Burns et al., 2002; Field et al., 2008). That said, lavender has also been used to improve mood (Goel and Grasso, 2004). Here, though, it should be born in mind that there are at least 45 species and 450 varieties of lavender according to the United States Lavender Growers Association website, and often it is unclear which species of lavender has been used in many of the academic studies, nor is it clear how much of a difference this might make (Spence, 2003).

There is a sense in which different scents might be appropriate for different locations in the home. Given that we spend something like a third of our lives asleep (or at least trying to; see Walker, 2018), then those scents that can help us to sleep are potentially very important. At other times, an alerting scent may be more appropriate (Warm et al., 1991; Diego et al., 1998; Moss et al., 2003). In this regard, peppermint odor has often been shown to be an effective alerting smell (Warm et al., 1991; Ho and Spence, 2005; Moss et al., 2008). At the same time, however, it is worth noting that expectancy/belief regarding the efficacy of certain essential oils also appears to modulate the effect that they actually have on people (Moss et al., 2006).

As well as positively influencing our mood and emotion, it has been suggested that certain semantically meaningful scents are also capable of priming specific behaviors (e.g., Baron, 1990). So, for example, according to the results of a couple of published studies, people engage in significantly more cleaning, and are more likely to pick up rubbish, with a citrus cleaning scent in the air (Holland et al., 2005; De Lange et al., 2012; though see also Toet et al., 2013, for evidence suggesting that scents may have somewhat different effects in virtual environments). Meanwhile, other researchers have reported that the presence of 'clean' ambient scents (a spray of citrus-scented Windex) can also promote reciprocity (in a one-shot anonymous trust game) and charitable behavior (e.g., as assessed by the intention to volunteer; Liljenquist et al., 2010). At the same time, however, the robustness of a number of these smell-induced behavioral priming effects have also been questioned by researchers (Smeets and Dijksterhuis, 2014; see also Doyen et al., 2012).

By now, a wide variety of largely aromatherapy odorants have been reported to have beneficial effects. It remains somewhat uncertain though as to whether the beneficial effects of aromatherapy scents can be explained by priming effects, based on associative learning, as in the case of the clean citrus scents mentioned above (see Herz, 2009), versus via a more direct (i.e., less cognitively mediated) physiological route (cf. Harada et al., 2018). While the associative learning account of ambient odor's influence on us undoubtedly explains much of the data, there is nevertheless some evidence to suggest that certain odors may have a more direct physiological effect (Saeki and Shiohara, 2001).

While the scent of air fresheners and cleaning products have been reported to have a positive effect on various aspects of behavior, mood, and well-being (Hosey, 2013), it is worth remembering that the airborne chemicals, and/or the result of their reaction with other contaminants that may be present in the indoor environment, may themselves constitute a form of air pollution (see Nazaroff and Weschler, 2004, for a review of the adverse health consequences associated with inhaling the chemicals that can be found in cleaning products; and Senger, 2011, on the sensitivity to perfume scent). It is important to note that while the building odor of our own home is one of the ambient smells that we are likely to be exposed to most frequently, it is also one of the smells that we are least likely to be aware of (see Dalton and Wysocki, 1996; McCooey, 2008; see also Našel et al., 1994).

SIGNATURE SCENTS: LEADING THE CONSUMER BY THE NOSE

In recent years, there has been growing awareness of the marketing effectiveness of various pleasant scents, especially food scents, thus perhaps helping to explain why it is that so many of us are now exposed to more food aromas in the built environment than perhaps ever before (see Spence, 2015, for a review). In the context of the shopping mall, it has even been suggested that the owners of food chains such as Cinnabon etc, deliberately search out locations for their stores that are close to the bottom of enclosed stairwells, thus ensuring that their appealing smells reach more of their potential customers' noses (see Nassauer, 2014, for a review). At the same time, however, a number of other traditional odorless environments have, in recent times, also acquired a food scent. Just think, for example, about how public spaces, such as book stores and train stations, now have the seemingly ubiquitous smell of coffee (Luttinger and Dicum, 2006, p. 164). Even clothing stores such as Uniqlo and Club Monaco have been getting in on the act (see Oldenburg, 1989, p. 39; Cheng, 2014).

There have even been reports of Japanese building firms deliberately releasing food scents through the air-conditioning of the building at different times on different floors, in order to help manage the flow of people to the restricted capacity canteen (Spence, 2002; Herz, 2007). Given the evidence showing that food smells influence our food choices (Gaillet-Torrent et al., 2013, 2014), one might therefore worry about whether we are all being 'nudged' by deliberate 'scent-sory' marketing strategies into eating more than we otherwise might (White, 2011; Spence, 2015)? The ubiquity of ambient food smells, and the unhealthy impact that such smells might be having on our waistlines, have led some commentators to suggest that many of us should perhaps be wearing inserts in our nostrils to help reduce our exposure to ambient food smells, and thus help fight olfactory temptation[3] (e.g., Best, 2018; though see also Biswas and Szocs, 2019).

There has long been awareness of the marketing potential associated with various non-food smells (Mitchell et al., 1964; Miller, 1991, 1993; Hunter, 1995; Goldkuhl and Styvén, 2007), and commercial interest in scent marketing would appear to be on the rise (Trivedi, 2006). In the best case scenario, an ambient scent is deliberately introduced that happens to be both distinctive, so that it can be recognized by the consumer, and hence be associated with a specific brand (this is what is known as a signature scent; Minsky et al., 2018). At the same time, however, it should also deliver a functional benefit as well – be that in terms of improving the customers' mood or increasing sales (see Spence et al., 2014, for a review). And while much of the research in scent marketing thus far has been led by those chains whose products naturally smell,[4] the approach has, in recent years, been extended to a number of other product categories, where the products themselves do not necessarily have their own distinctive scent (think here only of white goods and consumer electronics; e.g., Trivedi, 2006).

At the present time, there is a large literature demonstrating the impact of scent on various aspects of shopper behavior (e.g., Gulas and Bloch, 1995; Spangenberg et al., 1996, 2006; Fiore et al., 2000; Chebat and Michon, 2003; Davies et al., 2003; Milotic, 2003; Ward et al., 2007; Orth and Bourrain, 2008; Bradford and Desrochers, 2009; Morrison et al., 2011; Vinitzky and Mazursky, 2011; Teller and Dennis, 2012; Doucé et al., 2013; Madzharov et al., 2015; Rimkute et al., 2016; see Gilbert, 2008, Chapter 9: "Zombies at the mall," for a review). Although there is simply not the space to review all of this research here, it should be recognized that there are likely to be a range of different mechanisms at play in terms of helping to explain the effects of the presence of an appealing/pleasant ambient scent on consumers in commercial and public spaces. On the one hand, ambient smells can influence people's approach-avoidance behavior (e.g., Pacelle, 1992). Relevant here, it has been reported that consumers find simpler scents easier to process than they do more complex scents, and that this may exert an influence over their approach behavior (Herrmann et al., 2013). Though note that defining what, exactly, is meant by 'complex' in this context, is by no means a simple matter to ascertain (see Spence and Wang, 2018).

As we have seen already, ambient scent sometimes influences people's mood and arousal as well (Leenders et al., 2019), and can apparently even enhance pro-social behaviors (Baron, 1997a,b) not to mention social interaction (Zemke and Shoemaker, 2007, 2008). Thereafter, semantic associations with scent, including with signature scents (Danziger, 2017; Minsky et al., 2018), may become important, priming certain thoughts, associations, and even behaviors (i.e., think of it as a kind of olfactory branding effect). Finally, there are also the more-or-less idiosyncratic individual associations that many of us form with specific scents (Pallasmaa, 1994; Van Campen, 2014; Herz, 2016). There are, in other words, multiple routes to the impact of ambient smells on consumer behavior and well-being. At the same time, however, one also needs to consider the ethical implications of ambient scenting (see also Hirsch, 1995, for one particularly worrying example; Spence, 2020c). Ultimately, though, it can be argued that only limited progress will be made in understanding the impact of ambient scent on well-being, or anything else (e.g., store sales), by considering the sense of smell in isolation from the other senses.

SMELL IN THE MULTISENSORY BUILT ENVIRONMENT

Our well-being (not to mention our behavior) is determined not just by the olfactory ambience, but rather by our response to the total multisensory environment (Spence et al., 2014). As such, it can be argued that it makes little sense to focus solely on ambient scent when considering the impact of the sensory aspects of the built environment on well-being. After all, the senses presumably interact to determine our perception of the environment/atmosphere (Böhme, 2019), just as they do in many other aspects of our everyday perception (Spence, 2020e, 2021). Architectural theorists are increasingly coming to recognize this. Just take Malnar (2017, p. 146), who has noted that: *"The point of immersing people within an environment is to activate the full range of the senses."* Meanwhile, some years earlier, Pallasmaa (2000, p. 78) made a similar point, writing that: *"Every significant experience of architecture is multi-sensory; qualities of matter, space and scale are measured by the eye, ear, nose, skin, tongue, skeleton and muscle."* (see also Feld, 1996, p. 99).

The problem, though, is that, as yet, there has been relatively little research directed at the question of how atmospheric/environmental multisensory cues actually interact to influence our perception, behavior, mood, and well-being (Verissimo and Pereira, 2013; see also Velasco et al., 2014). Mattila and Wirtz (2001, pp. 273–274) drew attention to this lacuna two decades ago, when they wrote that: *"Past studies have examined the effects of individual pleasant stimuli such as music, color or scent on consumer behavior, but have failed to examine how these stimuli might interact."* To date, only a relatively small number of studies have directly studied the influence of combined ambient/atmospheric cues on people's perception, feelings, and/or behavior, with much of this multisensory research having been conducted in the field of sensory marketing, which is where we turn first.

In one influential early study, Mattila and Wirtz (2001) manipulated the olfactory environment (no scent, a low arousal scent [lavender], or a high arousal scent [grapefruit]) while simultaneously manipulating the presence of music (no music, low arousal slow-tempo music, or high arousal fast tempo music) in a physical retail outlet. Intriguingly, when the scent and music were congruent in terms of their arousal potential, the customers (or, at least the 270 of them who agreed to be interviewed) rated the store environment more positively,

[3]https://noznoz.com/

[4]Just think about how the distinctive smell of Lush cosmetics can often be detected many meters down the street. In this case the company does not package many of their products, hence meaning that it is the authentic smell of their products that is being detailed in this case.

exhibited higher levels of approach and impulse buying behavior, and expressed more satisfaction.[5] It is unclear on the basis of Mattila and Wirtz's results whether the effects of a novel combination of grapefruit scent and high-tempo music (which was the congruent combination of stimuli that appeared to be driving the effects reported) might soon wear off. As yet, I am not aware of anyone having conducted the appropriate studies to investigate how long-lasting the influence of such atmospheric multisensory cue combinations might be in the marketplace (though see Girard et al., 2019a,b, for a preliminary start in this direction).

A few years later, Spangenberg et al. (2005) conducted a study in which they attempted to assess the consequences of combining congruent Christmas-related scent (the mysterious-sounding 'Enchanted Christmas') and music on students' evaluation of a department store, as seen in a series of photographs showing a store and its merchandise. A total of 140 students responded regarding their attitude toward the store, its merchandise, and their likelihood of visiting. On the basis of their results, Spangenberg et al. (2005, p. 1588) concluded that: *"Retailers need to be aware that not all combinations of music and scent positively affect shoppers. Non-congruent combinations are unlikely to elicit favorable outcomes. Retailers might be better advised to use a single environmental cue rather than incongruent combinations of music and scent."* In fact, one might be tempted to go even further, given that nothing in Spangenberg et al.'s (2005) results actually suggested that congruent olfactory and auditory cues were any better than a well-chosen auditory track by itself. That is, the highest store ratings were documented when the non-Christmas music was presented in the absence of any specific ambient scent. At the same time, however, it is worth bearing in mind here, given that Spangenberg et al. (2005) only presented a series of pictures to the participants, other findings suggesting that scents do not have quite the same effect in virtual reality environments (Toet et al., 2013; see also Jiang et al., 2016).

In another study, conducted by Morrin and Chebat (2005), adding scent and sound in the setting of a North American Mall reduced unplanned purchases as compared to either of the unisensory interventions amongst almost 800 shoppers. Although they provide no evidence to support their claim, Morrin and Chebat (2005, p. 188) suggested that the suppression of unplanned sales in their multisensory condition might have reflected the consequences of sensory overload (Malhotra, 1984). However, an alternative possibility is that the combination of low-tempo relaxing music (60 beats per minute) with a complex citrus scent (comprising three citrus notes, that was likely alerting) may have been perceived by shoppers as incongruent, and hence lacking in processing fluency (Reber, 2012; Herrmann et al., 2013; Winkielman et al., 2015).

Fenko and Loock (2014) conducted an intriguing study in a plastic surgeon's office in Recklinghausen, Germany (N = 117 participants in a between-participants design). While the addition of the pleasant and relaxing scent of lavender or pleasant music with nature sounds (both stimuli were chosen to be high on pleasantness and low on arousal) helped to reduce anxiety for those patients waiting for their appointment, combining these two cues was actually found to be no more effective that the 'no stimulation' baseline condition. What is more, the sensory interventions had no effect on perceived waiting time either. While the stimuli were chosen to be congruent in terms of their pleasantness, it is unclear whether they were also perceived to be semantically congruent or not. As such, these results highlight the need to consider olfactory interventions in the context of the total multisensory atmosphere.

Recently, Ba and Kang (2019a) examined the nature of any crossmodal interactions between ambient sound and smell in a laboratory study designed to capture the sensory cues that might be encountered in a typical urban environment. In particular, these researchers paired the sounds of birds, conversation, and traffic, with the smells of flowers (lilac, osmanthus), coffee, or bread, at one of three levels (low, medium, or high) in each modality giving rise to a total of 129 stimulus combinations (consisting of both unimodal and multisensory stimulus presentations). The stimuli were rated by 168 student participants in terms of their comfort, liking, familiarity, intensity, and, for the auditory-olfactory stimulus combinations, their crossmodal congruency. Perhaps unsurprisingly, a complex array of interactions were documented, with increasing stimulus intensity sometimes enhancing the participants' comfort ratings, while sometimes leading to a negative response instead.

Although the very large number of stimulus conditions (N = 129) that were assessed in their study makes the drawing of any simple conclusions difficult, taken together, the complex array of significant findings reported nevertheless clearly do suggest that sound and scent can interact in terms of influencing people's evaluation of urban design (see also Ba and Kang, 2019b). Ba and Kang (2019a, p. 314) concluded that: *"For the overall evaluation, in the presence of birdsong and low-volume sound, the overall evaluation was unaffected by odor; for other combinations of sound and odor, with increased concentration, the overall evaluation improved.... a positive sensory stimulus can improve the evaluation of other senses, while a negative one has the opposite effect. There is a masking effect between audition and olfaction that is reflected in the finding that when one stimulus is stronger, the other has weaker perceptual intensity;... Furthermore, the relationship between sensory evaluation and overall evaluation showed that for overall comfort, the effect of sound was stronger than odor."*

Interim Summary

As the various results reported in this section make clear, it is the multisensory atmosphere that is ultimately going to determine how the smell of the built environment affects our well-being (Spence, 2002, 2020e, 2021). As the limited results that have been published to date in this area illustrate, combining olfactory and auditory cues (as but one example of combining multisensory atmospheric cues), does not necessarily

[5]Of course, given that only one example or a low arousal and a high arousal scent was used in Mattila and Wirtz's (2001) study, it is impossible to know whether it is the how arousing the scent was, or its specific sensory qualities, that were key to driving the effects reported in this study.

give rise to a positive outcome in terms of either people's well-being or product sales (Mattila and Wirtz, 2001; Morrin and Chebat, 2005; Spangenberg et al., 2005; Fenko and Loock, 2014; Ba and Kang, 2019a). Two of the key issues when thinking about smell as one component of the multisensory built environment are the dangers of sensory overload on the one hand (Malhotra, 1984) and sensory incongruency on the other. The latter, note, typically leading to a negatively valenced reduction of processing fluency (e.g., Reber, 2012; Winkielman et al., 2015). Note that similar challenges likely arise when considering the multisensory combination of visual, olfactory, and possibly also auditory cues (Pelgrim et al., 2006; Pavia, 2008; Jiang et al., 2016).

While congruency is often mentioned as a relevant construct in multisensory research, it is important to remember that it can be defined at multiple levels. For instance, as we have seen already in this section, sensory cues (such as scent and sound) may be more or less congruent in terms of their arousal/relaxation potential (e.g., Mattila and Wirtz, 2001), or in terms of their pleasantness (Fenko and Loock, 2014). At the same time, however, ambient sensory cues may also be rated as more or less congruent in terms of some more abstract crossmodal correspondence (Spence, 2020b) or semantic associations (Dalton et al., 2008), which can themselves operate at different levels of abstraction (Spangenberg et al., 2005). Ultimately, it is not altogether clear whether we maintain any particular priors about whether the various environmental cues should be congruent in the way that, for example, we have been shown to do when perceiving the various unisensory cues associated with a particular object or event (see Chen and Spence, 2017, for a review on the latter).

CONCLUSION

Although typically neglected, given our visually dominant nature (see Hutmacher, 2019, for a review), there is a growing realization that the smells that are associated with our predominantly indoor existence may be having a significant impact on our mood and well-being (see Spence, 2002, 2021, for reviews). This goes together with an emerging realization that the sense of smell is more important to human well-being than has been suggested by many scientists over the last century (McGann, 2017). Oftentimes, the focus with research on ambient smell's influence on well-being tends to be on the negative impact when considering phenomena such as SBS (Redlich et al., 1997; Love, 2018). At the same time, however, the emerging evidence also highlights the potentially positive impact that pleasant ambient scents can have on our social, emotional, and cognitive well-being, at least if managed appropriately. Scents, very often those associated with flowers, herbs, and spices, and other plants can be used to help us relax and sleep better at night, while making us more alert and productive during the day (see Spence, 2021, for a review). At the same time, however, it is worth reiterating Warren and Warrenburg's (1993) cautionary note that fragrance-evoked mood changes tend to be small, and that the stress-reducing response of fragrance in humans may be difficult to measure in those individuals who are not stressed to begin with.

In 1990, Shiseido Co., Ltd. of Tokyo (a leading manufacturer of cosmetics) reported, as part of their 'aroma engineering program' that releasing the right scent in the factory led to increased productivity and reduced accidents when pumped through the air-conditioning and heating ducts (see Warren and Riach, 2018). According to Gary Marx: *"The company's promotional brochure suggests one menu: lemon scent in the morning to wake workers up; a light floral scent to aid concentration at mid-morning; an odorfree lunch, and wood, lemon and floral scents in the afternoon."* Rather than thinking that one scent will necessarily suffice to improve well-being regardless of the situation, there is a very real sense in which different smells may be needed at different times (and in different places; e.g., see Gorman, 2017). Of course, such a dynamic approach to scenting the built environment likely requires progress to be made in terms of scent-release technology. That said, many of the home scent-delivery systems capable of delivering a range of odorants have not fared very well: think here only of Digiscents (e.g., Dusi, 2014), or P&G's ill-fated 'scent-stories' (see Herz, 2007). And while acknowledging the beneficial effects on mood and relief from stress that certain pleasant ambient fragrances may deliver, one also needs to be sensitive to the olfactory pollution that the fragrance of various cleaning and household fragranced products might give rise to (e.g., Lau et al., 1997; Anderson and Anderson, 1998; Nazaroff and Weschler, 2004; Caress and Steinemann, 2009; De Vader, 2010; Petry et al., 2014; Steinemann, 2016, 2019; Pain, 2017; Sarchet, 2017; Scully, 2019).

Ambient Smell and Evolutionary Psychology

As to why the right balance of olfactory stimulation should influence us, one might think in terms of evolutionary psychology (Wilson, 1984). It has been suggested that we may have evolved to appreciate those sights and sounds, and even those natural smells that would have helped our ancestors to survive. Given that our preference as far as the thermal conditions of the home environment has recently been shown to match most closely the temperature and humidity profile of the Ethiopian highlands where we evolved some five million years ago (see Just et al., 2019; Whipple, 2019), one might, I suppose, wonder whether we have also evolved to find pleasant those scents that would have been familiar/present in the environment at that time? That said, one of the interesting features about smell is the fact that we rapidly learn to associate meaning/mood/emotion with novel scents (e.g., Engen, 1982; Herz, 2007). It is certainly unlikely that many of the specific plant odors that have been demonstrated to affect us nowadays would have necessarily been present in Ethiopia all those many years ago.[6]

The other part of the evolutionary olfactory story is presumably the world smells more strongly during the warmer

[6]Though I suppose it might explain our strong response to geosmin, the distinctive smell of the earth after it has rained (Pelosi, 2016).

part of the day, and typically smells less fragrant at night (with the rare exception of plants such as night-flowering jasmine, Spence, 2021). As such, one might expect that our sensitivity to scent to be adapted to that natural cycle or rhythm (cf. Smith, 1977; Knowles, 2006). By contrast, the built environment would seem to have a much more constant level of olfactory stimulation – or at least it does in those parts of the built environment that are inhabited at night. However, the limited evidence that has been published to date has yet to provide support for this particular suggestion, appealing though it might be (Lötsch et al., 1997; Carskadon et al., 2015; though see also Goel and Grasso, 2004).

While the research that has been reviewed in this admittedly Anglophone article has focused almost exclusively on those smells that have been experienced indoors in western urban environments, it is worth noting that a parallel literature exists documenting the impact of the outdoor scents of the urban environment on us. In fact, there is growing interest in urban scentscapes (e.g., Porteous, 1985; Margolies, 2006; Diaconu, 2011; Henshaw, 2014), as highlighted by those making scentscape maps of cities (see Reinarz, 2014; Reynolds, 2014; Lipps, 2018; McLean, 2018; see also Dann and Jacobsen, 2003). The range of scents that are typically experienced outdoors are likely capable of exerting both a positive and negative effect on our well-being, depending on their specific identity, and our beliefs concerning their origins (Day, 2007; Gorman, 2017). Separately, there is growing interest in the scenting of public transport, such as, for example, trains and airports (e.g., Haehner et al., 2017; Canniford et al., 2018; Girard et al., 2019a,b).

Multisensory Atmospherics

The other important part of the equation when considering the smellscapes of the built environment (Xiao et al., 2018) is to consider the multisensory atmosphere. As the cultural geographer Porteous (1985, pp. 359–360) noted some years ago, odors make little sense without reference to the other senses. Mattila and Wirtz (2001, p. 285) made a similar point when they stated that it is *"the total configuration of cues that influence consumer responses"* rather than the atmospheric variables when considered in isolation. The relevant question here is whether or not the scent is congruent with the visual, and auditory aspects of the environment (Jiang et al., 2016; Ba and Kang, 2019a,b). The multisensory perception literature that has emerged over the last four decades or so suggests that when multiple cues are present, they may be integrated, revealing a pattern of sensory (normally visual) dominance, superadditivity, or, when the inputs are incongruent, sub-additivity.

Normally, we find it easier to process congruent combinations of multisensory stimuli – they tend to be processed more fluently (Reber et al., 1998, 2004; Reber, 2012). It would seem likely the same is true when it comes to the elements of the built environment, and hence we are presumably more likely to be drawn toward multisensorially congruent environments (Knasko, 1995; Spangenberg et al., 2005; though see also Mitchell et al., 1995; Schifferstein and Blok, 2002; Bosmans, 2006). At the same time, however, visual dominance means that the way we interpret a smell can sometimes be influenced by what we see (and potentially also hear around us; Ba and Kang, 2019a). And, as Rimkute et al. (2016) note, ensuring congruency can be difficult in non-uniform environments (i.e., in those stores offering multiple different classes of product).

While we appear to have a predisposition to integrate those sensory cues that belong to the same object or event (see Chen and Spence, 2017, for a review), it is, as yet, less clear whether we automatically integrate ambient atmospheric cues in quite the same manner. Certainly, it is less clear that people attend to atmospheric cues in quite the same way that they do when presented with objects or events in the laboratory (Spence, 2020a,e). At the same time, however, there is also a sense in which we may be conditioned to treat the various environmental cues as operating independently. Just think about how the music changes while the lighting and ambient scent stay the same in a restaurant, or when the lighting is turned down at some point in the evening, without there being any concomitant changes to the other sensory aspects of the environment. There is, though, a very real danger that by trying to study the effect of the multisensory built-environment on well-being, researchers may end up drawing their participants' attention to, and hence making more salient, the relative (in-)congruency of the component ambient stimuli presented in a way that would perhaps not normally be the case.

Looking to the future, especially during the era of pandemia, what is needed are more long-term studies (Girard et al., 2019a,b), and more studies conducted in relevant spaces in the built environment, be they offices, shops, home or transport, rather than just more laboratory studies with correspondingly low ecological validity. At the same time, given the multisensory nature of the built environment, it will be important to learn more concerning the various ways in which ambient smell interacts with other environmental sensory cues to determine how the built environment affects our well-being.

AUTHOR CONTRIBUTIONS

CS wrote all parts of this review.

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Effect of Fragrant Primula Flowers on Physiology and Psychology in Female College Students: An Empirical Study

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Indoor plants can positively impact physical and mental health in daily life. However, the benefits of viewing indoor plants may be enhanced if the plants emit a fragrant aroma. In this crossover-design study, we measured the physiological and psychological effects of fragrant and non-fragrant Primula plants on 50 female college students, and explored whether aroma stimulation had additive benefits for this group. Non-fragrant *Primula malacoides Franch* was used as a control stimulus, and *Primula forbesii Franch*, which has a floral fragrance, was used as an experimental stimulus. We measured blood pressure, pulse rate, and electroencephalogram (EEG) to evaluate physiological responses, and used a mood state profile and the semantic differential (SD) method to evaluate psychological responses. We found that mean blood pressure and pulse rate decreased significantly after the experiment in both conditions. EEGs showed that the mean values of high alpha waves, high beta waves, and relaxation scores were significantly higher in the experimental vs. control condition. The average scores on each subscale of the psychological questionnaire improved after the experiment in both conditions, and the vitality (V) subscale and total emotional state scores were significantly better in the experimental vs. control condition. The results of the SD method showed that the sense of relaxation and comfort were significantly higher in the experimental vs. control condition. Compared with the non-fragrant Primula, the fragrant Primula induced relatively better physiological and psychological effects.

Keywords: fragrance stimulation, Primula, electroencephalogram, blood pressure, pulse rate, psychological questionnaire

INTRODUCTION

Since the turn of the 20th century, as electronic information technology has been leaping forward, people are enabled to work and get entertained by more significantly relying on the machine environment (Reyns et al., 2011). The main living environment of modern society has transformed from outdoors to indoors, so individual daily activities are primarily generated indoors (Chang and Chen, 2005; Gong et al., 2012; Linjing and Qihong, 2018). Poor air quality and limited opportunities for physical activity in indoor environments have been associated with a decrease in work efficiency as well as various physiological and psychological conditions (Gullone, 2000; Watts et al., 2015; Reichert et al., 2019). Therefore, the deliberate construction of improved indoor environments has been a subject of increasing focus by researchers (Flies et al., 2019).

Previous theories such as the Pro Nature Theory (Kellert, 1995), Attention Recovery Theory (Kaplan, 1995), and Stress Relief Theory (Ulrich et al., 2008) all state that the natural environment plays an important role in promoting human physical and psychological health. Although plants are generally found in parks and other public green spaces, indoor plants represent a natural resource that can be low-cost and more convenient to access for urban residents. Indoor plants can effectively increase contact time and intimacy with nature, and thereby promote physical and psychological health (Bringslimark et al., 2009; Deng and Deng, 2018).

Most existing research on the impact of indoor plants on human beings has focused on the visual perception of plants. Previous studies have confirmed that visual contact with indoor plants can increase relaxation, relieve stress (Ulrich, 1986; Bringslimark et al., 2009), improve work efficiency (Evensen et al., 2015), enhance work and life satisfaction (Dravigne et al., 2008; Qin et al., 2014), and even relieve pain (Park et al., 2004).

However, many plants, especially ornamental plants, have aromatic characteristics (Haviland-Jones et al., 2005; Bushdid et al., 2014). Fragrant plants can represent a vital natural resource and impact physical and psychological health *via* olfactory channels (Lorig et al., 1990; Jo et al., 2013; Glass et al., 2014; Swamy and Sinniah, 2015). For example, the aroma of rose essential oil has been found to induce physiological and psychological relaxation (Kim et al., 2016), and the aromas of flowers and plants have been found to positively influence patients who have undergone surgery, even reducing the intake of postoperative analgesics (Park and Mattson, 2009).

As a research method for examining the effect of indoor plant aromas on human recovery, psychological questionnaires have been widely used (Ulrich et al., 2008). Since the physiological responses of humans to environmental stimuli may exceed their subjective self-cognition, it is difficult to objectively measure these physiological and emotional responses using psychological questionnaires. Therefore, some scholars have proposed a new research method in which brain waves are used to represent emotional state (Niedermeyer and Silva, 2004). Electroencephalogram (EEG) refers to the recording of electrical signals of the human brain at a scalp level (Lina and Karwowski, 2020). Under the active brain, the postsynaptic potentials of pyramidal neurons will be hyperpolarized and depolarized, and EEG signals are generated. Specific to this method, sensors are placed on the scalp surface to record electrophysiological signals generated by brain activities, which are considered to objectively indicate human emotion changes at a physiological level. The mentioned electrical signals fall to the frequency bands, i.e., delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), and beta (12–30 Hz). Human behavior, thoughts, and emotions can change the activity of different frequencies of brain waves. Alpha and beta waves are considered to be most closely related to human emotions. Alpha waves reflect a relatively calm and relaxed state, while beta waves correspond to lucidity and quick thinking (Lagopoulos et al., 2009; Alarcao and Fonseca, 2017). An EEG study revealed that the aroma of Japanese plum blossoms reduced brain waves associated with negative emotions and memory impairment (Jo et al., 2013). Further, contact with natural plants was found to enhance alpha and beta waves, reflecting a reduction in mental stress (Hassan et al., 2018a). Experiments by Kim et al. (2016) revealed that an orchid scent produced stronger alpha EEG waves than did a rose aroma, indicating that the orchid scent induced greater feelings of tranquility and relaxation. However, relatively few studies have investigated the physiological effects of aromas using EEG.

At present, most studies examining the effect of plant aromas on humans have used essential oils or perfumes instead of actual plant materials (Jo et al., 2013; Ali et al., 2015; Kim et al., 2016). However, we mainly experience plant odor through exposure to live plants in daily life. To address this in the present study, we exposed participants to live plants, and carried out comparative experiments regarding the most common forms of human-plant contact. As opposed to the mentioned, existing studies using live plants tended to primarily compare the effects of different experimental stimuli, or draw a comparison of the effect of an experimental stimulus vs. a control. Commonly, these studies inadvertently determined the joint effect of vision and smell, in which the effect of olfaction was not distinguished (Adachi et al., 2000; Park and Mattson, 2009; Qin et al., 2014). When participants are subjected to visual stimulation with live plants, the additional effect of aroma is not generally measured. However, this is an important consideration in terms of the role of aromatic stimulation in plant-induced health benefits. Therefore, in the present study, the additional effects exerted by aromatic and non-aromatic plants were compared to determine the effects of fragrant Primula flowers on physiology and psychology in female college students. We measured physiological data including pulse rate, blood pressure, and brain waves, as well as psychological data collected *via* questionnaire.

We had two hypotheses: (1) The exposure to fragrant Primula and non-fragrant Primula will help female college students gain better physiological and psychological states; (2) Fragrant Primula, as compared with non-fragrant Primula, will more significantly enhance physiological and psychological states of female college students.

The present study aims to explore effects of fragrant and non-fragrant Primula flowers on physiological and psychological states of female college students, as well as the additional effect exerted by the fragrance of Primula.

MATERIALS AND METHODS

Participants

In Chinese college dormitory, considerable female students like to cultivate small indoor plants for leisure and decompression. As indicated from existing studies, females are usually more sensitive to odors than males in their daily lives (Camille et al., 2013). To determine the physiological and psychological effects of plant aroma in depth, this study recruited 50 female college students with an average age of 22.32 ± 2.56 years, an average height of 161.58 ± 5.56 cm, and an average weight of 54.05 ± 7.64 kg. Although our sample was relatively homogenous, which could limit the generalizability of our results, this approach was advantageous in that we did not expect to observe differences in olfactory responses resulting from gender, age, or culture. The selection criteria for the participants included: (1) normal olfactory function, no recent history of a cold, sinusitis, or other similar conditions; (2) good physical and psychological health; and (3) no recent use of recreational or pharmaceutical drugs. In addition, within the 48 h before the experiment, participants were asked to abstain from several odorous stimulus (e.g., alcohol, tobacco, caffeine, and perfume).

All participants were informed regarding the content of the experiment, and were told that they had the right to withdraw from the experiment at any time. All participants completed an informed consent form. All study procedures were carried out in accordance with the ethical standards of the National Research Council, and were in accordance with the declaration of Helsinki.

Materials

Primula is very popular among indoor ornamental plants. It is one of the top-selling indoor potted flowering plants in Europe, America, and East Asia because of it produces colorful flowers early in the season. We selected two kinds of Primula in this experiment. The first was *Primula malacoides Franch*, which is a native Chinese variety with a long history of origin. It was introduced into Europe at the end of the 19th century and has been widely cultivated all over the world, with many horticultural varieties. This kind of Primula has no fragrance (Karlsson, 2001). The second was *Primula forbesii Franch*, which is a wild flower species widely distributed in Southwest China. Primula flowers exhibit a bright color and high ornamental value. Moreover, it can be easily cultivated in a large scale and maintained. It produces a moderate amount of flowers, which have a fresh and elegant fragrance (Hayta et al., 2016). We determined these two kinds of Primula to be suitable materials for testing the effects of aromatic plant stimulation.

Laboratory Environment

To ensure strict control the experimental variables, the environmental settings of Ikei et al. (2014) and Hassan et al. (2018a) were referenced and two laboratories with the same indoor layout were selected as the experimental sites for the control condition and the experimental condition. Next to the two laboratories, preparation rooms were arranged in which to measure participant physiological and psychological data before the experiment began. The ceiling and walls of the two laboratories were white, with no decoration. During the experiment, the windows and curtains in each laboratory were kept closed to reduce external sound and light interference. Ten flowerpots with Primula were arranged on the table to ensure that they took up the major field of vision of the participants. Participants were seated in a chair 0.2 m away from the table to closely view and smell the plants, and the distance could be regulated by complying with the participants' height (**Figure 1**). During the experiment, the participants were asked to maintain a sitting posture, to relax, and to breathe evenly. The participants in the control condition were exposed to *Primula malacoides Franch*. The participants viewed the plants and did not receive any olfactory stimulation. Those in the experimental condition were exposed to *Primula forbesii Franch*, which has a natural fragrance. The participants viewed the plants, while calmly inhaling the flower fragrance. During the experiment, the room temperature was kept at 25°C and the relative humidity was kept at 60%. Thus, the concentration and transmission of the flower fragrance did not change significantly with time.

Measurement Items

The experimental data were divided into physiological data and psychological data. Physiological data included pulse rate

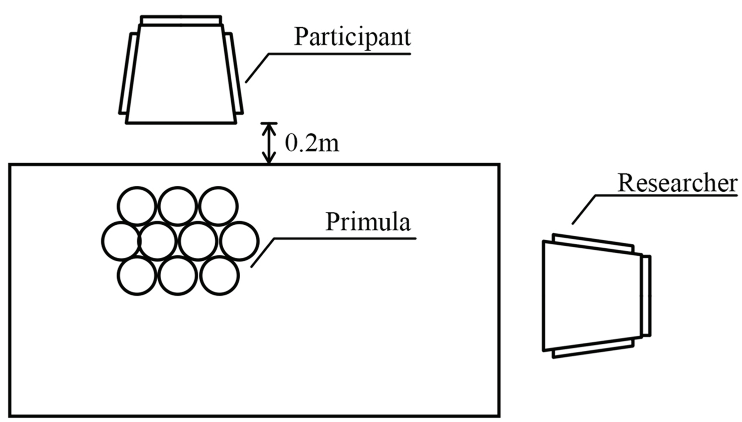

FIGURE 1 | Diagram of the physical set up in relation to the participant.

(BPM), blood pressure [systolic (mmHg), diastolic (mmHg)], and brain waves. It is generally considered that alpha wave and beta wave display the closest relationship to human emotions, in which high alpha wave (about 10–12 Hz) is closely correlated with relaxation, and high beta wave (about 21–30 Hz) corresponds to more attention and alertness (Coben et al., 2010; Bălan et al., 2019). By employing the methods of relevant literature (Hassan et al., 2018a,b), high alpha and high beta waves were analyzed here. Blood pressure and pulse rate were measured two times using a sphygmomanometer on the left arm (Omron, hem-7011, China). We used a Neurosky mindwave EEG headset (Beijing Oriental Creation Technology Co., Ltd., China) to measure EEG signals transmitted from the forehead. The headset had four essential components: (1) a headband, (2) an ear clip, (3) a sensor arm containing the EEG electrode, and (4) a Bluetooth device. The device was light and compact, and did not cause obvious discomfort to users. The device continuously recorded brain wave data and mean value per minute was reported. We used e-Sense™ software for EEG data processing. Specifically, brain wave signals during states of relaxation and attention can be sorted from weak to strong on a scale from 1 to 100 by this software (Sezer et al., 2017). Psychological data included the profile of mood states (POMS) and the semantic differential (SD) method. The POMS includes 40 items, with seven subscales: tension (T), anger (A), fatigue (F), depression (D), vitality (V), confusion (C), and self-esteem (E). Total Mood Disturbance (TMD) was calculated according to the scores from each subscale, with lower TMD scores reflecting a better overall emotional state. The SD method can be used directly quantify the subjective perception of external stimuli. In this study, we selected three adjective items, i.e., comfortable, fascinated, and relaxed, to examine participant psychological responses. Participant scores were calculated according to the content of verbal descriptions and the degree of subjective identification, using a scale ranging from −5 to 5.

Experimental Procedure

The 50 participants were randomly divided into two groups. The experiment had a crossover design. On the first day of the experiment, the first group (25 people) viewed the fragrant Primula in the laboratory and experienced the olfactory stimulation, while the second group (25 people) viewed the odorless Primula in the laboratory, and thus did not receive olfactory stimulation. On the next day, the two groups were switched such that they repeated the experiment with the alternate condition. To avoid changes in measurement caused by the physiological clock, the activity took place from 8:00–11:30 am on each day.

Before the beginning of the experiment, the participants were informed regarding the content of the experiment and told that they could withdraw from the experiment at any time. All participants signed informed consent forms. First, the participants were invited into the preparation room and asked to sit down for 5 min. They then completed measurements of blood pressure, pulse rate, and completed a mood state scale. Subsequently, each participant entered the laboratory, put on EEG equipment, and closed their eyes to rest for 3 min to reach a stable state. Next, raw EEG data were acquired at a 1-min interval till the 10-min Primula exposure experience was completed. According to previous studies, 10 min experience was enough for the participants to have a significant recovery through exposure to the natural settings (Ulrich et al., 2002; Jo et al., 2013; Hassan et al., 2018a; Deng et al., 2020). After the experience, the participants rested for 5 min in a sitting position. They then underwent blood pressure and pulse rate measurements, and completed the mood state and semantic difference scales. When all measurements were completed, the participants were thanked for their involvement and excused from the laboratory. After the entire experiment was over, each participant would receive a small gift and a reward of $5.

Data Analysis

Excel and SPSS 19 were used to analyze the statistical data. A paired *t*-test was used to analyze the pulse rate and blood pressure data. To analyze the EEG data, this study conducted a repeated measures ANOVA and performed the multivariate variance statistical test. The attention and relaxation scores were collected from the e-Sense™ software and analyzed using a one-way ANOVA. The SD data were also analyzed using a one-way ANOVA. The Wilcoxon signed rank test was used to analyze the POMS data. The threshold for statistical significance was set at $p < 0.05$.

RESULTS

Blood Pressure and Pulse Rate

The systolic blood pressure, diastolic blood pressure, and pulse rate data are shown in **Figure 2**. Before the experiment, we found no significant differences between the control condition and experimental condition in terms of the three physiological indexes. After the experiment, the mean systolic blood pressure in the control condition exhibited a decreasing trend, although this difference was not significant (104.88 ± 10.90 and 104.56 ± 10.12, $p > 0.05$); the mean diastolic blood pressure exhibited a non-significant decreasing trend (65.34 ± 12.35 and 63.86 ± 10.97, $p > 0.05$); and the mean pulse rate was significantly decreased (72.92 ± 7.06 and 70.94 ± 6.99, $p < 0.05$).

After the participants completed the experimental condition, the mean systolic blood pressure exhibited a decreasing trend (103.24 ± 7.80 and 101.86 ± 6.57, $p > 0.05$), the mean diastolic blood pressure exhibited a decreasing trend (65.42 ± 8.65 and 64.76 ± 9.00, $p > 0.05$), and the mean heart rate was significantly decreased (73.56 + 9.44 and 70.02 + 9.17, $p < 0.01$).

Any differences between the experimental condition and control condition in terms of systolic blood pressure, diastolic blood pressure, and heart rate after the experiment were not significant.

Brain Waves

Figures 3, 4 show the EEG data. When we compared the high alpha and high beta EEG data before vs. after the experiment, we observed significant differences in both conditions.

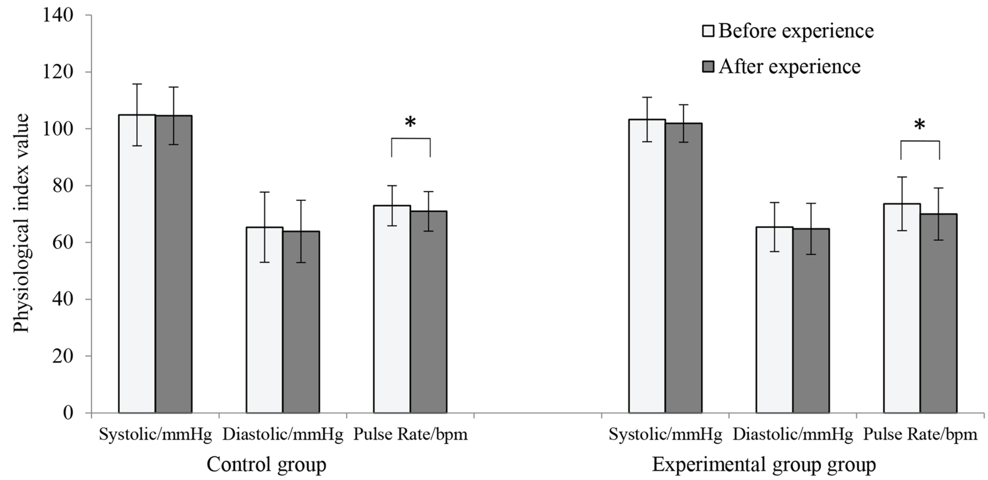

FIGURE 2 | Systolic blood pressure, diastolic blood pressure, and pulse rate measurements before and after the experiment in the control condition and experimental condition (n = 50; mean ± SD; $^*p < 0.05$; verified by a paired t-test).

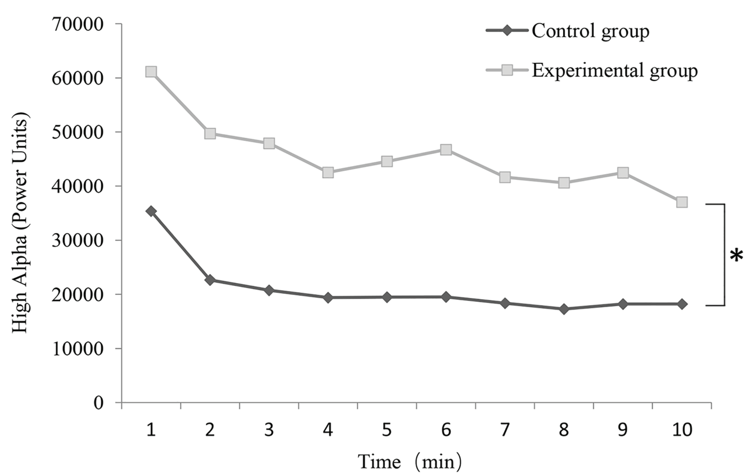

FIGURE 3 | Change in high alpha wave (power units) value in each 1-min epoch in the control and experimental conditions (n = 50; mean ± SD; $^*p < 0.05$; verified by repeated ANOVA and multivariate variance statistical test).

Analysis of the 1-min EEG epochs indicated that the mean alpha wave values and mean beta wave values were both higher when the participants completed the experimental vs. control condition. In each condition, the mean values of both the alpha and beta waves reached the highest point in the first minute of the experiment.

The alpha wave values in the control condition and experimental condition were analyzed by a repeated ANOVA, and the results are shown in **Figure 3**. The multivariate variance statistical test was performed based on Pillai's Trace. As indicated from the result, mean alpha wave values between the conditions regarding changes over time showed a significant difference [$F(9, 90) = 4.845$, $p = 0.000 < 0.05$, $\eta^2 = 0.326$]. No interaction was identified between time and condition [$F(9, 90) = 0.912$, $p = 0.519 > 0.05$, $\eta^2 = 0.084$]. In addition, as suggested from Mauchly's test of sphericity, $p = 0.000 < 0.05$, and the epsilon value was 0.490 < 0.750, so Greenhouse-Geisser was employed for correction (Maxwell and Delaney, 2004). The significant time effect of alpha wave was identified [$F(4.410, 432.147) = 9.742$, $p = 0.000 < 0.05$, $\eta^2 = 0.090$], whereas a slight interaction was found between time and condition [$F(4.410, 432.147) = 0.441$, $p = 0.797 > 0.05$, $\eta^2 = 0.004$]. The above results complied with those of the multivariate variance statistical test in the significance of time effect and interaction. The main effect of alpha wave values between the control condition and the experimental condition was significant [$F(1, 98) = 32.171$, $p = 0.000 < 0.05$, $\eta^2 = 0.247$].

The beta wave values in the control condition and experimental condition were analyzed by a repeated ANOVA, and the results are shown in **Figure 4**. Pillai's Trace was used in the multivariate variance statistical test, indicating that the beta wave varied significantly over time under both conditions [$F(9, 90) = 6.981$, $p = 0.000 < 0.05$, $\eta^2 = 0.410$], and a slight interaction between time and condition was suggested [$F(9, 90) = 1.252$, $p = 0.258 > 0.05$, $\eta^2 = 0.117$]. Moreover, as revealed in Mauchly's test of sphericity, $p = 0.000 < 0.05$, and the value of epsilon reached 0.376 < 0.750, so Greenhouse-Geisser was employed for correction. A significant time effect of beta wave was identified [$F(3.388, 332.035) = 13.370$, $p = 0.000 < 0.05$, $\eta^2 = 0.120$], whereas no interaction was reported between time and condition [$F(3.388, 332.035) = 0.638$, $p = 0.610 > 0.05$, $\eta^2 = 0.111$]. The mentioned results complied with those of the multivariate variance statistical test in the significance of time effect and interaction. The main effect of beta wave values between the control condition and experimental condition was significant [$F(1, 98) = 6.523$, $p = 0.012 < 0.05$, $\eta^2 = 0.062$].

The results of the EEG analysis conducted using the e-Sense software are shown in **Figure 5**. The average attention score in the experimental condition was higher than that in the control condition (55.30 ± 9.18 and 52.04 ± 10.34, $p > 0.05$), and the average relaxation score in the experimental condition was significantly higher than that in the control condition (60.78 ± 9.87 and 54.34 ± 10.47, $p < 0.05$).

Profile of Mood States

The POMS results are shown in **Figure 6**. Before the experience, there were no significant differences between the control condition and the experimental condition. In the control condition, after viewing the non-fragrant Primula, the positive scale score increased, while the negative scale score decreased. The tension and confusion subscale scores decreased significantly, while self-esteem increased significantly. After the participants under the experimental condition observed and smelled the Primula, the scores for the respective scale were upregulated. To be specific, the average Tension, Confusion, TMD scores were downregulated significantly, and vitality score was elevated significantly. The subscale scores after experiencing the fragrant Primula were compared between the two conditions. The results

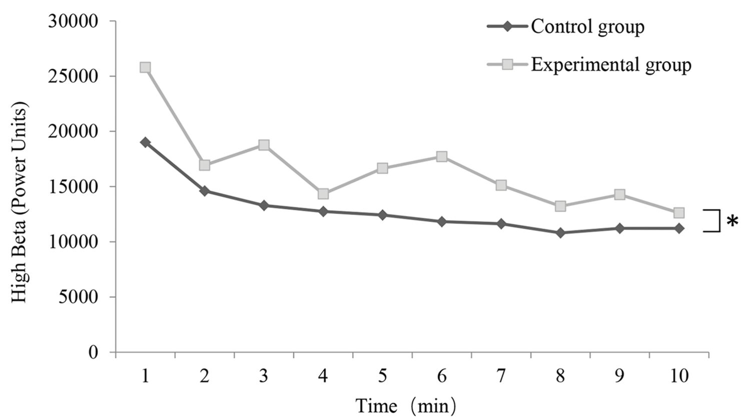

FIGURE 4 | Change in high beta wave (power units) value in each 1-min epoch in the control and experimental conditions ($n = 50$; mean ± SD; $^*p < 0.05$; verified by repeated ANOVA and multivariate variance statistical test).

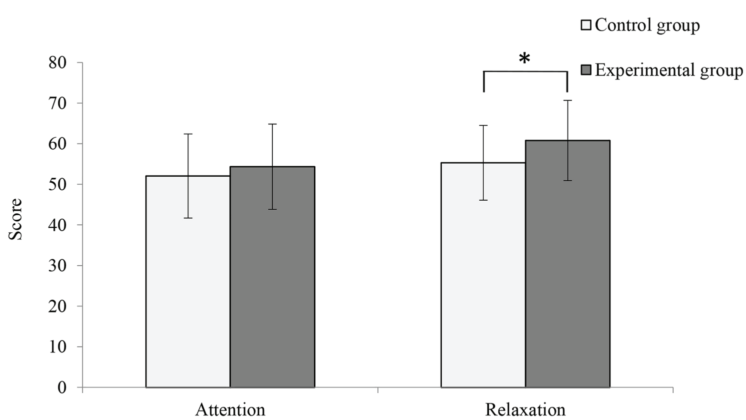

FIGURE 5 | Comparison of mean attention and relaxation scores between the control and experimental conditions ($n = 50$; mean ± SD; $^*p < 0.05$; verified by one way ANOVA).

showed that the average positive scale score was higher after the experimental condition vs. the control condition, and the average negative scale score was lower after the experimental condition vs. the control condition. The vitality subscale scores and the TMD after the experimental condition were significantly higher than those after the control condition, suggesting that the experimental condition induced greater vitality and was perceived as a better overall emotional experience compared with the control condition.

SD Method

Figure 7 shows the differences in the participants' subjective feelings, as measured using the SD method, according to exposure to the fragrant and non-fragrant Primula before and after the experiment. The mean values of "comfortable" and "relaxed" in the experimental condition were significantly higher than those in the control condition (comfortable: 1.84 ± 1.2 and 2.42 ± 0.94, $p < 0.05$; relaxed: 2.20 ± 1.21 and 2.70 ± 0.99, $p < 0.05$). The mean value of "fascinated" in the experimental condition was higher than that in the control condition, but this difference was not significant (2.24 ± 1.17 and 2.58 ± 1.12, $p > 0.05$).

DISCUSSION

Effects on Blood Pressure and Pulse Rate

We observed a downward trend in the systolic blood pressure and diastolic blood pressure, and a significant decrease in the

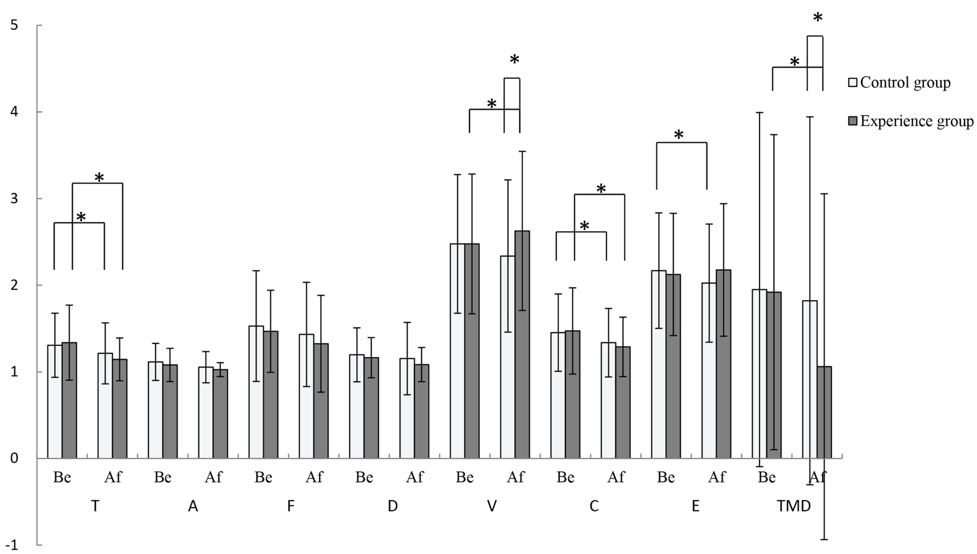

FIGURE 6 | Profile of mood states (POMS) scores before and after the control condition and the experimental condition (n = 50; mean ± SD; $^*p < 0.05$; verified by a paired t-test).

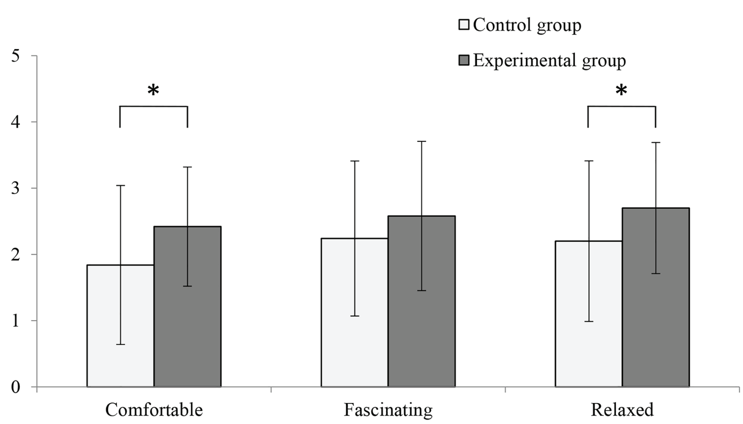

FIGURE 7 | Comparisons between the control and experimental conditions, conducted using the semantic differential (SD) method (n = 50; mean ± SD; $^*p < 0.05$; verified by one-way ANOVA).

pulse rate in both the control and experimental conditions. Previous studies had shown that the sympathetic and parasympathetic nervous systems in the human body produce changes in blood pressure and heart rate when emotion is influenced by stress or relaxation (Schwartz et al., 1981; Deng and Deng, 2018). As mentioned in the literatures, the stress emotion induces the rise of blood pressure and pulse rate, while the relaxed emotion produces the decrease (Zanstra and Johnston, 2011; Hassan et al., 2018b). Therefore, it was presumably suggested that the Primula plants with or without fragrance could be able to regulate the sympathetic and parasympathetic nervous system and improve participants' emotion. Our results supported previous studies on the emotional improvement caused by plants and plant fragrance (Lee et al., 2015; Zhao et al., 2019). Surprisingly, no significant differences were found in blood pressure and pulse rate between non-fragrant and fragrant Primula plants. This finding was also reported in the *Chrysanthemum indicum* (Kim et al., 2018). Whether Primula fragrance has additional effects on sympathetic nervous system and parasympathetic nervous system needs further study combined with more physiological indicators, such as high-frequency heart rate variability and galvanic skin response.

Effects on EEG

Our results showed that the mean alpha wave value was significantly higher in the experimental condition compared with the control condition. In addition, the mean relaxation score in the experimental condition was significantly higher than that in the control condition. Alpha waves are known to be correlated with decreased mental stress, increased relaxation, and enhanced memory ability (Alarcao and Fonseca, 2017; Lina and Karwowski, 2020). Further, several reports have shown that exposure to the natural environment induces increased alpha wave strength, which is related to physiological relaxation and recovery effects (Kim et al., 2013, p. 38; Alarcao and Fonseca, 2017; Ursuţiu et al., 2018). This finding is consistent with that of Kim et al. (2016), who reported dramatically increased alpha waves after participants smelled an aromatic extract of orchid petals. Given the apparent connections between alpha wave power and relaxation (Hassan et al., 2018a; Tao et al., 2020), our findings, while preliminary, suggest that smelling fragrant Primula plants may have had a stronger restorative effect on participants than smelling non-fragrant Primula plants. Therefore, one of the suggestions of this result is to use fragrant flowers in places that need to create a relaxing atmosphere, such as studios, living rooms, hospitals, and so on.

Our results showed that both beta wave value and the attention score were significantly higher in the experimental condition compared with the control condition. Previous studies had shown that the emergence and modulation of beta waves represent attention and concentration (Coben et al., 2010). For instance, participants' beta waves became stronger after viewing pictures of natural landscapes, and energy levels and attention increased (Jiang et al., 2019). This result is consistent with that of Hassan et al. (2018a), who reported significantly enhanced beta waves after viewing ornamental plants, while the participants became more attentive. These related studies showed that higher beta waves were associated with improved attention. In this study, the experimental condition produced higher beta value and attention score, suggesting that fragrant Primula may improve attention to a greater extent than non-fragrant Primula. Therefore, it may be suggested that an effective use of fragrant Primula is to be placed in the workplace, increase the concentration level of stuffs, and improve their working efficiency.

The mean alpha and beta values observed in the experimental condition were both significantly higher than those in the control condition, as were the attention and relaxation scores. This tends to infer that states of relaxation and concentration can occur simultaneously to some extent. These findings are consistent with related research on emotional changes caused by environmental contact, including virtual visual stimulation experiments (Guo et al., 2020), walking in a bamboo forest and a city environment (Hassan et al., 2018b), and horticultural activity (Hassan et al., 2018a), etc. These studies consistently reported higher mean alpha and beta values, reflecting relatively higher levels of relaxation and attention.

In terms of changes in EEG over time, the mean alpha and beta values in the two conditions reached their highest points during the first minute of the trial. Afterward, the mean alpha and beta values decreased and gradually reached a stable level. This may be due to changes in the experimental environment. Overall, the average alpha and beta values in the experimental condition were significantly higher than those in the control condition. Our results suggest that the fragrant Primula induced a stronger physiological and psychological effect, which reflects emotional relaxation and improved attention (Islarn and Ahmad, 2015). It suggested that olfaction benefited neural activity in a unique way, which could not be achieved by visual stimuli alone.

Effects on Psychology

The results of the POMS questionnaire in the present study indicated trends toward improvement in most of the average scores on each scale in both the control and experimental conditions, with some significant changes. After the experiment, experimental condition got the higher positive scale score and the lower negative scale score vs. the control condition. Further, the mean TMD was significantly higher in the experimental vs. control condition, suggesting that the fragrant Primula induced a better emotional experience. The mean vitality scale score was significantly higher under the experimental condition than the control, demonstrating that aromatic stimulation of Primula can enable the participants to achieve more clear-headed and positive psychological state (Takayama et al., 2014). On a psychological level, fragrance is known to affect emotional state. Olfactory environments have been found to have an important impact on the spatial experience of residents and tourists, as well as playing a role in regulating psychology, relieving stress, and improving happiness and self-esteem (Glass et al., 2014). Therefore, the results of this study revealed the potential value of fragrant Primula in daily life space or public space, so as to promote people's positive emotions and reduce negative emotions.

The SD directly reflects the subjective feelings of respondents. In this study, the SD data likely indicated that the fragrant Primula made the participants feel more relaxed and comfortable. In related studies, fresh roses were used as an olfactory stimulant, and the results of the SD also showed that participants exposed to the roses experienced a heightened sense of comfort compared with a control condition (Igarashi et al., 2014). Therefore, the results of this study were consistent with previous studies.

Relationship Between Physiological and Psychological Findings

After examining the collected physiological and psychological data, we were able to infer that the changes in these two data types were related. After contact with two kinds of Primula, the participant blood pressure and pulse had decreased by varying degrees. Further, scores on the positive subscales in the POMS had increased, and scores on the negative subscales had decreased. These data inferred that both kinds of Primula elicited some degree of improvement in physiological and psychological state (Park et al., 2017).

Our finding of significantly higher alpha values and relaxation scores in the experimental condition compared with the control condition confirmed that the fragrant Primula induced a more powerful relaxation effect. The results of POMS and SD showed that participants in the experimental condition had lower TMD scores and higher relaxation scores, which is consistent with the EEG data. The fragrant Primula induced higher beta values, which corresponded to the significant increase in the average vigor scale score in the POMS. Taken together, these physiological and psychological results support each other, which may infer that the fragrant Primula made the participants more relaxed and more attentive, which likely had a positive effect on emotions.

In general, both kinds of Primula improved the physiological and psychological state of participants, although the fragrant Primula had a stronger effect.

Research Limitations

This study had the following limitations, which should be taken into account in future research. First, as impacted by the limitations of the experiment scale, only female college students were included here as participants. Future studies should examine people with different demographic characteristics and cross-cultural backgrounds to explore the universality of the experimental results. Second, we only studied the effects of aromatic plant stimulation from several physiological and psychological aspects, while measurements in additional fields, such as pharmacology, biomedicine, and cognitive psychology, may be informative. Therefore, future studies should involve a more diverse participant group, use the evaluation of more physiological indexes, and complete a more in-depth exploration of the specific mechanisms of olfactory effects.

CONCLUSION

In this study, we used blood pressure, pulse rate, EEG, POMS, and SD data to examine the effects of the fragrant *Primula forbesii Franch* and the non-fragrant *Primula malacoides Franch* on the physiological and psychological state of female college students. Compared with the non-fragrant Primula, the fragrant Primula modulated EEG and many psychological indexes in a way that reflected greater relaxation and attention. This infers that, in addition to the positive impact of visual stimulation, aromatic stimulation *via* the Primula plant can have important beneficial effects.

Our results suggest that indoor plants, which are a simple and economic way to improve the quality of indoor environments, have beneficial health effects and are thus worth promoting. Further, our data demonstrate the important role of aromatic stimulation in the effects of indoor plants on human health. Therefore, we suggest that aromatic plants be selected during indoor plant landscaping to better promote the physical and psychological health of visitors, and improve quality of life. This notion is especially worth promoting in areas where public green areas are scarce.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by local Ethics Committee of the College of Landscape Architecture, Sichuan Agricultural University, China. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XL, YJ, and LD contributed to conception of the study. LD and MJ contributed to design of the study. SJ and LD contributed to statistical analysis. LD, HL, BG, and YJ contributed to experimental organization. SJ wrote the first draft of the manuscript. SJ, XL, HL, BG, MJ, YJ, JM, LS, and ZH reviewed and edited the draft. SJ, XL, and MJ contributed to project administration. All authors contributed to the article and approved the submitted version.

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Garden Smellscape–Experiences of Plant Scents in a Nature-Based Intervention

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This study explores how participants suffering from stress-related mental disorders describe their perception, interaction, and lived experience of garden smellscape during their nature-based rehabilitation. Natural elements, and especially nature smells, have been found to have a profound effect on stress reduction, suggesting an interesting link between odor in nature and stress reduction. The study was conducted as a longitudinal case-study, running over a period of 5 years, investigating participants' perceptions of a garden smellscape, after completing a 12-weeks nature-based rehabilitation in Alnarp Rehabilitation Garden, Sweden. All participants were treated for stress-related mental disorders. Data were collected through retrospective semi-structured individual interviews and analyzed according to interpretative phenomenological analysis. The results revealed in what way nature odor (odor in nature) evoked associations, emotions, and physical reactions and provide examples of how nature scents function as a catalyst for sensory awareness and memories. Findings supported the understanding that experiencing the smell of plants, especially pelargonium, may facilitate stress reduction and support mental recovery in a real-life context. The results of the study can be used for several purposes; thus, they are relevant for actors within the development of nature-based therapy, as well as stakeholders within the horticultural industry.

Keywords: pelargonium, horticulture therapy, odor, public health, ambient scent, stress-related mental disorder, well-being

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INTRODUCTION

Stress and stressful life situations can have a negative effect on a person's executive functions (e.g., memory, cognitive performance, and mood) as well as sensory system, in terms of increased or reduced sensitivity (Jonsdottir et al., 2013). When exploring activities and treatments that are considered to alleviate the negative effects of stress, nature and natural elements have been identified as possessing qualities that may support well-being and mitigate the effects of stress. This link between nature and human well-being, especially the understanding of how different elements of nature underpin a positive impact, is of great interest. Several studies have explored the health benefits to people who reside in natural environments (Mitchell and Popham, 2008; Hartig et al., 2014; Frumkin et al., 2017); exploring how nature can contribute to restore cognitive functions and facilitate mental recovery (Ulrich et al., 1991; Van den Berg et al., 2010; Tyrväinen et al., 2014) as well as nature's capacity to reduce stress (Ulrich et al., 1991; Sonntag-Öström et al., 2011;

Corazon et al., 2019). Further, there are also promising evidences that nature exposure may have an influence in the decrease of inflammatory conditions when inhaling certain volatile natural compounds (Andersen et al., 2021).

Smellscape is a central concept when studying and exploring the holistic odor experience of a place, such as a garden. The term was described by Porteous (1990, pp. 21–45) as the totality of the olfactory landscape in a specific environment (Henshaw, 2014, p. 5). Recently, the concept of urban smellscape has been explored by Henshaw (2014) to understand the perception and experience in a real-life situation has explored the concept of urban smellscape. Henshaw covers different perspectives of olfactory stimuli but interestingly touches on the aspects of how to design restorative smellscapes. In a recent Virtual Reality (VR) study on urban smellscape, Hedblom et al. (2019) identified that odor has a greater impact on stress reduction than visual and auditory stimuli. They highlighted that smellscapes in urban settings are an important aspect for human health and well-being. Yet, the understanding of the mechanisms behind the identified phenomena, especially the significance of odor perception, is less well researched (Henshaw, 2014, p. 5; Hedblom et al., 2019).

In human evolution, the key to survival has been the sense of smell, as it can detect and signal danger or safety and trigger an instinctive and subconscious reaction to fight, flight, or stay (Porteous, 1943). The odor perception comprises (1) odor characteristics, (2) environmental, and (3) individual factors (Henshaw, 2014, p. 26). The odor characteristics depend on the rate of evaporation, the concentration, and intensity, as well as the trigeminal stimulation. The environmental factors such as air temperature and quality, the surface of the environment, and wind have a significant impact on the detection of the odor. The individual factors for identifying and detecting odor can vary depending on age, gender, and a person's health status. Odor memory is formed from the very early days of our life and develops during our entire lifetime (Sugiyama et al., 2015). It has been shown that odors have a significant impact on memory, for example, the presence of odors can improve recognition (Dinh et al., 1999; Parker et al., 2001). Pointer and Bond (1998) suggest that context-dependent memory processes may underlie the formation and retrieval of odor-evoked memories, while Olofsson et al. (2016) have shown links between odor and memory due to genetics, pointing out the ϵ4 allele of the Apolipoprotein E gene as a risk factor. Köster et al. (2014) point out that unexpected experience of odors are easy to note and to remember.

Further, Olofsson et al. (2020) showed that the olfactory system was highly responsive to training and could promote cross-sensory transfer by increasing the visual learning. It has also been shown that exposure to odors, both outdoor and in-door odors, may enhance the olfactory function as well as odor memory (Mahmut et al., 2020b). There are also reports showing that loss of olfactory sense is associated with cognitive decline and dementia (Behrman et al., 2014; Stanciu et al., 2014). The decline of the *olfactory sense*, i.e., perception of odors and flavors, has been connected to age, different diseases, and mental health in previous studies (Murphy, 2002; Hummel et al., 2007; Bahar-Fuchs et al., 2011). However, Mahmut et al. (2020a) suggest that mindfulness training may improve perception of odors. The individual differences have been proven to be large, and the decline is often larger in men than in women (Hummel et al., 2002). However, studies suggest that the heterogeneity in olfactory decline is often related to secondary factors such as medication and dental health (Nordin et al., 2012; Sulmont-Rossé et al., 2015). Recent findings suggest that the age-related decline in olfactory sensitivity is not uniform but rather odor specific, as identification of mushroom-like odor and cinnamon was found to be equally identified across all ages (Seow et al., 2016).

The olfactory receptors are found in a small part of the epithelium, which is in our nasal cavity. These receptors are activated by volatile chemical molecules that stimulate the olfactory receptors, either *orthonasally*–through the nose when we smell–or *retronasally*, i.e., via the mouth, where the "odor molecules" are released from the food or beverage when we chew and thus contribute to multisensory flavor perception when we eat (Albinsson et al., 2017; Wolfe et al., 2017). Natural odors, such as, e.g., *Convallaria majalis* L. (Liliaceae), *Jasminum sambac* L. (Oleaceae), *Rosa x alba* L. (Rosaceae), and Chrysanthemum, that have been perceived as pleasant can evoke the feeling of joy, improve mood (Weber and Heuberger, 2008; Francisca et al., 2019) and have a calming effect on one's mind (Pálsdóttir et al., 2014; Sidenius et al., 2017). Olfactory properties of essential oils such as lavender, rosemary, and chamomile have been suggested to have a positive effect on mood and objective cognitive performance (Toda and Morimoto, 2008; Moss et al., 2009), which is in line with findings suggesting the stress-reducing effects, in what is more holistically described as, e.g., "green odors" (Fujita et al., 2010). Natural odors are also a central part of the multi-sensory experience and nature-based intervention called forest bathing in conifer forest, which presently is being used in Japan, to improve human health and reduce stress (Tsunetsugu et al., 2010). The positive effects of a coniferous forest are also identified in other studies where a walk or stay in the coniferous forest showed increased well-being and reduce stress level (Park et al., 2010; Dolling et al., 2017; Li, 2019). When separating the visual, auditory, and olfactory nature stimuli on stress reduction (such as feeling calm and relaxed), smells seem to have a more profound effect on stress reduction than visual and auditory stimuli (Hedblom et al., 2019), suggesting an interesting link between smells of nature and stress reduction. Due to lack of research in life world context the aim of the study was to investigate how participants in nature-based rehabilitation describe their perceptions and lived experiences of a garden smellscape.

MATERIALS AND METHODS

The study was conducted as a longitudinal single case-study (Yin, 2009), running over a period of 5 years, investigating participants' perceptions of a garden smellscape, after completing a 12-weeks nature-based intervention in Alnarp Rehabilitation Garden, Sweden. It should be notified that this study differs from aromatherapy by not including aromatic oils, topical applications, massage or inhalations but perceived plant odor in a garden context.

Participants

All participants were treated for stress-related mental disorders, i.e., exhaustion disorder (ICD- F43.8a), or depression (ICD-F32.0 and ICD-F32.1). The exclusion criterion to take part in the nature-based intervention was known alcohol or drug abuse. The participants were Swedish residents, mean age 45.5 years (25–62 years), with various levels of educational and professional status. Altogether, 59 former participants (50 women: nine men) participated in the study.

Procedure

Nature-Based Intervention

Since 2002, the Swedish University of Agricultural Sciences has conducted innovation projects on nature-based intervention at SLU Alnarp Rehabilitation Garden (Stigsdotter, 2003; Adevi, 2012; Tenngart Ivarsson and Grahn, 2012). In this context, nature-based intervention is defined as a health intervention (World Health Organization [WHO], 2021), implemented in an outdoor setting dominated by natural elements (Grahn et al., 2010; Corazon, 2012; Pálsdóttir et al., 2018a; Kristjánsdóttir et al., 2020; Segal et al., 2021) to support the rehabilitation process of individuals suffering from stress-related mental disorders, mainly exhaustion disorders (ICD 10 F42.8) (Gliese, 2014, pp. 13–15). The intervention was performed as a 12-weeks rehabilitation program supporting the participant's rehabilitation process.

Each intervention group consisted of up to eight individuals (Pálsdóttir, 2016) including four treatment groups each year, i.e., (1) fall-winter, (2) winter-spring, (3) spring-summer, and (4) summer-fall. In order to cover each season at least three times, the study was run over a period of 5 years. An interdisciplinary team of four professions ran the rehabilitation program: an occupational therapist, a physiotherapist, a medical doctor specialist in mental health, and a horticulturist. The program ran 4 days a week for four hours each day and included rehabilitation sessions such as horticulture therapy, psychotherapy, occupational therapy, and physiotherapy (Pálsdóttir et al., 2013). The rehabilitation programs offered activities for both work and rest, all of which intended to stimulate the participants' sensory experience. Each day was divided into four main sections–all activities were performed outdoors or in the greenhouses and in extreme weathers indoors: (1) morning gathering with herbal tea brewed on different kind of herbs (different kind of odors); (2) relaxation; (3) garden/horticultural activities and therapeutic sessions; and finally, (4) gathering and closure for the day (Pálsdóttir, 2014, pp. 35–36; Pálsdóttir, 2016).

The 2 ha garden was divided into two main areas: (1) the cultivation and garden area, a formal and cultivated space. The area had more of a garden or park-like character and (2) the nature area, a non-cultivated area with an informal appearance, including free growing vegetation and trees. The area had more of a natural characteristic (**Figure 1**). The vegetation in the garden included broad-leaf and evergreen trees, shrubs, perennials, and annuals as well as spring and fall bulbs, all for stimulating the different senses during the different seasons. The plant selection for the garden was based on using familiar plants (in Swedish context) that were easy to propagate and inexpensive. Attention was paid to visual aesthetics, i.e., different shapes, forms, and colors as well as olfactory and texture aesthetics, i.e., scented and tactile plants. There were places in the garden where one could engage in horticultural activities together with other participants or on their own, as well as places where one could sit and enjoy the surroundings (Pálsdóttir et al., 2018b).

The formal garden area included a large traditional vegetable garden of 300 m^2 as well as a smaller area with raised beddings to lift the crops closer toward the participants' face to enjoy the odor and the taste of the crops. Also, there were two greenhouses, one production house of 100 m^2 and one domed greenhouse "grow point" of 49 m^2 for potted vegetated plants and for early-stage propagation of seedlings and cuttings (**Figure 2**).

The "grow point" greenhouse was kept heated during winter for storing semi-hard plants. At the time of the study, the pelargonium collection was vast and included both scented as well as flowering varieties. Pelargonium sp. is an established cultivated plant, and the most produced potted plant in Sweden. Pelargonium sp. has a characteristic scent of geraniol, citronellol, mentol, and eucalyptol, compounds found both in the tentacles on the stems and leaves (Martinsson, 2000, p. 158). During winter, the greenhouse was full of rosemary (*Rosmarinus Officianlis L.*), lavender (*Lavendula* sp.), verbena (*Aloysia* sp.), and ground cherries (*Physalis* sp.) potted plants in addition to the geranium (*Pelargonium* sp.) for winter storage. The greenhouse was open to the participants, who were welcome to rest or work with the plants as they wished. The participants could engage in tasks on their own or together with others, e.g., taking cuttings, watering the plants, trimming and removing dead leaves and over bloomed flowers. At the beginning of the intervention, the head gardener showed the participants how to take care of the plants, so they would be comfortable doing this on their own.

Each morning, the daily program started with a gathering and drinking herbal tea. The tea was either brewed with fresh or dried plant leaves harvested from the garden. Often, the tea was made with fresh leaves from one of the geranium plants, as it was possible to harvest during all seasons. The head gardener showed the participants the different plants as well as how to propagate them by either cutting or by seeds. The tea was often made using leaves from pelargonium (e.g., different varieties *Pelargonium* spp.; *Pelargonium × domesticum*; *Pelargonium × hortum; Pelargonium graviolens*, *P. graviolens "Dr. Westerlund;" Pelargonium crispum*, and *Pelargonium odoratissiumum*) and of menthe (*Mentha × piperita* L. and *Mentha* spp.). Sometimes other plants were also used to make the tea, such as rosemary, lemon verbena (*Aloysia Citrodora*), marigold (*Tagetes* spp.), and pot marigold (*Calendula Officinalis L.*). Besides using the leaves for the tea, the plants were also harvested for other types of consumption, e.g., cakes, pesto, and herb salts.

Data Collection and Ethics Statement

All data are handled in accordance with the recommendations of the Swedish Ethical Review Authority for similar studies, and

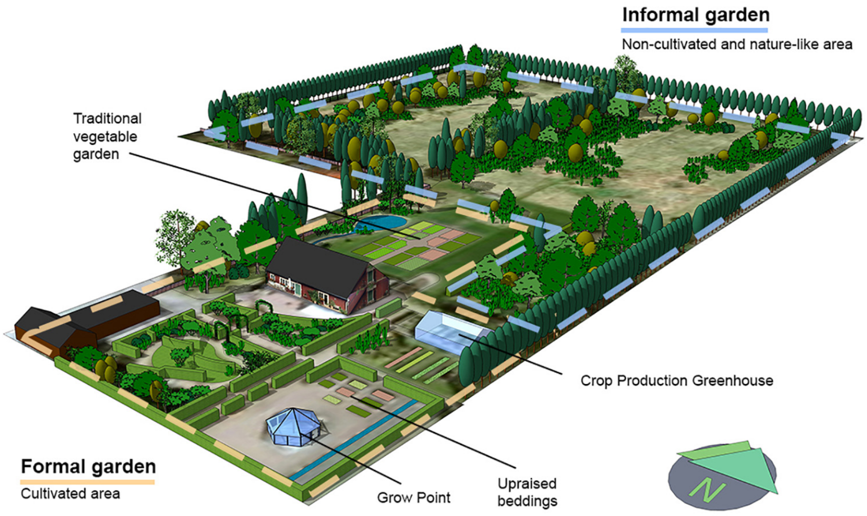

FIGURE 1 | Alnarp Rehabilitation Garden (2 ha) is divided into two main areas; the formal and cultivated garden (marked with yellow a dotted line) and the nature area (marked with a blue dotted line). Illustration by Cerwén G. 2021.

the study also follows SLU's data handling policy, in accordance with the General Data Protection Regulation. Data were collected from December 2007 until fall 2012. After each intervention group (four each year), the participants were asked to give their informed consent if they wanted to participate in an individual interview. All participants could withdraw from the study at any given point without further explanation as well as pass on questions if they did not want to reply to the questions. The participation was anonymous. The study was conducted as a retrospective semi-structured individual interview study. The focus of the interview was the lived experience of the nature-based intervention and on the role of the nature/garden for the participants' recovery process (Pálsdóttir, 2014; Pálsdóttir et al., 2014, 2018b; Cerwén et al., 2016). The first author conducted the interviews, within a month after the participants had ended their 12-weeks rehabilitation; all interviews took place in the rehabilitation garden in Alnarp. Each interview lasted for about 1 hour and was recorded, following the informants' signed consent, and afterward transcribed for the analysis.

FIGURE 2 | "Grow Point," a domed greenhouse of 49 m^2 used for storage of vegetative plants (e.g., pelargonium) and for early-stage propagation of seedlings and cuttings.

Data Analysis

The 59 transcribed interviews were systematically searched to extract all aspects of odor mentioned in the interviews. As the interviews were conducted in Swedish, the search was conducted with Swedish terms related to scent, smell, olfactory, and odors and specific scented plants and herbs.

When each of the word was detected, the relevant surrounding text was read to collect the whole section where the topic was mentioned. All the sections mentioning the participants' experiences relating to odor were collected into one document and analyzed according to stepwise procedure of interpretative phenomenological analysis (Smith et al., 1999, 2009). Interpretative phenomenological analysis aims to explore the participants' lived experience of a certain phenomenon, i.e., the perceived and lived experience of a garden smellscape in the context of nature-based rehabilitation.

The first and the second author, independently read the text several times to get a sense of the whole content, making notes on the aspects of interest related to the study aim. Then the main themes were abstracted and clustered so superordinate themes emerged. At the end of this process, the two authors compared, discussed, and arrived at an agreement on the main themes. Finally, all four authors discussed and agreed on the final formulation of the main themes grounded in the participants' narratives (raw data). The results are presented anonymously at a group level.

RESULTS

Four superordinate themes emerged, describing the participants' perceptions and lived experience of the Alnarp Rehabilitation

Garden smellscape. The results related to both the indoor (green house) and outdoor nature (the garden) experience and environments, see **Figure 1**. The plants referred to by the participants thus cover both traditional potted plants, vegetables, annuals, perennials, herbs, semi-woody shrubs, and fruit trees as well as nature in general. Besides the four main themes, one specific odor was mentioned more often than others, i.e., the odor from *Pelargonium* sp. Therefore, a special attention was given to the use of this species.

Nature Scent–Associations, Emotions, and Physical Reactions

In general, the participants' associations with nature scents were positive and expressed in terms such as nice smell, appreciation for natural fragrances, contributing to stress reduction and the feeling of being calm and relaxed, happiness, and joy of life. "*I go and feel the plants but also just stop and stand and just take in the plants, take in the place, the peace that is there and yes, breathe it in, you can say*." Participants also expressed how nature scents increased the perceived closeness to nature, sensuality, and what was described as an appreciated disconnection of the intellect and connection to the body and mind. The participants mentioned many kinds of plants and plant material that they liked the smell of, such as the odor of herbs, fruits, flowers, leaves, and needles to dried straw and wood. All those odors were associated with pleasantness, feeling calm and happy, as well as the feeling of being present in the moment. All of which can contribute to stress reduction. The connectedness to nature through olfactory stimuli was expressed as reconnecting with the inner self, feeling alive and happy. One species, in particular, was mentioned more than others and with more descriptions of pleasant feelings and feeling calm when touching the leaves and smelling the odor, i.e., *Pelargonium* sp. was often mentioned in connection with the smell of citrus. Some varieties did not smell pleasant but were still appreciated as a sensory stimulus and fun to compare with the other pleasant-smelling plants.

Apart from expressing associations relating to specific plants (e.g., pelargonium), the concept of more holistic sensory descriptions such as the odor of "green house" and "garden" odor emerged several times. The participants had positive associations to soil and planting, both in indoor and outdoor plant related activities. Additional examples of participants expressing associations with nature scents include spring, being outdoors, "breathe in the plants," and safety. Participants also described physical reactions in relation to lemon-scented plants, such as *"a kick for the brain*" (e.g., P*elargonium*, *Thymus*, and *Aloysia*).

It also became clear that the conversations about smells gave rise to reflections on natural and unnatural odors. The odors represented in the greenhouse, garden, or nature were described as natural scents, which participants separated from artificial smells. Unlike natural smells, artificial odors were described as unpleasant and sharp. Perfume was compared to the smell of cigarettes, viewed as pollution, intrusive, and leading to people taking up too much space. They evoked negative emotions, such as stressful and irritating. Despite the overall positive associations to nature scents, some participants also raised negative aspects connected to nature smells, such as being allergic or just simply not appreciating the smell of, e.g., pelargonium, due to what was described as its compact and too rich smell.

Natural/Nature Smell Functioning as a Catalyst for Sensory Awareness and Memories

Several participants expressed how they interact with plants and touch them, often with the aim to feel the smell of the plant and achieve the feeling of calm.

> *"...felt when I sat there and it was to touch all these spices, it will be the smells, it is the senses. Just that you get started a little, you are triggered to get started."*

Participants who had experienced hypersensitivity and had difficulties in using their senses and experiencing smells, sounds, or taste expressed that nature scents could function as a catalyst to sensory awareness. *"Because I have not had my senses activated before. I did not see anything, I did not smell anything. . ."* Regardless of whether the person felt a lack of sensory experiences, or that the sensory experiences were too strong, natural scents seemed to be perceived as detectable or appropriate and tolerable. The sensory experience of plants was also related to existential issues such as being alive: *"I was so aware of how the grass smelled and I had also started to feel like a little more alive there."* Participants who felt stressed expressed a desire to approach the plants, i.e., to smell and touch them, activities and sensory experiences that were experienced as relieving the stress. This was frequently and intentionally used as a medium for stress reduction, first practiced when in the rehabilitation program in the garden and then later brought into their home environment.

The participants produced their own plants by cuttings and selected their favorites to bring back home, both as a memory of Alnarp and to have their own sensory garden to use when they felt stressed and needed calming, especially some of the lemon/citrus scented geranium varieties. Several participants described how natural smells such as green house, soil, and straw evoked positive memories from childhood to life. The olfactory sense functions as a link, bringing happiness from childhood to the present.

> " *It reminds me of when I was with my grandmother in her garden when I was a child, went there in the garden paths and her little greenhouse they had behind their little cottage and so, it was a very happy period as well*".

Often, the positive memories related to time with grandparents in the garden or in the forest and helped the participants to reconnect with the feeling of joyfulness. The odor memories also helped the participants to recollect pleasant scents they used when needing their moods to be uplifted. The participants also expressed how unnatural smells brought back negative memories, such as stressful situations at work (perfume) and being a patient in a hospital (the smell of hospitals). Also, scents that signaled danger such as smoke and fire evoked anxiety in the participants. Further, they described how sensory stimuli was possible in nature but not in the indoor environment at the healthcare units. There was nothing there that could positively stimulate their senses compared to what was possible in the garden.

The Seasonal Variation of Smell

Participants expressed that there was a special smell in the green house which appeared to be intense and at times almost overwhelming, especially in combination with high temperatures. This was not the case for smells from the outdoor environment. It was also obvious that the sensory experiences varied during the different seasons, and depending on the time of the year, the natural smells were different. One patient expressed a sense of melancholy when approaching apples during late fall. The patient viewed the natural elements (an apple) and its state of degradation as a parable of the self.

> *"All the different varieties that smell and taste different… maybe there was some kind of melancholy in that total decay and which rhymed well with my mood, maybe because I was also mismanaged and decayed."*

Participants who were undergoing treatment during the winter also expressed not being able to have a sensory experience of the outdoor plants during winter. During winter, the smells are primarily related to the scent of plants in the green houses, especially the geranium in the grow point greenhouse.

The Fascination With Pelargonium

Since the most frequently mentioned plant species, concerning smell, was *Pelargonium* sp., especially the odor connected to citrus, we paid special attention to this species. Participants expressed a special interest in scented pelargonium varieties, in which both the leaves and the flowers gave odors, described as apple, peppermint, orange, rose, eucalyptus, and citrus. The participants liked to experiment with the different odors, rubbing the leaves and then smelling the best and the least pleasant scent. This experiment was mostly done together with others but when enjoying the favorite smell, it was done in solitude. During the program, the participants learned about different plants, how to propagate and cultivate them, and how to use/consume them. This interaction awakened an interest in keeping and cultivating plants in the garden as well as at home.

Several participants mentioned their pelargonium collection at home as their "Alnarp plants," which made it possible for them to feel the same calmness at home as felt in the rehabilitation garden at Alnarp. The olfactory and visual pleasantness were the main reasons for keeping their pelargonium collection at home. Other reasons were the tactile experience of holding the leaves in their hands and brewing tea. At the time of the study, one species of pelargonium, Dr. Westerlund, was found in abundance at the location.

DISCUSSION

The exploration of the perceived smellscape in the nature-based rehabilitation garden revealed four main themes concerning nature scents: (1) associations, emotions, and physical reactions; (2) Natural/nature scent functioning as a catalyst for sensory awareness and memories; (3) seasonal variation of scents; and finally, (4) the fascination with pelargonium. Identified themes provide example of several olfactory mechanisms that can be found in the garden context (natural scent) and outside of the garden context (unnatural scent) (**Figure 3**). The participants distinguished between natural odors and artificial odors, with the latter being associated with negative emotions, memories, and often stressful events. The natural odors were dominantly reported to evoke positive emotions, memories, and being joyful as well as stress reducing.

Several experimental studies have identified nature scents as important sensory stimuli, supporting stress reduction (Toda and Morimoto, 2008; Fujita et al., 2010), as well as there are odors inducing feelings of safety and comfort (Köster et al., 2014). Only a few studies have been conducted in a real-life context of lived experiences, particularly in a rehabilitation context.

It has been shown that odors affect eating behavior and seem to determine appetite and food choices, and thereby health (Hoover et al., 2020). In a recent study by Hedblom et al. (2019), implemented in a multisensory VR environment, the researchers found that a high rating of forest smell (olfactory stimuli: fir and mushroom) and park environment (olfactory stimuli: grass) resulted in a lower psychological stress response compared to an urban environment with olfactory stimuli of gunpowder and diesel. The perceived pleasantness of visual, olfactory, and auditory experiences at three different virtual environments (park, forest, and city) significantly differed, pointing out the olfactory sensory (scent) experience as the most important stimuli for stress reduction. The current study provides examples of how the act of handling and experiencing the smell of plants may facilitate stress reduction and support mental recovery in a real-life context (the Alnarp Rehabilitation Garden). Participants also expressed that natural olfactory stimuli (soil, wood, dried straw, vegetation) led to mental as well as physical relaxation. These were experiences that evoked feelings of being calm and happy, which is in line with effortless fascination as a source of mental restoration, as described by (Kaplan et al., 1989).

In the present study, natural smells such as lavender, grass, wood, and conifer needles were mentioned as pleasant and evoking strong feelings of connectedness to nature. Also, the feeling of being outdoors and breathing in the plants were associated with being part of nature. Nature connectedness is an eudemonic aspect of human well-being and has been positively correlated with a feeling of mindfulness and feeling happy (Howell et al., 2013; Capaldi et al., 2014). The participants described this as reconnecting with their inner self, feeling alive and happy. These feelings of being happy brought back positive memories from childhood (Proustian memories) and reconnected to feelings of joyfulness. The pleasant olfactory stimuli seemed to have a positive impact on the participants' mood and also brought back happy memories and emotions from the past. Individuals suffering from stress-related disorders can have a dysfunctional sensory system, in terms of increased or reduced sensitivity (Jonsdottir et al., 2013). In such cases, they either sense little or nothing from the smellscape around

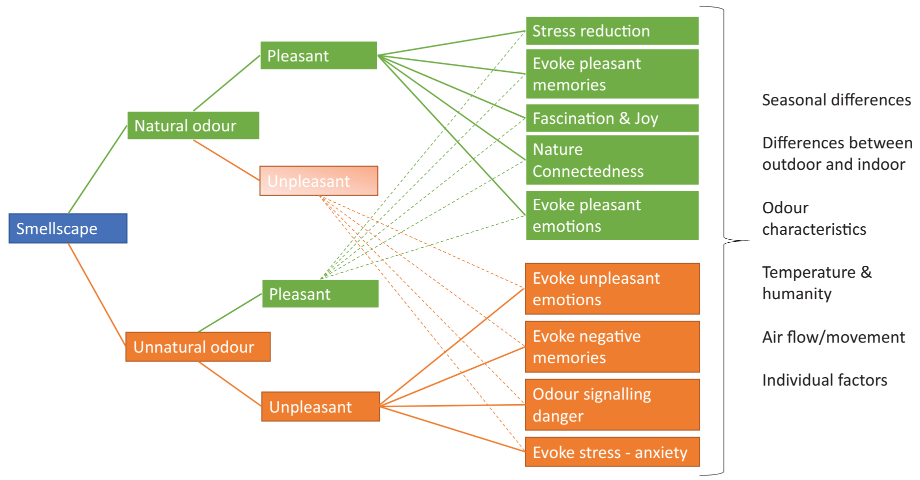

FIGURE 3 | Illustration of olfactory mechanism identified as natural and unnatural odor.

them or are hypersensitive. Regardless of these conditions, the participants in the study seemingly perceived the natural smells as being tolerable, whereas the unnatural smells were less tolerable. It turned out that unnatural/artificial scents were often referred to as unpleasant and evoked both negative memories and emotions from the workplace and hospital environment, as illustrated in **Figure 3**. Olfactory stimuli such as from perfume, smell of cigarettes, and "hospital scent" were associated with stressful situations, being harsh and unpleasant, and associated with being a patient. In comparison with the indoor environment (workplace and hospital), the garden milieu was perceived as a place offering positive sensory stimuli, supporting their well-being. Pelargonium/geranium were mentioned repeatedly and perceived as popular among the participants. The results specifically indicate a specific positive link between sensory odor experiences with pelargoniums, described as rose, lemon, and citrus, and stress reduction as the participants intentionally used the smell of plants for stress reduction, both in the garden and then at home. Even though the location provided a vast variation of pelargonium scents, one was mentioned numerous times, i.e., pelargonium "Graveolens," particularly a variety called "Dr. Westerlunds." The explanation for this is partly that it had been identified as possessing a well-liked citrus odor and that due to plant physiological properties, it is easy to propagate which makes it suitable for implementing in activities within the program. Taking this into consideration, it is reasonable to assume that a great proportion of identified associations and expressed experiences with geranium, in general, are in fact closely linked to Dr. Westerlund. Previous studies exploring geranium have pointed out its health-promoting effects (Peace Rhind, 2014, pp. 304–305) and already during the 19th century, Dr. Ernst Westerlund (Swedish physician) recommended pelargonium (*P. graviolens)* for cleaning the air from diseases (Martinsson, 2000, pp. 164–167). More recently, the smell pelargonium has been identified as reducing anxiety (Morris et al., 1995) as well as enhancing relaxation and improving sleep (Spence, 2020). These findings support the results of the study; however, future studies are needed to get a better understanding and clarity on the subject.

Future Studies

It was interesting to note the great fascination with pelargonium/geranium, and its stress reducing effects. Considering the great presence of the variety Dr. Westerlund, and that this variety has been studied scientifically in the past, it is reasonable to use this variety as a starting point for future experiments. However, in order to fully understand the mechanisms underpinning this effect, future studies should focus on identifying chemical compounds of pelargonium and the sensory perception of these compounds. Such knowledge is of great importance in knowing what nature odors may induce the perceived feeling of being relaxed and calm. A compilation of the geranium's fragrance properties can be of great interest and benefit to the public, researchers as well as stakeholders and growers within the horticultural industry. Results such as those presented in this study, as well as future in-depth analysis and scientific grounding of the chemical aspects and other specific properties of plants, can further contribute to an increased interest in plant scents and how they affect humans. An effective plant aroma is for example lavender; it has been used in medicine as a narcotic, anti-inflammatory, and antidepressant substance (Khalil et al., 2019). It has for example been shown that lavender aroma was effective in reducing anxiety among cancer patients (Abbaszadeh et al., 2020). In lavender, the substances linalool and linalool acetate may stimulate the parasympathetic system, causing narcotic effects (Karadag et al., 2017).

CONCLUSION

The study provides answers to what role scented plants play in nature-based rehabilitation for participants suffering from stress-related mental disorder. Finally, the result adds knowledge regarding whether there is a particular species, citrus scented pelargonium, which may reduce stress and support mental recovery more than others, specifically, its qualities. The results of the study can be used for several purposes, depending on the target group, and thus become relevant for actors within the development of nature-based therapies, but also firms and stakeholders within the horticultural industry, e.g., growers, nurseries, and producers of raw materials to produce plant extracts and geranium products. This indicates a potential for further development of novel products for stress reduction by using nature-based compounds or the plant itself.

LIMITATIONS

Although the study was conducted over 5 years, including 59 representatives from all intervention groups during that time, the study only focused on one target group, i.e., individuals suffering from stress-related disorders. We acknowledge that other parts of the nature-based intervention program also contributed to stress reduction but in this study, we wanted to highlight the role of scent garden context. Therefore, we do not acclaim that overall stress reduction is solemnly due to scent experience. It is additionally important to highlight that the interviews are based on the participant's narratives of how, e.g., plants have affected their mood and/or emotions. Since the participants not specifically were requested to consciously discuss alternative reasons to these perceived emotions/mood states we can't claim with complete accuracy that the perceived effects always were caused by, e.g., plants. In order to increase the ecological validity of studies on lived experience and perception of a garden smellscape, other target groups should be included in future studies, both individuals participating in health interventions and the public. We found the use of interpretative phenomenological analysis an appropriate choice of method as it aims to explore in detail individual experience of a specific phenomenon, in this case, their experience of scent in the context of nature-based rehabilitation. However, the method is criticized for lacking standardization and fundamentally being a subjective approach suggesting other researchers might come up with a different interpretation of participants' narratives.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed by the Region Ethical Committee in Lund, Sweden. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AMP contributed with the acquisition of data, analysis and interpretation of data, and drafted the initial manuscript and **Figure 3**. SS contributed with the analysis and interpretation of the data, and revised the article critically for important intellectual content. LM and KW revised the article critically for important intellectual content. All authors contributed to the conception and design of the study, including revision, reading, and approving the submitted version.

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REVIEW
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Scent in Motion: On the Multiple Uses of Ambient Scent in the Context of Passenger Transport

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There is undoubtedly growing interest in the role of scent in the design of multisensory experiences. However, to date, the majority of the research has focused on its use in the (static) built environment. As highlighted by this narrative review, somewhat different challenges and opportunities arise just as soon as one starts to consider olfaction in the case of transportation–what might be called "scent in motion." For instance, levels of anxiety/stress while traveling are often higher (especially in the case of air travel), while, at the same time, the passenger's personal space is frequently compromised. Four key functional roles for scent in the context of passenger transportation are outlined. They include the masking of malodour, the introduction of branded signature scents, short-term olfactory marketing interventions, and the functional use of scent to enhance the experience of travel. In the latter case, one might consider the use of scent to help reduce the stress/anxiety amongst airplane passengers or to give the impression of cleanliness. Meanwhile, in the case of driving, scents have been suggested as an inoffensive means of alerting/relaxing the driver and may also help tackle the problem of motion sickness. The specific challenges associated with scent in motion are reviewed and a number of future opportunities highlighted.

Keywords: transport, malodour, scent, functional scents, signature scents, scent marketing

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INTRODUCTION

Scent plays an important role in our experience of the built environment (see Spence, 2020c, for a recent review). This should come as little surprise when it is realized that the world's majority urban population spends an estimated 90–95% of their time indoors (Ott and Roberts, 1998; Klepeis et al., 2001; Wargocki, 2001; Velux YouGov Report, 2018)[1]. In this review, I will consider the role played by ambient scent in passenger transportation–what might be considered "scent in motion," though, as we will see later, sometimes it will be more a case of "stench in motion" (Robinson, 2016). To give some context, North Americans spend an average of an hour a day behind the wheel (https://www.volpe.dot.gov/news/how-much-time-do-americans-spend-behind-wheel), be it the daily commute or the school run (see also Chapin, 1974). This represents a not inconsiderable source of stress for many people, especially when their travel is, for whatever reason, impeded (Novaco et al., 1990). Indeed, commuting/travel is one of the few aspects of our daily lives that has not gotten any faster as the decades have gone by Colvile (2017). At present, average speeds in

[1]Currently, around 55% of the population live are thought to live in urban areas, up from 30% in 1950, see https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

the world's growing number of megacities are around 15 km/h (Nyirinkindi and Paris, 2020), and that figure is predicted to drop down to 3 km/h by 2030.

Regardless of the sector (be it healthcare, retail, etc.), increasing competition in the marketplace typically leads to a greater focus on the experience. In the case of passenger transportation, the shift in focus is from the final destination and the duration/cost of the trip to a greater emphasis on the experiential qualities of the journey itself (as probed by the all too frequent request for feedback along the lines of "How was the experience?"). The much anticipated arrival of space tourism further promises to elevate transportation to an entirely new level, at least for the lucky few who can afford to partake in this admittedly niche activity (see Henderson and Tsui, 2019). Indeed, transportation is an especially dynamic sector currently, with radical challenges to conventional business models an increasingly common occurrence—-think here only of the disruption offered by the likes of Neutonomy, Uber, and Tesla (see Smart, 2017; Woodward et al., 2017; Spence, 2021a; though see also Diao et al., 2021; Liberatore, 2021, on the downside of rideshare apps, otherwise referred to as Transportation Network Companies (TNCs), such as Uber and Lyft). What is more, the introduction of flying taxis may be closer than many people think (The Local, 2019; Pasztor and Tangel, 2020; see also Murphy, 2021). All that before we get to Richard Branson's Hyperloop Propulsion Pods, with matching signature scent (see Giacobbe, 2021). Given the highly-dynamic and competitive nature of the transportation market, there is a growing opportunity to enhance/differentiate the multisensory travel experience for passengers via design that targets the sense of smell.

That said, when thinking about the multisensory experience of travel, it is important to consider how our experience, especially of public transport, typically involves not only the time spent on the move but often requires the passengers to transit through, and often wait in, stations (see Schivelbusch, 2014, on the early history of the railway station), airports (Wattanacharoensil, 2019), bus/tram stops, etc. These spaces are, properly considered, therefore a part of the experience of travel too (cf. Goetz, 2019), though equally also fit within any discussion of scent in the built environment. Indeed, given the importance of primacy/recent effects to human memory, they may actually play a disproportionately important role in the passengers' memory of their travel experiences (see Carbone and Haeckel, 1994; Berry et al., 2002; Carbone, 2004; LaTour and Carbone, 2014, on the notion of "Sticktion"). Hence, in the narrative review that follows, I will look at the role of scent in all stages of the journey and across a wide range of different forms of travel. As we will see in a moment, though, while many of the same issues and opportunities present themselves in the case of scent in the built environment (static) and in the case of dynamic scent (i.e., transport), there are also a number of salient differences. It should also be noted that, as has just been mentioned, the distinction between scent in motion and scent's use in the built (i.e., static) environment is by no means always clear-cut, with stations, airports, etc. fitting naturally into both categories.

Air Pollution

The topic of air pollution is also very relevant to the themes of this review inasmuch as many forms of transportation are associated with high levels of air pollution, some of which are detected consciously by those who are themselves traveling, or else by others who may be in the vicinity. Indeed, levels of air pollution in and around different forms of transportation (i.e., both for those who are traveling and those who find themselves nearby) tend to be much higher than is commonly the case when considering the olfactory atmosphere of the built environment. For instance, just take Oxford Street in London, often mentioned as one of the most polluted streets in the world in terms of traffic-related air pollution (cf. Popovich et al., 2019). The levels of nitrogen dioxide (NO_2) recorded on this world-famous shopping street are dangerously (not to mention illegally) high more than 80% of the time.

The deleterious effects on respiratory health of such transport-related pollution are well-documented (WHO Technical Report, 2013; van Veldhoven et al., 2019). Increased levels of air pollution may result in increased road rage amongst drivers. Consistent with such a view, almost 50 years ago, researchers in California had already highlighted how the number of road traffic accidents in Los Angeles correlated with the level of air pollution (Ury et al., 1972)[2]. Relevant here, therefore, is recent research reported by Dmitrenko et al. (2020) showing how pleasant scents can be used to promote safer driving, better mood, and improved well-being in angry drivers.

The air that people breathe in (in particular, the particulate matter) when traveling on underground transportation can be pretty toxic (cf. Gouveia and Maisonet, 2005; Paton, 2019; Radnedge, 2019), with a trip on the London Underground, the dirtiest in the world, exposing passengers to dangerously high levels of particulate matter. The levels of toxic airborne pollutants in the atmosphere in the London Underground, are currently almost 20 times higher than recommended by the World Health Organization (WHO). Given such shocking figures, one might think that adding a pleasant scent is probably the last thing that commuters should be worrying about. As another example of the olfactory pollution that was once associated with travel, one need only think back to the days when a flimsy cloth curtain was all that separated the smoking section at the back of the airplane from the rest of the non-smoking passengers. While a separate non-smoking section has been mandated in planes in the US since 1973, smoking was only banned completely on flights to/from or within the US in 2000, while the ban only came in much later in China; c. 2016; (Pallini, 2020). Given the well-established dangers of passive smoking, this would also have to constitute a pretty polluted olfactory environment (Crawford and Holcomb, 1991; Repace, 2004). Furthermore, one of the arguments put forward by those who are against airport expansion relates to the likely increase in air pollution experienced by those living in surrounding neighborhoods (e.g., see Anon, 2021b).

[2]Though, on reflection, perhaps this isn't all that surprising given that the more pollution there is, the more cars one might expect there to be on the roads, all else being equal.

Fortunately, however, most of us typically spend much less time exposed to such pollutants (which may, or may not, be perceptible consciously), meaning that any deleterious effects on our health and well-being are, if not mitigated entirely, at least reduced significantly as compared to the volatile organic compounds (VOCs) that are typically found in poorly-ventilated home or office environments where we spend so much more of our time (see Spence, 2002, 2021a; though see also Watson, 2021). Here, for instance, one might wonder whether there is an equivalent to the sick-building syndrome (SBS; Spence, 2002, 2020c; Love, 2018) that was sometimes reported half a century ago—-something of the sort of sick transport syndrome (STS; a quick online search reveals the existence of Sick Yacht Syndrome, SYS; https://www.rgf.com/article/sick-yacht-syndrome/)?[3] There is, though, a separate question about exposure to air pollution amongst those who work in the transportation/travel industries (Repace, 2004; Bloomberg, 2017). Finally here, it is worth highlighting how the emergence of the Covid-19 pandemic, has bought into sharp focus the potentially infectious atmosphere while traveling on public transport (e.g., see Anon, 2021a; Bunyan, 2021)–and see Luke et al. (2020) for the crucial role that transportation played in facilitating the spread of the Spanish Flu a century earlier.

Anxiety

One of the other noticeable differences between scent in the built environment (see Spence, 2020a, Spence, 2020b) and scent in motion (e.g., in transportation) relates to the fact that for many of us, travel (especially air travel) is a major cause of anxiety. Historically, anxiety associated with transportation has often been triggered by the introduction of new, often much faster, forms of travel, such as, for example, the train (i.e., for those who were used to traveling by horse-drawn carriage or stagecoach; see Schivelbusch, 2014). Indeed, the palpable concerns of many early rail passengers (and a number of eminent doctors/medics), was eloquently brought out in Schivelbusch's 2014, *The Railway Journey*. Similarly, when the first public elevator was introduced in 1857 in the US (described in the initial patent as a "vertical railway"; Prisco, 2019), at the Manhattan Department store E.W. Haughtwhat & Company in New York it was not a success, closing 3 years later (Bernard, 2014; Prisco, 2019). In this case, it may well have been the confined nature of the space (possibly triggering claustrophobia), not to mention the hidden nature of the underlying operations (mechanisms), that made the public nervous (e.g., Bernard, 2014; cf. Schivelbusch, 2014). The anxiety that this once novel form of transport gave rise to initially was eventually ameliorated by the introduction of mirrored surfaces (to show the passengers who else is in the lift with them, while also making the space look bigger) and the so-called busboy (whose presence continued long after it was strictly needed). Elevator music may also have been used to help calm those who felt anxious (see Friedrich, 1984; Lanza, 2004)[4].

Nowadays, though, the most anxiety-inducing form of public transport would appear to be air travel. To give some sense of the problem, 40% of the population in North America experiences some degree of anxiety associated with this form of travel. An estimated 6.5% of them suffer from a fear of flying known as aviophobia (Gould, 2017), while 2.5% have a clinical phobia. This means that they either avoid flying altogether or do so while enduring significant distress (Schaaff, 2019). This is, of course, somewhat ironic given the statistics showing that per mile traveled, one is significantly more likely to die when traveling by road than by air (Schaaff, 2019), as was much commented on following 9/11.

As we will see at several points in this review, driving represents a very particular form of transport inasmuch as there is a potentially important distinction between the driver and any passengers. While both share the same olfactory space/atmosphere, the majority of the multisensory interventions in this area have been targeted at the driver (e.g., alerting/relaxing them) rather than at their passengers[5]. Relevant here, it terms of anxiety, it has been suggested that many motorists appear to drive more dangerously following the introduction of the latest new car safety innovations. The suggestion is that this helps them to maintain a certain desirable level of perceived risk/anxiety, a phenomenon known as "risk compensation" (Peltzman, 1975; Wilde, 1982; Evans and Graham, 1991). Relevant to the theme of the present review, the research shows that ambient scents tend to exert a more positive effect over our mood and well-being when we are stressed/anxious than when we are calm (Warren and Warrenburg, 1993)[6]. Hence, it could be imagined that ambient scent would play a more important role in the context of transportation than in the context of the built environment.

Personal Space

Crowding is also often more likely to be a problem on public transport than is typically the case in the built environment (as highlighted by people's oft-discussed dislike of sitting in the middle seat on the train: McGeeham, 2005; Evans and Wener, 2007)[7]. Interpersonal space is much lower still when it comes to those passengers who are forced to travel in the confined space of mass transportation (be it Mass Transit or the London Tube) at rush hour that pretty much anywhere else (cf. Dipodjoyo, 2019). Is there any other situation, one might

[3]That said, the incidence of SBS (Love, 2018) would appear to be in decline, perhaps due to improved ventilation.

[4]Relevant to the present review, while "elevator music" became an expression in its own right, I have heard no mention of elevator scent (though see Robinson, 2016; Valenti, 2018, for the Elevator Scent launched by Off White and Byredo). One concern, though, about introducing scent in this case is the highly-confined nature of the space.

[5]The rise of the semi-autonomous and fully autonomous vehicles is, though, slowly starting to blur this particular distinction (Anon, 2016; Kurczewski, 2020). Relevant here, the potential use of scent to enhance an individual's trust in the context of autonomous driving represents a particularly intriguing direction for research (see Wintersberger et al., 2019).

[6]After a decade of research studying the impact of fragrance on mood and well-being for International Flavors & Fragrances (IFF), one of the world's largest flavor houses, Warren and Warrenburg (1993, p. 9) arrived at the following conclusions: *"1. Fragrance-evoked mood changes are small, but beneficial to our well-being. 2. Fragrance can be used to reduce the stress response in humans, but its physiological effects on a non-stressed subject are minimal and difficult to measure."*.

[7]Meanwhile, keeping the middle seat on the airplane empty has been suggested to be an effective strategy to reduce Covid-19 infection rates while flying (Matthews, 2020).

FIGURE 1 | Do we ever get closer to unknown strangers than on the underground? [Copyright P. Summers].

ask, where one's personal space is so radically compromised (see **Figure 1**)? Combined with the often high temperatures (Thompson, 2014)[8] and lack of natural ventilation, this invasion of the passenger's personal space (Sommer, 1959, 1969; Horowitz et al., 1964; Felipe and Sommer, 1966; Dosey and Meisels, 1969; Kennedy et al., 2009) in the London Tube, but also on other forms of public transport, can soon lead to an awareness of other people's body odors that most of us would rather do without. The overpowering odors can be especially noticeable in the summertime when it can get very hot down there (according to one press report concerning the London Underground, in the summer it is sometimes above the legal temperature for transporting livestock; see Thompson, 2014). The reduced personal space brings the passenger much closer to the smell of unknown others than is typically the case elsewhere in our daily lives. What is more, this is typically found to be an unpleasant experience with those other unknown passengers of other races and/or social classes often suggested to have a distinctive, and frequently disliked, scent (e.g., Orwell, 1937; Largey and Watson, 1972; Classen, 1992; Manalansan, 2006; Bever, 2019)[9].

One artist who has worked in this space is Angela Ellsworth. In a provocative piece of what I presume can only be called "olfactory performance art," Ellsworth wore a jersey cocktail dress soaked in her own urine to the opening reception for the Token City installation (a subway simulation) by artist Muriel Magenta at the Arizona State University Art Museum in 1997 (http://museumofwalking.net/works/solo_actual1.html). According to Drobnick (2006), the idea behind the guerrilla art project (going by the name Actual Odor), was precisely to draw people's attention to the way in which malodour destroys any social boundaries that exist in a subway, as it permeates the space and transcends visual barriers or experiences.

[8]Note that high temperatures have also been linked to increased anti-social behavior (Baron and Ransberger, 1978).

[9]This, one of the themes brought out in Oscar-winning Korean movie, Parasite – a very dark comedy indeed (Lawless, 2020)!.

On the Rise of Olfactory Sensitivities

The typically more confined space, and reduced interpersonal distance/space, involved in most forms of public transport differentiates it from our experience of the built environment (Spence, 2020a,b). As we will see below, the confined space may sometimes also increase people's sensitivity to any olfactory manipulation. At the same time, however, it is worth stressing how one of the challenges associated with the deliberate scenting of the built environment in recent decades has been the increasing complaints of those suffering from multiple chemical sensitivity (MCS) syndrome (Lacour et al., 2005). That said, the majority of cases of fragrance sensitivity that have been described in the literature would appear to have been triggered by personal fragrance rather than by ambient scent (Spence, 2002; Byatt, 2003; Fletcher, 2005; Caress and Steinemann, 2009; Steinemann, 2019). In turn, this may perhaps be related to the shift away from the overpoweringly-heavy personal fragrances that were such a distinctive feature of the 1980's, at least in North America)[10]. According to the latest research, such enhanced responsivity to olfactory stimuli appears to reflect a response bias rather than enhanced sensitivity to particular odorants (Andersson et al., 2020). I am not aware of such complaints related to olfactory sensitivities having been tied to the ambient fragrancing of public transport.

SCENT IN MOTION: THE MULTIPLE ROLES OF AMBIENT SCENT IN DIFFERENT FORMS OF TRANSPORT

Traditional means of getting from a-to-b, such as walking, but also traveling on horseback, bicycle, or motorbike (Pirsig, 1974), or these days, on an e-scooter, have in common exposure to the elements. This typically includes the ambient scent of the built or natural environment through which a person is traveling[11]. What is lost, when this aspect of the experience is denied (e.g., due to anosmia), has been highlighted by various writers (e.g., Tafalla, 2013, 2014). Commentators have also drawn attention to the rich world of scent that pedestrians might encounter when moving through the city via the development of scent maps of cities such as the one made of Amsterdam (e.g., see Degen and Rose, 2012; though see also Tan, 2013; Henshaw, 2014; Poon, 2015; Leimbach, 2017; McLean, 2018). The contemporary experience of scent while passing through the city contrasts radically with the frequent historical complaint concerning the stench of human effluence that nearly always greeted the nostrils of those moving through urban areas in centuries gone by (e.g., Corbin, 1986; Potter, 1999; Jütte, 2005; el-Khoury, 2006; Bradley, 2015; see also Edensor, 2014; Misra, 2015)[12].

While artists and designers have drawn attention to the olfactory interest/pleasure of a walk through the city, there has been far less research on the impact of such smells, and how they may interact, or be integrated, with other components of the multisensory environment (Ba and Kang, 2019a,b). Though it is worth noting that in these cases the observer is in motion while the scents themselves are static. More often than not, in the examples reviewed below, the scent is delivered from the vehicle or carriage that is itself moving. This observation, once again, hinting at the challenges associated with delivering a clear definition of what constitutes "scent in motion."

In the rest of this section, I would like to consider various of the major forms of transport[13], and assess the differing role/opportunity that scent has played. However, rather than organizing this section on the basis of different modes of transport (be it bus, train, tram, or plane, etc.), it seemed more enlightening to organize the review around the four different principal purposes for which scent have seemingly been introduced into passenger transport. These are: masking malodour, olfactory marketing, signature scents, and functional scents.

Scent in Motion: Masking Malodour/Pollution

As has been noted already, levels of pollution are often much higher in or around transportation than in the built environment. While issues of noise pollution from various means of transport are a major cause for concern (e.g., Burne, 2014; Owen, 2019; Benfield et al., 2020), it is the olfactory, or atmospheric, component of pollution that will be the focus here. That said, it is important to note that many of the pollutants that are so bad for our health are not perceived consciously. One attempt to mask any unpleasant odors in the London Underground took place in 2001, when a pleasant scent by the name of "Madeleine" was introduced for a trial period into several stations. The fragrance had already been introduced successfully into the Paris Metro in 1998, not to mention in the Hong Kong Metro. It must therefore have seemed like a good idea to those in charge of Transport for London to do the same. A scent-encapsulated fragrance described as smelling like *"a fresh, watery floral bouquet of rose and jasmine, combined with citrus top notes, tiny touches of fruit and herbs, giving way to woody accents and a hint of sweetness in the base"* was deposited on the floors in St. James' Park, Euston, and Piccadilly stations to be released when the passengers walked over them.

The confined space on the underground, where people have no choice but to breathe in the air, makes the deliberate introduction of ambient scent a more sensitive and challenging topic than it might be elsewhere. Indeed, the commuters soon started to complain once they became aware of what was going on. In this case, part of the problem, may have been the fragrance

[10] As an article in The New York Times in 1988 put it: *"The American woman has acquired a taste for eaux de toilettes and colognes that are unusually strong and lasting"* (Wells, 1988).

[11] Along these lines, one of the protagonists, Martha Coffin Wright in Dorothy Wickenden's The agitators, writes in a letter about the members of the pubic watching a wedding in 1860 in the United States that they were there: "to hear the music, and 'take a smell" (Wickenden, 2021, p. 162).

[12] Intriguingly, though, some Ancient Roman sources actually have the city-dwellers complaining about the foul goaty/garlicky smell that greeted their nostrils on visiting the countryside (Morley, 2015, p. 117).

[13] Transport is defined as taking or carrying (people or goods) from one place to another by means of a vehicle, aircraft, or ship etc.

itself, which was described by one commuter as a *"cheap fragrance that smells slightly like industrial cleaner. It's a good idea as long as you use a fragrance that doesn't make the station smell like a toilet."* (quoted in Addley, 2001). It turns out that while the scent released on the various underground systems has the same name, "Madeleine," its composition is subtly altered depending on the local conditions (Anon, 2001a,b).

Along similar lines, in 2019, a number of the trams on Vienna's U-bahn trialed perfumed carriages following complaints that the underground vehicles were sometimes unpleasantly smelly during summertime (despite widespread air-conditioning). A pleasant yet subtle citrus fruit scent was introduced in order to minimize malodour (Walker, 2019). As is often the case, this olfactory intervention appears to be as much sensory marketing as anything else. One of the other intriguing reasons for bus services and mass transit to introduce a pleasant scent has been in the hope that it might help nudge more people to use public transport (Poon, 2017). In decades gone by, motorists would sometimes hang a scented card (often in the shape of a pine tree or orange) from the rear-view mirror that would slowly release the matching scent thereby hopefully masking any malodour that might otherwise have been perceptible in the car (for a simple sense-hack involving a clothes peg and essential oil, see Cleary, 2021). Even Tesla have come out with a scented card smelling of musk in the shape of Elon Musk's head. According to the website (https://elonsmusk.co/): *"The original Elon Musk air freshener, made with the real scent of Musk. Make your car smell like the world's hardest working billionaire."* According to press reports, a number of the airlines also pump fragrance into the air conditioning in their planes in order to help eliminate malodour (McGuire, 2017).

Scent in Motion: Marketing via the Nose

In recent years, a number of more-or-less successful marketing campaigns have been introduced on various forms of public transport in confined spaces such as the Underground. Olfactory marketing has the advantage over other media that in confined spaces such as the Underground, commuters/travelers are exposed to the message no matter where they look or on what they happen to be attending to visually (cf. Nibbe and Orth, 2017). One such olfactory marketing campaign that was introduced into the London Underground two decades ago was pulled after only a day though. The campaign for the Amaretto di Saronno liqueur brand involved releasing the drink's distinctive almond aroma into the underground. The plan had been to release an almond scent into the ventilation system for 2 weeks, hoping to appeal to the olfactory sensibilities of those who found themselves on the tube. Unfortunately, however, the campaign coincided with the release of an article in the country's most widely read newspaper, informing their readers how to recognize signs of terrorist activity. Commuters, especially those on the underground, were warned to be extremely cautious should they detect an almond-like smell, given that the poisonous gas cyanide is made from almonds (albeit bitter almonds), just like the drink (Jury, 2002; Lim, 2014, p. 84)!

In 2010, on Highway 150 in Moorseville, North Carolina, USA, a huge billboard for Bloom, a division of Food Lion, a grocery store displayed a piece of steak on a fork (see **Figure 2**). The ScentAir company created a scent that smells of black pepper and BBQ that was pumped out to passing motorists by means of a large fan positioned at its base that blew over a number of BBQ fragrance oil cartridges. The scent was dispersed in the mornings and afternoons when commuter traffic was likely to be at its peak. One bemused motorist described it thus: *"It smells like, uh, barbecue, like hickory or something being barbecued and smells like steak."* (Aronoff, 2010).

A decade later, scent dispensers were installed on a number of city buses in Seoul, South Korea, that recognized when the Dunkin' Donuts jingle played on the radio. They responded by releasing coffee aroma for the passengers to inhale. The idea behind this Dunkin' Donuts *"Flavor Radio"* campaign was that after stepping off the bus, the passengers would soon enough come across one of the chain's many stores and thus be primed to pay a visit. With a 16% spike in visitors to Dunkin' Donuts branches situated close to a bus stop, not to mention a 29% increase in coffee sales, the evidence suggests that this multisensory marketing strategy (i.e., involving both scent and sound) really did work (Garber, 2012). Others have reported that releasing the smell of coffee on the petrol station forecourt also leads to a dramatic increase in sales (Pape, 2009; Spence, 2015).

In 2013, I was involved in an olfactory marketing campaign with a London-based marketing agency. The campaign involved a specially-modified London taxi (a black cab) being sent out around the capital's streets pumping-out the smell of McCain's Ready Baked Jackets, basically microwavable oven-baked potatoes (Anon, 2013). At the same time, a few 3D video signs were erected at a number of bus stops. The idea was that curious commuters who chose to push the button on the baked potato were surprised when a pleasant baked potato aroma was released (see **Figure 3**). In the words of one commentator: *"Each billboard includes a fiberglass potato sculpture and a mysterious button: Push it, and the tuber discharges the aroma of "slow oven-baked jacket potatoes."*

The following year (i.e., 2014), Tennent Caledonian launched a new drink Lemon T., a light lager mixed with lemon soda. In this case, parts of the Glasgow subway were ambiently-scented with a product-congruent sweet lemon aroma that was supposedly subtle enough not to distract commuters from their journey (Sutton, 2018). Meanwhile, in India, in 2016, the car manufacturer Ford teamed up with advertising agency Kinetic Worldwide to place a number of multisensory billboards to advertise the Ford Mustang at airports (McEleny, 2016). Not only did the motion-activated billboards play the sound of the car's engine to passers-by, but they also emitted smoke to mimic the look and smell of burning tire rubber. Another intriguing example of out-of-home scent marketing comes from Marriott International, who spray scents that are designed to match the destinations offered in its travel program in the vicinity of advertisements displayed in public places (e.g., releasing a coconut aroma for Greece; Mobile Marketing, 2020; Murphy, 2020).

Objections have though, on occasion, been raised to the use of food scents in olfactory marketing. This was exactly what happened when the "Got milk" campaign in California decided

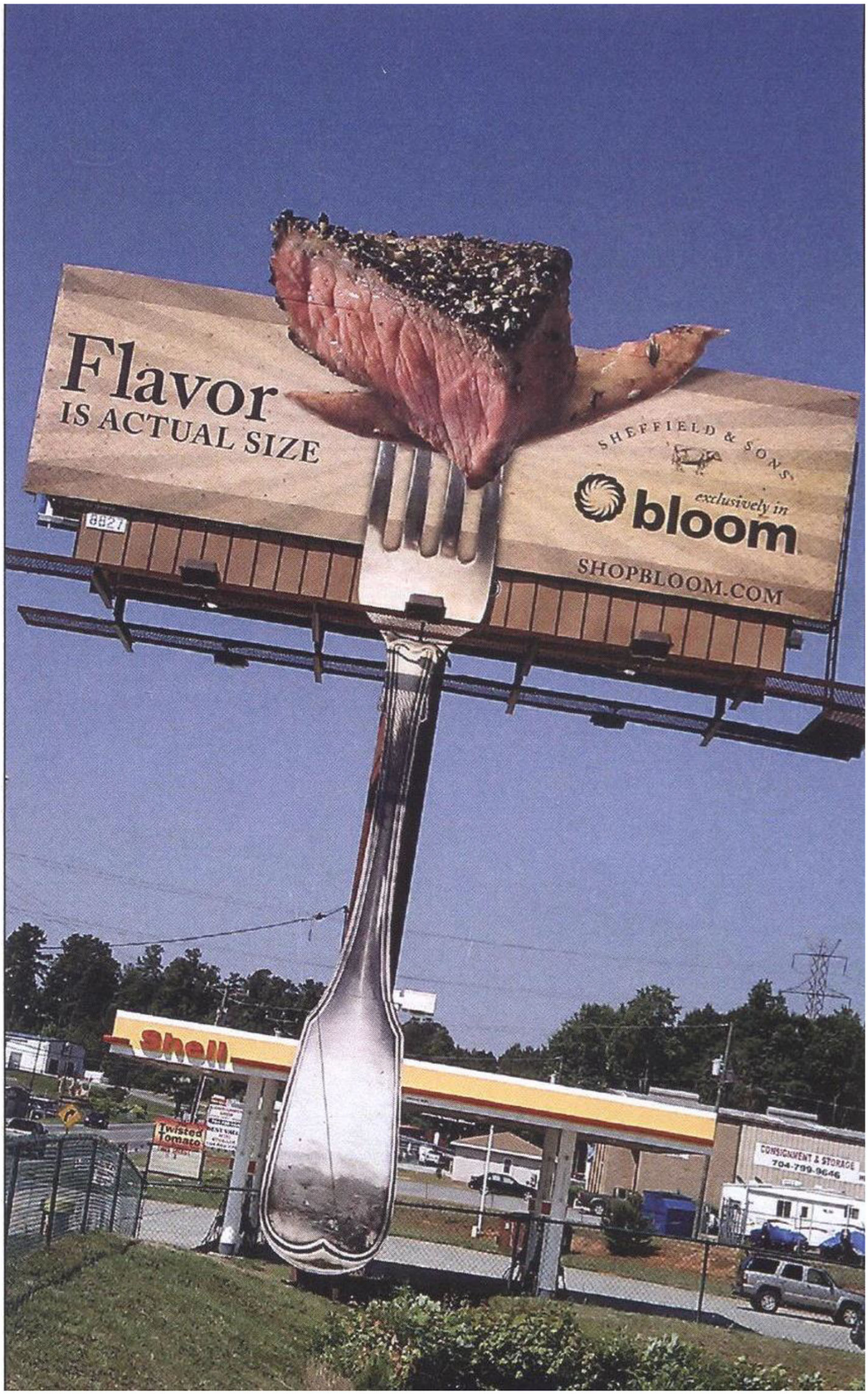

FIGURE 2 | Scented advertisement on Highway 150, North Carolina, USA. In this case, while the commuter is moving, the scent is stationary.

that it would be a good idea to start scenting bus shelters with the aroma of cookies in order to give their advertising something of a multisensory boost. The campaign was pulled within days of its launch over concerns that it was grossly-insensitive to the many hungry homeless people in the state who used the shelters to sleep (Cuneo, 2006; Gordon, 2006; Elliott, 2008; Metcalfe, 2012).

What distinguishes the various olfactory marketing campaigns that have been discussed in this section (as well

FIGURE 3 | Touch the tattie and smell that delicious oven-baked potato smell. Multisensory marketing at a London bus-stop.

as a couple of other campaigns that took place in British train stations and at Heathrow airport; see Cable, 2014; Polden, 2015) is the typically short-lasting nature of the intervention. These interventions can, though, be seen as part of a wider trend toward the emergence of scent marketing (Morrin, 2010; Sendra-Nadal and Carbonell-Barrachina, 2017; Minsky et al., 2018). As Sutton (2018, p. 132) describes the situation: *"In an industry which has been traditionally dominated by visual stimuli, organizations using Out Of Home (OOH) advertising are increasingly utilizing olfactory elements to entice, engage and entertain target audiences."* Part of the appeal of scenting public transportation is undoubtedly the captive nature of the audience.

Signature Scents (Branding)

Given the extensive and growing use of bespoke scent to help deliver a pleasant olfactory identity for everything from sporting venues (Albrecht, 2013; Doll, 2013; Martinez, 2013) to ultra-high-end apartments (Schroeder, 2018)[14], and from hotel chains (such as the distinctive White Tea scent from the Westin Hotel Group; Kaysen, 2016; Wiedmann et al., 2016; Minsky et al., 2018; Spence, 2018b)[15] through to retail stores (Spence et al., 2014). In such cases, the fragrance may be blown in through the ductwork, or else delivered by means of stand-alone machines (Kaysen, 2016; Minsky et al., 2018). One challenge, though, is that scent delivered in one room may well end up being distributed through the ductwork to other parts of the building unintentionally contaminating the entire building's ventilation system (see Lai, 2015). One solution, as proposed by Dmitrenko et al. (2017a), is therefore to build a separate air extraction system (i.e., disconnected from the building's central ventilation system) for an indoor space in which a scent is released.

In terms of the signature scent of transportation companies, it has been the airlines who would appear to have led the way. So, for example, Singapore airlines has long used a particular fragrance Stefan Floridian Waters in its planes (Lindstrom, 2005; Strutner, 2015; see also Carey, 2015). Indeed, commentators often comment on how a sense of luxury in the airline sector is perceived in terms of distinctive, bespoke, scent, for instance Singapore Airlines perfume being experienced not just in the cabin but also in the hot towels that passengers are given to refresh themselves (Wiedmann et al., 2016). Looking to the future, premium land-based transportation services might be able to distinguish themselves, and the experience they provide,

[14]It should though, be noted that some commentators believe that the scenting of different spaces in new building developments is nothing more than a gimmick (Kaysen, 2016).

[15]Perhaps triggered by claims that people will refuse to check in if they detect a strange smell in the lobby of a hotel (Pacelle, 1992).

in part by the use of luxurious signature scent (see https://www.premiumscenting.com/). Hinting at the possibilities in this space, only last year, Ford patented an app to check ride-share cars for bad smells before a passenger gets in (Maddireddy, 2020; Yeung et al., 2020).

Accepting that branded signature scents might be a good idea for the travel industry more generally, the good news is that there are methods available (such as the semantic differential technique, SDT; Dalton et al., 2008) to help align the qualities of the scent with the key brand attributes (cf. Vogt, 2008; Minsky et al., 2018)[16]. It will be an interesting question for future research to determine whether the design of signature scents based on the synaesthetic associations experienced by creative perfumiers, such as Dawn Goldworm, the successful synaesthetic scent director of 12.29, a New York based fragrance design agency (see Kaysen, 2016; Schroeder, 2018) are any more successful than those based on SDT and/or the crossmodal correspondences (see Spence, 2020e, for a review).

Functional Benefits of Scent in Motion

An extensive body of research shows that ambient scents can affect people's mood, their perception, and also their behavior (Spence, 2020c,d). Perhaps unsurprisingly, therefore, there has been interest in capitalizing on the functional uses of ambient scent in the context of transportation. This has most frequently been discussed/studied in the context of driving where, unlike for most other forms of transport, the person traveling may well also be the one who is in charge of the vehicle. It is worth noting that any attempt to modulate the driver's state of mind (be it counteract sleepiness, or calm the overexcited driver down) via the functional use of scent is inevitably also going to be experienced by any passengers who are traveling (Spence, 2021a)[17]. Ambient in-car fragrance can help to mask malodour and hence potentially (functionally) improve the driver's mood (Ho and Spence, 2008, 2013), and possibly resulting in their driving more safely too (Baron and Kalsher, 1998). Another functional use of scent in the context of driving is to help alert the sleepy motorist (Martin and Cooper, 2007; Raudenbush et al., 2009; Yoshida et al., 2011; Fruhata et al., 2013). At the same time, however, it should be stressed that the higher visual perceptual load of the driver means that their awareness of ambient scent while on the road is likely to be markedly reduced due to what has been termed "inattentional amnesia" (Forster and Spence, 2018).

A number of further functional uses for scent in the context of driving have been articulated recently by the work of Dmitrenko et al. So, for example, in one study, Dmitrenko et al. (2019) examined the use of olfactory notifications to reduce speeding. Meanwhile, the results of a second study highlighted the possibility of using different olfactory cues to notify the driver of different relevant events (Dmitrenko et al., 2017b; see also Hiroike et al., 2009; Okazaki et al., 2018). Finally, these researchers have also reported how olfactory notifications can also be used help to reduce the number of driving-relevant mistakes in the simulator setting (Dmitrenko et al., 2018). Note here also that in 2013 Ford cars applied for a patent concerning a smell notification system for drivers (see Kolich and Ford Global Technologies LLC, 2013). Another intriguing functional use for scent in the context of manual or autonomous driving relates to the alleviation of travel/motion sickness (e.g., Keshavarz et al., 2015; Ranasinghe et al., 2020; Schartmüller and Riener, 2020).

Of course, no one needs a high tech gadget in order to deliver the synthetic scent of nature. As was mentioned a little earlier, drivers have been dangling scent-infused cardboard pine trees from their rear-view mirrors for decades. However, the problem with this solution is that our brains tend to adapt pretty quickly to pleasant or neutral smells. So while you might notice the scent as you open your car door, my guess is that you probably won't think about it much after that. Several studies have demonstrated how the periodic delivery of pulsed scent (e.g., peppermint) can help enhance operator performance (e.g., Warm et al., 1991; Ho and Spence, 2005, 2008; Mahachandra et al., 2015). The Aroma Shooter (http://www.aromajoin.com/) which provides a directional olfactory stream might be especially appropriate for those applications where the scent is targeted specifically at the driver (see also Dmitrenko et al., 2016). However, that said, this particular device is no longer positioned in the vehicular context. There is mention in the US Press of another olfactory delivery device Cyrano being possibly used to deliver scents to drivers (see Baig, 2016).

A few years ago, the British company Jaguar looked into developing a scent display for their vehicles. The idea was for the GPS to periodically check on the car's location and instruct the device to pump the appropriate synthetic natural scent into the cabin. For example, just imagine how much more pleasant it would be to drive through the forest if your nostrils were stimulated by the scent of pine, say, or perhaps the wonderful smell of the earth just after it has rained (geosmin does a pretty good job in this regard). At the same time, however, research from the world of entertainment has highlighted how, unless the scent is chosen very carefully, that ambient pine scent is more likely to remind whoever smells it of a cleaning product, rather than bringing them closer to nature (Spence, 2020d, 2021b), even when the source object (e.g., a pine tree) is clearly visible.

In 2004, Citroen launched their C4 model with a nine-scent olfactory display operating through the ventilation system. The scents were split into groups of three, designed to be congruent with notions of "travel," "vitality," and "well-being" and were intended to provide scent for 6 months before it would need to be refilled (Hanlon, 2004). A decade later, Mercedes incorporated an olfactory display in certain of its new models too (Clark, 2013). While such olfactory interventions undoubtedly represent an intriguing direction when it comes to realizing the idea of "scent in motion," my oft-stated belief is that, as with any other olfactorily-enabled digital device, it will ultimately fail for the simple reason that the customer will not think it worthwhile to buy the refill (Spence et al., 2017).

Of course, cost is likely not to be an issue for the owner of a Bentley car that also offers Sterling silver atomizers to personalize the multisensory experience in their Mulliner

[16]Though here it should also be noted that cultural (not to mention individual) differences in the meaning/association of scents have been reported (Trivedi, 2006; see also Truong, 2018).

[17]Of course, this concern also applies to the use of auditory alerts too (see Ho and Spence, 2008).

edition cars (see https://www.bentleymotors.com/content/brandmaster/master/bentleymotors/en/world-of-bentley/mulliner/personal-commissioning/personalising-your-bentley.html#3f3f8d7bb768277e2e9b127c73364c6f). Meanwhile, BMW have also been working on creating their own in-car perfumes too for their 7-Series (Boeriu, 2015). According to the latter online commentary: *"The optional Ambient Air package features options to ionize the air or fragrance the vehicle interior with selected scents, both of which can be controlled from the air conditioning control console or the iDrive menu. There are three levels of intensity and 8 scents to choose from. The scents can be chosen from the Blue Suite and Green suite, and Golden Suite and Authentic Suite."*

While it is easy enough to demonstrate the benefits to the user's mood or experience of adding an extra sensory input (Spence, 2021a), the existence of the "fundamental misattribution error" means that as visually-dominant creatures (Hutmacher, 2019), we typically attribute our enhanced pleasure (or experience) to the visual element of a multisensory experience rather than to the olfactory component. The latter, as was mentioned before, may anyway be missed due to the phenomenon of inattentional anosmia (Forster and Spence, 2018). Who knows whether scent displays might 1 day be used to arouse dozy driver instead of the loud and unpleasant auditory alerts that are more commonly used today. Certainly, it is easy to imagine how pumping out an arousing ambient scent such as cinnamon, peppermint, rosemary, eucalyptus, grapefruit (Fruhata et al., 2013) or lemon might prove to be a much less aversive way of achieving the same result than a loud sound, say (Ho and Spence, 2008, 2013). That said, a multisensory approach to modifying the driver's state is likely going to work best here as elsewhere (Bounds, 1996; Ho and Spence, 2008; Spence, 2012; Fruhata et al., 2013).

The functional use of scent has therefore been considered in relation to modifying various aspects of driver performance and experience (Ho and Spence, 2013; Dmitrenko et al., 2016; Mustafa et al., 2016). However, given the rapid adaptation to constant ambient scent, the periodic release of scent holds much more promise as far as the delivery of functional scents is concerned, especially if you want drivers to pay attention to what they are smelling. It would also be good to have more research showing whether sudden-onset olfactory stimuli can automatically (i.e., exogenously) capture attention in a way that constant ambient odors fail to do, often because they are no longer perceived consciously (Funato et al., 2009; Forster and Spence, 2018; though see also Bordegoni et al., 2017; Spence, 2020c).

Another functional use of scent in the context of transportation relates to research showing that those scents we associate with cleanliness can be used to encourage people not to litter/pick up waste (De Lange et al., 2012). So, for example, the presence of an ambient "clean" scent, such as pine or citrus, can help to make a space appear cleaner. The presence of such scents may also help to reduce littering too. At the same time, however, it should be noted that olfactory priming effects have not always proven so easy to replicate (see Smeets and Dijksterhuis, 2014, for a review). There is also a separate line of empirical research, and hence potential opportunity, to use scent functionally to enhance the passengers' multisensory experience/nudge to engage in more prosocial behaviors (e.g., Schiffman and Siebert, 1991; Gueguen, 2001; Spence, 2002, 2021b; Holland et al., 2005; Liljenquist et al., 2010; De Lange et al., 2012; Henshaw et al., 2018), while at the same time possibly also improving their mood (e.g., Warren and Warrenburg, 1993; Spence, 2020c). Finally, it is worth noting how a pleasant scent was introduced onto bus services and mass transit in Singapore the hope that it might help nudge more people to use public transport (cf. Kutzbach, 2010; Poon, 2017). This scent-sory nudging strategy laid bare in the title of a paper in Bloomberg news by Linda Poon (2017): *"To entice riders, Singapore buses get a 'signature scent': Will more people ride public transit if it smells nice?"*

New Car Smell: A Multifunctional Olfactory Signal

One smell that is often mentioned in the context of transportation and which has been noticeably absent from this review so far is "new car smell" (see Aikman, 1951; Moran, 2000a,b,c). While ratings of which models or marques have the best scent are published annually, suggesting they are distinctive, they have never become differentiated enough to support brand recognition in the absence of other cues[18]. The reason for this is because this evocative smell can be considered as relating to several of the categories outlined above, while not really belonging in any one. Modern car interiors tend to smell terrible unless they are suitably treated (Spence, 2002)[19]. The volatile odors (VOCs) released from the plastic/synthetic materials so often used in car interiors in decades gone by used to make them smell unpleasantly fishy (Shea, 1971; Grabbs et al., 2000; Ritter, 2002). At the same time, however, according to research from California, that oh-so-desirable car smell may actually be carcinogenic (Reddam and Volz, 2021; Watson, 2021).

While many of the car companies have teams of expert noses dedicated to the optimization of the synthetic smell that greets the customer (see Moran, 2000b), these scents do not really qualify as signature scents for a couple of reasons: On the one hand, the consumer considers it the smell of the vehicle (i.e., product-intrinsic; Van Lente and Herman, 2001), rather than of the brand. On the other, while different marques do smell somewhat different (i.e., some new cars do smell better than others), the relevant question is whether drivers are able to distinguish between the smell of a new Volkswagen (VW) vs. Ford car, say. In the absence of evidence, my guess is that this distinction is simply too subtle for most drivers to be able to recognize the marque reliably solely on the basis of the new car smell. In fact, it is an intriguing question is to just how many high street brands actually have a distinctive, and instantly recognizable, signature scent beyond the likes of Lush, Subway,

[18]Luxury yachts represent a vibrant niche market (one might consider, new yacht smell for the superrich?; https://yachtscent.com/), and holiday cruises are very big business, representing the fastest growing sector of the travel market, at least they were pre-Covid-19 (Giese, 2020). However, I am not aware of any research on the role of scent in this particular environment (though see Hood, 2019, for the recent introduction of a signature fragrance, Ship No. 1, linked to Virgin Voyages cruises).
[19]Some decades ago now, Rolls-Royce even ran a scented add in Architectural Digest that allowed readers to smell the leathery Rolls interior (Gibbs, 1988).

Cinnabon, and perhaps a few others (see Nassauer, 2014). One can only wonder how distinctive the signature scent, Nuance, introduced by General Motors for its Cadillac car in 2003 may have been (Lindstrom, 2005).

SC Gordon Ltd., the coachbuilders of Rolls-Royce cars, have developed their own unique new car smell designed specifically to mimic the aromatic blend of leather and wood of a vintage 1965 Silver Cloud model! The car cologne is applied when new cars come in for repair, and according to Hugh Hadland, Managing Director of the company, *"People say they don't understand what we've done, but that their cars come back different and better."* It seems that just one dash of the luxury perfume is enough to restore that sense of luxury in even the most expensive of consumer purchases (Seat sniffers, 2000), and can even be used to add value when people come to resell their own car (Aikman, 1951; Hamilton, 1966; Wright, 1966). Intriguingly, surveys consistently highlight a strong relationship between how much consumers like a vehicle's interior smell and how they rate the vehicle's interior overall (Power and Associates, 2000). One other intriguing question here concerns the role of new car scent in the seemingly irrational desire to buy new car—-given how rapidly they are known to depreciate (Rohrer, 2008). Intriguingly, new car smell is not appreciated by everyone. Truong (2018) has reported that: "According to JD Power, more than 10% of drivers in China—the world's largest auto market—complained about the new-car smell in its 2018 survey." Such findings have resulted in Ford filing a patent for a technique to strip its new models of their new car smell in the region.

Food Scents in Transportation

Before moving on, it is perhaps worth noting in passing that food and drink are often consumed while travelers are on the move. For instance according to an interview with Michael Pollen, North Americans consume 20% of their meals while at the wheel in their cars (https://news.stanford.edu/news/multi/features/food/eating.html). This is what is sometimes referred to as dashboard dining or cup-holder cuisine (Hill, 2005; see also Morrison, 2021, for one view of the future of dining in autonomous cars). Designed food experience for passengers on other forms of transport has also occupied the minds of many researchers' (e.g., Horwitz and Singley, 2004; Muecke, 2004; Spence, 2017a,b; Taylor et al., 2019, 2020). Returning to a theme that was mentioned earlier in this review, it has been suggested by de Syon (2008) that the provision of food on airplanes may also be one means of helping passengers to manage their anxiety (though more could certainly be done in this regard; e.g., Delahaye, 2017).

Much of the profit, at least amongst the budget airlines comes from the sale of food and drink, and the on-board duty free shop (Ciesluk, 2020). As such, this must raise the temptation to use smell to sell. Similarly, think only of how the food and beverage offering is used as one of the key differentiators between different classes of service in the air (Economy, Business, First; O'Flaherty, 2015; Spence, 2017a,b). British trains, with their distinction between Standard and First Class carriages, also use the food offering to discriminate between the different classes of service. The challenge in certain transportation situations is to deal with the deleterious effects of the dry air/lowered cabin air pressure, not to mention the 80 dB of background noise, as has been documented in the case of delivering tasty food in the air (Spence, 2017a,b,c; Spence, 2018a).

As such, one probably needs to consider how the smell associated with any F&B offering may influence the olfactory atmosphere, not only for those who are eating, but also for those who are not. Indeed, consuming certain forms of food are banned on public transport in some transport systems. For example, it is forbidden to drink alcohol or eat hot foods on many forms of public transport in the UK and elsewhere (see Hello Magazine, 2017). The latter prohibition presumably designed to minimize the olfactory discomfort to the other passengers), while chewing gum has long been banned on public transit in Singapore (presumably to help reduce litter and mess; Metz, 2015). One example of what goes wrong if one doesn't take account of what the aroma of food may remind the passenger of is highlighted by the case of Virgin Australia. The smell of parmesan sandwiches were misinterpreted as the smell of sweaty old socks (both share the volatile compound valeric acid), and made many of the passengers fall sick (Buaya, 2016)[20].

Future Travel: Space Tourism

There is growing excitement about the impending emergence of space tourism (Henderson and Tsui, 2019). As several different companies (SpaceX, Virgin Galactic, Space Blue Origin, etc.) compete to be the first to offer a commercial service, important questions remain about the nature of the multisensory experience that the customers will be offered (Obrist et al., 2019). The starting point is not good, given that reports from astronauts describing space as smelling like: *"gunpowder, hot metal, welding"* (New York Hall of Science, 2016). The repeated recycling of limited air can potentially lead to the build-up of volatile pollutants (Taylor et al., 2019, 2020). At the same time, however, the lowered gravitational pull also leads to the build up of blood in the head, and this may constrict the nasal airways (NPR, 2012), leading to what is known as "space anosmia" (Varma et al., 2000). However, a more pressing problem might be to deal with space sickness that many feel on entering space (Crampton, 1993). As such, any scent that can help to reduce anxiety and/or counteract the effect of travel sickness might be considered a good idea (though see Paillard et al., 2014; Keshavarz et al., 2015).

SCENTED TRAVEL: SCENTED TERMINALS AND STATIONS

Commercial travel often involves passengers transiting through terminals both prior to, and more briefly upon, arrival. Think of train stations, airports, subway/metro stations, and even bus/tram stops. Such spaces constitute an integral part of the experience of travel. In fact, looking back the discussion of

[20]Here one is reminded of Mark Twain's (Clemens, 1957) "The Invalid's Story" in which a man becomes increasingly distressed while riding in a freight car with what he imagines can only be a coffin containing a pungent, putrid corpse. Unable to tolerate the nauseating smell any longer, he eventually jumps off the train into a winter storm, contracting a fatal illness. However, before he dies, he learns that the coffin in the freight car was actually a large crate of cheese.

scenting the metro/underground involved the smell of the terminal not the transportation itself (i.e., the carriages). By contrast, when discussing the scent of air travel, the focus was very much on the scent of the airplanes/airlines rather than the airports (see Klara, 2012). That said, there has been interest in scenting the airline passenger's experience prior to take-off. For instance, two decades ago, British Airways (BA) introduced a functional scent into their airport lounges (Spence, 2002). According to a report that appeared in *The Wall Street Journal* (Ellison and White, 2000), a signature scent called "Meadow Grass" was introduced into their executive airport lounges. The idea was that the weary business traveler would be greeted by a familiar scent as soon as they walked into the lounge (no matter what continent they happened to be on), signaling that their journey was near its end (or presumably, just beginning). It is noticeable how contemporary scenting strategies tend to try and ensure a consistent olfactory identity across all touch points (i.e., including both airline lounges and the airplane itself). For instance, Delta Airlines deliberately used a fragrance of orange peel, sandalwood, cedar and leather, part of a move to create a signature airline aroma to charm passengers in airport lounge lobbies, such as at Chicago's O'Hare airport (Carey, 2015).

The olfactory ambience of airports would seem to differ substantially as a function of the country that one happens to be transiting through. While most airports are olfactorily neutral[21], the atmosphere in North American airports tends to be heavy with the smell of food franchises (see Nassauer, 2014). The broadly appealing smell of coffee has become a distinctive smell of train stations and many other public spaces. And while there has been some discussion of given entire shopping centers a branded scent (see Spence et al., 2014), I haven't heard anything similar for airports as yet. That said, pre-Covid-19, I was always struck flying in to Heathrow by the cheap clean fragrance, my response then much like that of those quoted earlier regarding the scenting of the underground that was disbursed throughout the terminal—-from what source I never was able to ascertain. In this case, it is unclear into which category we should put the scenting strategy.

Intriguingly, there are also examples of olfactory performance artists who have worked with the scent of such familiar, yet often transitorily experienced, spaces. Consider here only the work of Helgard Haug, a young performance artist who won a prize in support of a public art piece at the subway station Berlin Alexanderplatz, once the social center of East Berlin. In 2000, Haug commissioned a distillation of the scents of Berlin Alexanderplatz that were presented in tiny souvenir glass vials dispensed in the station. The perfumer designed the scent based on his own perception of the station without chemical analysis. U-deur included the smell of bread as one of the primary odors (because there was once a bakery stand in the subway) along with the smells of cleaning agents, oil, and electricity. According to Drobnick (2006), the public response to the project was apparently extraordinary. People wrote that the little sniff-bottle brought to mind memories and associations with the smells of a divided Berlin, for instance, the "dead" stations that West Berlin subway trains went through after passing the Wall. At the same time, thoughts about the Stasi archive with its items saturated with the body odor of East German criminals and dissidents were also triggered in the minds of some.

[21] And of course, the duty free fragrance counters are a distinctive feature of the majority of airports, though the scent is typically not widely dispersed.

CHALLENGES WITH CONTROLLING THE OLFACTORY ENVIRONMENT

The technical means of introducing and controlling scent, and, more importantly, getting the level right, is by no easy, especially in the case of scent in motion. What is more, olfactory adaptation/habituation means that those working in a scented environment may soon lose any awareness of the scent whereas occasional passengers may find the scent to be much stronger (Spence, 2020c). Furthermore, too often (or so it would seem), cheap synthetic scents (or at least scents that are perceived as such) are used. Creating a bespoke solutions can be expensive (Spence et al., 2017), and trade marking specific scents is a challenging business (Hammersley, 1998) thus making innovation in this space even more challenging.

Most successful approaches to scenting the environment, be it in the context of scenting the built environment or scent in motion, as discussed here, do not occur in isolation, but rather involve the coordinated stimulation of multiple senses, be it in the car (e.g., Bijsterveld et al., 2014), in the underground/underground car-park or metro station (Sayin et al., 2015), or while in the air. Here it is important to stress that multisensory interactions often influence olfactory perception (e.g., Velasco et al., 2014). As such, it can be hard to know how exactly a scent will be perceived until it is actually introduced *in situ*. Indeed, problems associated with sensory overload and sensory incongruency (Malhotra, 1984; Spence, 2020a,b) have been used to explain why the benefits of adding one sense sometimes disappear in real-world interventions when scent and sound interventions have been combined (e.g., Mattila and Wirtz, 2001; Morrin and Chebat, 2005; Fenko and Loock, 2014; see also Spangenberg et al., 2005).

CONCLUSIONS

While those thinking about the scent of transport in the modern era have often focused on masking the scent of the typically confined space, or of the passengers – both those who are currently present (Walker, 2019) and those who have long since left their olfactory mark (see Robinson, 2016; see also Anon, 2015)—there is also growing interest in branding the experience by means of the introduction of signature scents. To date, this has primarily occurred in the context of the airlines (Lindstrom, 2005; Carey, 2015; Strutner, 2015; Wiedmann et al., 2016), but there seems little reason to believe that the approach will not be extended to other forms of transportation, especially given the dynamic nature of the sector currently (cf. Baskas, 2019). It is crucial, especially at the luxury end of the market, that signature scents are used as part of a multisensory marketing/design strategy (Wiedmann et al., 2016; Spence, 2021a). Typically, the most effective sensory interventions engage multiple senses (see Bounds, 1996; Spence, 2012; Fruhata et al., 2013), while ensuring congruency across multiple sensory touchpoints and avoiding the dangers of sensory overload (Spence, 2021a).

At present, the smell is just one of the aspects of the experience of luxury travel that those tempting their customers with the virtual reality (VR) experience before they travel typically fails to capture (Yerman, 2015; though see also Cable, 2014, for the use of scent to help mentally transport travelers to their destination; and Flavián et al., 2021, for the latest research in this area). Perhaps also worth mentioning here are the various that olfactory-displays "on the go" that have been enabled by head-mounted displays (HMDs; e.g., Yanagida et al., 2004; Howell et al., 2016; Ranasinghe et al., 2018; Comşa et al., 2019; Saleme et al., 2019; Nakamoto et al., 2020).

A number of scent-based marketing interventions, although typically short-lived, have also been associated with the theme of scent in motion in recent years (although in such cases it is more often the case that the scent itself is static, while the traveler/passenger passes through, or by the scented location). Scent-based marketing interventions, although not yet widespread, continue to flourish (e.g., Garber, 2012; Anon, 2013; Cable, 2014; Polden, 2015; McEleny, 2016; Mobile Marketing, 2020; Murphy, 2020). That said, as we have seen here, problems have, on occasion, arisen in part due to confined space and the involuntary nature of the passenger's engagement with the olfactory stimulus, especially in confined space (cf. Anon, 2001a,b; Jury, 2002; Lim, 2014). Looking to the future, it would seem likely that the development of functional branded scents will increasingly be a feature of our experience of travel (Ho and Spence, 2008, 2013; Spence, 2021a), at the interface between the more artistic and scientific worlds of fragrance (Drobnick, 2006).

The functional use of scent in a passenger transport/travel context includes everything from the suggestion that ambient scents could be used to help reduce anxiety amongst the 40% of passengers who report that flying makes them anxious (Strutner, 2015) through to attempts to use pleasant scent in order to help tackle motion sickness (Keshavarz et al., 2015; Ranasinghe et al., 2020; Schartmüller and Riener, 2020). Some are even considering whether scent can be used strategically to help nudge more people to take more sustainable and environmentally friendly forms of transport (Poon, 2017). After all, it is worth noting that travel is typically involved when we go on holiday, with the global tourism market estimated to be worth a trillion dollars annually (World Travel Tourism Council, 2017). As such, anything that can be done to help reduce global tourism's carbon footprint, estimated in 2018 (i.e., pre-Covid-19) to represent 8% of global greenhouse gas emissions (Lenzen et al., 2018), through sensory nudging (possibly involving olfaction) toward more environmentally-friendly forms of transportation, would seem like an avenue that has to be worth pursuing in the future (cf. Poon, 2017).

One area of particular interest regarding the future of olfactory displays in the automative industry, relates to the emerging benefits of the nature effect (Williams, 2017; Spence, 2021a), the olfactory version of which one might call aromatherapy (Spence, 2003). It will be interesting to see whether the benefits of the nature effect can be incorporated thus delivering a benefit for driver's well-being. It is also interesting here to note how some car companies have been trying to develop vehicle interiors that are so pleasurable that people choose to sit in their car even once their journey has ended. It would seem that getting the olfactory atmosphere right will be a key component to the success of any such enterprise. Another suggestion here relates to the emerging problem about how to facilitate switching between being a passive passenger and an active driver semi-autonomous vehicles. Olfactory signaling might help to mark out these different states with driving presumably being associated with a more alerting/arousing state of mind, while the other is presumably more relaxing. Finally here, one might also wonder whether scents could potentially be used to help wayfinding while driving (cf. Hamburger and Knauff, 2019).

Finally, there is a sense in which, at least to your present author, when the proposed form of transport being discussed, moves further into the future, such as for example, Virgin Hyperloop (Giacobbe, 2021), that realizing what taking this new form of transport will smell like somehow makes it more believable, "more real." One might argue that scent, while an important part of the experience of any form of transportation, would be figured out later in the day (given its aesthetic rather than functional role). That scent design (along with sound design) is brought forward in the design process, etc. seems to be playing a role, perhaps a fifth role of olfaction, in making one hypothetical version of the future of transportation, of scent in motion, more believable, somehow more tangible.

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Recent Advances in Smellscape Research for the Built Environment

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The interrelationships between humans, smells and the built environment have been the focus of increasing numbers of research studies in the past ten years. This paper reviews these trends and identifies the challenges in smellscape research from three aspects: methodological approaches, artistic design interventions and museum practices, and odour policy making. In response to the gaps and challenges identified, three areas of future research have also been identified for this field: smell archives and databases, social justice within odour control and management, and research into advanced building materials.

Keywords: smellscape, odour policy making, olfaction, built environment, art and design, museum, citizen science, technology

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INTRODUCTION

This paper describes recent advances in smellscape research and offers recommendations for future work to scholars, practitioners and artists. The smellscape concept was introduced by Porteous (1985), who suggested that perceptions of smell, while comparable to spatially ordered visual impressions, differ in their episodic nature, and academic interest in the concept and its analysis and design approaches has grown over the past 30 years. Henshaw (2014, p. 5) supplemented Porteous's definition of smellscape, describing it as "referring to the overall smell environment, but with the acknowledgment that as human beings, we are only capable of detecting this partially at any one point of time, although we may carry a mental image or memory of the smellscape in its totality." The word *smell* in this concept differs from *odour*—the combined substances in the air that cause olfactory sensations—as it emphasizes the human experience as a perceptual construct (Xiao et al., 2018a).

A search of the Scopus database (**Figure 1**; the search terms are reported in the caption) aimed to find scientific publications at the intersection of smellscape and built environment studies. To provide a baseline, a second search used only "odour" as a keyword. The numbers of the two queries differed by three orders of magnitude, but, while the latter shows a relatively stable linear growth over time, the former has grown exponentially in the past 10 years, which likely reflects a growing interest in the concept of smellscape as a user-centred approach in the built environment community. Three main themes emerged from a qualitative review of the titles and abstracts of the smellscape-related search:

- smellscape as intangible heritage and an element of historical and cultural value: studies dealing with scents of the past, smell geographies, historical reconstructions and smells in museums and exhibitions (∼20 papers)

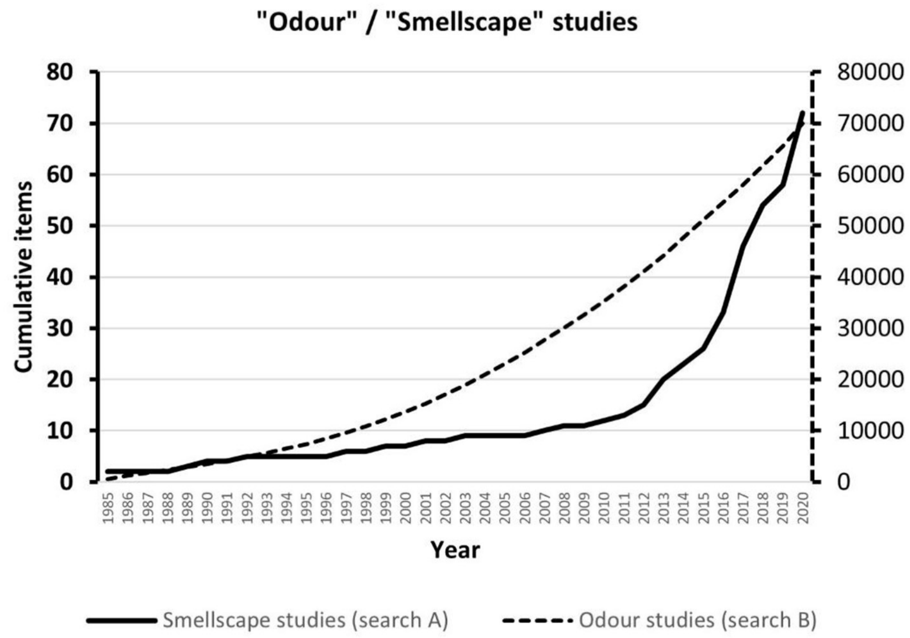

FIGURE 1 | Cumulative number of scientific publications on smellscape and the built environment (search A) and odour research in general (search B). Query string in Scopus for search A: TITLE-ABS-KEY (smellscap*) OR TITLE-ABS-KEY (smell) AND TITLE-ABS-KEY ("built environment"). Query string in Scopus for search B: TITLE-ABS-KEY(odour).

- smellscape as a therapeutic or experiential element: studies related to laboratory experiments for environmental assessment, sensory-deprived people and smell as an element for tourism and well-being (∼22 papers)
- smellscape as a design approach for the built environment: studies dealing with design and perception models, smell mapping and representation and smell as a place-making element and component of the public space (∼28 papers)

All these themes raise similar methodological challenges in dealing with what is possibly the least tangible dimension of human life in the built environment. Similarly, they all highlight the interest in not leaving the smell experience to chance but rather considering it as a designable element at both the small (i.e., space, building) and large (i.e., city) scale.

METHODOLOGICAL APPROACHES IN SMELLSCAPE RESEARCH

In urban and architectural studies, smellscape research takes qualitative approaches to consider the social and psychological impacts of diverse smells from peoples' *in situ* experiences or recalled memories. Methods such as smellwalks, interviews, observations and the scale rating of perceptual factors (i.e., like/dislike, familiar-unfamiliar) are commonly employed to collect data on people's experiences and subjective evaluations of the olfactory environment in real contexts. Recent years have seen growth in laboratory experiments using virtual reality technologies to test design hypotheses or perceptions of existing spaces through multisensory interactions with two or more modalities involving the sense of smell (see Jiang et al., 2016; Ba and Kang, 2019a). Although such experiments have revealed the impossibility to fully replicating a smell environment, these methods are useful for testing the impact of adding a specific smell to an existing context. For example, Doukakis et al. (2019) proposed an audio-olfactory-visual environmental setting that enables a controlled olfactory impulse at various concentrations through computational programming and simulation. In addition to the use of subjective data, objective data from electroencephalography, eye-tracking, heart rate variations and the galvanic skin responses used in neuro-biological studies are also emerging in laboratory experiments to study people's stress levels and emotional responses (see Spence, 2020a; Jiang et al., 2021; McEwan et al., 2021).

The biggest challenge to the advance of smellscape research and practice in the built environment is the lack of applicable smell databases to aid the design process and predict outcomes. Spatial-odour relationships can be simulated through air flow simulation software, such as CFD, AERMOD and CULPUFF, but sampling odour on site to enable such simulations is still not a straightforward process, as it requires laboratory analysis by chemistry specialists (see EN 13725:2003). In urban planning practice, simulations of odour dispersion and concentration are mostly limited to the sites of industrial or waste management plants, and they target specific odorants. By contrast, the smellscape approach considers the implications of smells in spatial design to create a positive impact on human well-being by both controlling negative odorants and introducing scents into spaces. A data set per unit of the odorants in everyday sources of smell—objects, plants and foods as well as cosmetic and cleaning products—would be needed to aid in the prediction of the total smell environment to support spatial planning and design. Harel et al. (2003) proposed a three-component system called iSmell for creating a smell database, including a sniffer space (the odorants in the ambient environment), a sensory space (the detection of odorants) and a psychophysical space, but no further development of the project has been reported. Obrist et al. (2014) summarized 10 categories of people's associations of smells in everyday life by analyzing participants' smell stories. These can be used to develop future human-computer interaction systems that match spaces, smells and situations with potential olfactory perceptions as a reference for designers to create more pleasant smell experiences, enhance storytelling and avoid embarrassing moments caused by smells. For example, in the positive smell stories, the most frequent words used to describe the quality of smells perceived are pleasant (60%), clean (42%), sweet (38%) and fresh (31%).The associated context and personal data can be traced via the database. A designer intending to design a space that smelt fresh and clean could refer to the spatial form, social conditions and actual smell experiences from those stories to determine its design elements. However, a smell data set that matches smells, experiences and behaviors would be essential to achieving that goal.

The practice of smell mapping takes an anthropocentric approach to the detection, description and depiction of temporal- and location-specific olfactory environments (McLean, 2019). Situated within communication design, smell mapping deploys the smellwalk as a method of data collection and to create subsequent representational formats to illustrate subjective, dynamic, vernacular urban smellscapes (Henshaw, 2015). Normally conducted with up to 20 people who sniff passing air and close-up objects, the smellwalk invites participants to foreground their olfactory sense and temporarily attend to an alternative sensory modality, but the global Covid-19 pandemic presented immediate challenges to the practice of large-group smellwalking. While Covid-19 precautions vary, a responsible approach would limit group sizes in accordance with government guidance and restrictions. The reduced group sizes, however, would result in the collection of less fruitful data on people's *in situ* experiences of the temporary time-space settings specific to the walk, and the urban smellwalk methodology includes active sniffing in both indoor and outdoor spaces, which might necessitate wearing face masks. The choice of material and fitting of face masks would likely alter the detection of subtle odours.

Future research agendas for smell mapping and olfactory representation may comprise four major strands: cross-modal, historical, digital and future archive. Cross-modal approaches are crucial to understanding human interaction with the smellscape (Ndichu, 2020; Spence, 2020b). Historical smellscapes combine olfactory descriptors, local context and human habituation (see Kiechle, 2017; Dugan, 2018; Tullett, 2019), and both cross-modal and historical smellscapes benefit from multilayered mapping design approaches (**Figure 2**) that are sympathetic to the era and narrative being depicted (McLean, 2020a,b). Any future archive of smell will need to identify the criteria for olfactory selection and preservation (see Bembibre and Strlič, 2017) and determine the mechanisms for representation. While the Odeuropa (2020) project uses Artificial Intelligence (AI) to collect a database of smell references, the use of digital technology in smell representation requires further work to explore how digital platforms might work to empathically record and convey human experience.

REDISCOVERING DESIGNED SMELLSCAPES

Many public officials think of odours only as something to be controlled or eliminated, and even many urban designers overlook smells' positive contributions to health and aesthetic satisfaction (Henshaw, 2014). This neglect of the benefits of the urban smellscape no doubt partly results from the traditional disparagement of the sense of smell in Western culture, but it is also an extension of modern sanitary campaigns that led to the relative deodorisation of most Western cities (Classen et al., 1994, p. 78; Jütte, 2005, p. 267). Unfortunately, some people mistake any odour they find personally distasteful for pollution. But one needs to distinguish pollutants—chemicals in the air that can cause actual harm, but that may or may not be detectable by their odour, such as carbon monoxide—from odourants—molecules that are by definition detectable but may cause no harm at all. Conversely, chemicals such as carbon dioxide- in normal conditions undetectable by its odour but may cause physiological consequences- are often ignored. Among the unfortunate effects of a focus on deodorisation and control is the increasing olfactory blandness of some upscale areas of many cities, which often contributes to a loss of the sense of place (Meighan, 2008).

If urban designers were to become more alert to the positive contributions of distinctive smells, they might not only begin to regard many existing odours as assets rather than nuisances but also begin to create new smellscapes that enhance a sense of well-being and aesthetic satisfaction (Pálsdóttir et al., 2021). Henshaw (2014, p. 5) speaks of these benefits as part of the "restorative" use of odours, a concept familiar from environmental psychology studies showing the benefits of exposure to nature. Such studies suggest the generous use of fragrant trees, green spaces, parks, waterways, ponds and fountains in urban design (Xiao et al., 2018b). Ba and Kang (2019b) also suggest that the olfactory experience of a fragrant tree can reduce the annoyance of traffic noise pollution. In the past, such features have been treated primarily as visual objects. Even then, they were often resisted by local governments because of their maintenance expense.

More controversial is the possibility of scenting public spaces with artificially created odours, which, considering the variability of odour preferences and sensitivities, may not be a good idea. Moreover, because a pleasant odour raised to a high intensity can become unpleasant, spreading a fragrance of sufficient concentration to mask traffic or other smells might make the fragrance as offensive as the exhaust fumes. Whatever interventions designers make, they will have to consider not only the appropriate intensity levels but also what types of smells will be consistent with

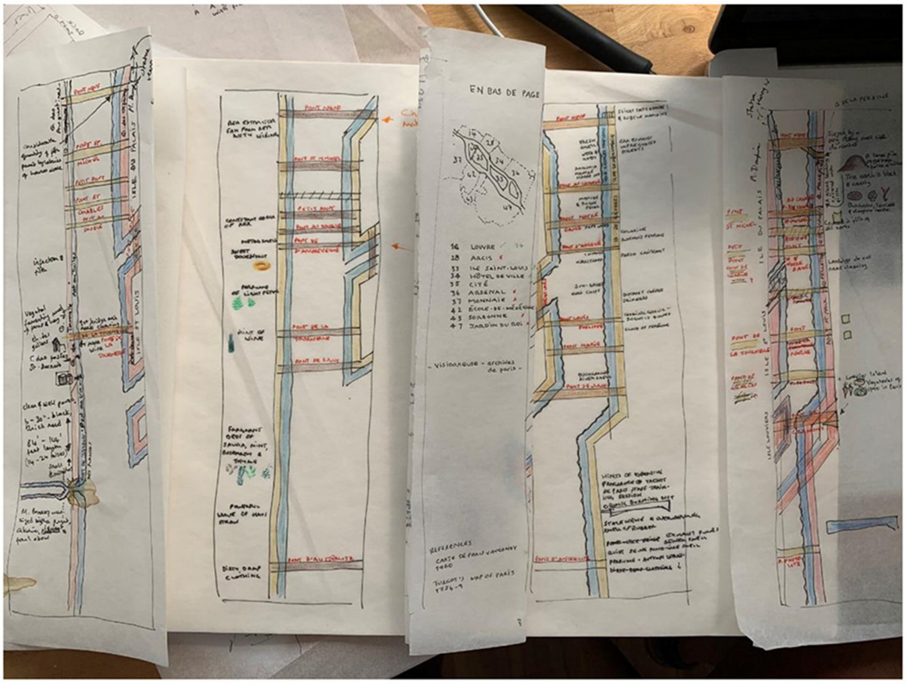

FIGURE 2 | Deploying fictional itinerary mapping practice techniques to depict a historical smellscape alongside a contemporary version (© Kate McLean, 2020).

the locale and acceptable to most residents. The practice of smell management and design should also consider individuals' personal and cultural resonances through behaviours and bodily movements in spaces (Wareen and Riach, 2018).

Artists also have a role to play in showing residents both the realities and possibilities of urban smellscapes. Among the most notable interventions of this kind have been the smellwalks conducted by Sissel Tolaas and Kate McLean, who have subsequently used the results to make artworks that are displayed in galleries and museums (Shiner, 2020, p. 278–281). The Australian artist Cat Jones produced an art installation for the 2017 Sydney Festival by interviewing 10 prominent cultural leaders about the city's past and present smellscapes and then playing the interviews for the public, accompanied by her imaginative recreation of the mentioned smells (Leimbach, 2017).

Considering possible applications of the smellscape approach in indoor contexts, a growing number of museums have become aware of a mismatch between their collections and their ocular-centric presentation to audiences. Consequently, visually oriented art museums, such as Amsterdam's Rijksmuseum, the Louvre in Paris and New York's Metropolitan Museum of Art, have integrated historically informed scents in their tours and displays. As challenging and contradictory as it may seem to address the nose in museums of visual art (Clapot, 2019), this approach has many advantages. Olfactory storytelling can add tremendously to the appreciation of the historical context of displayed objects and enhance the feeling of being momentarily transported to another time and place (Stevenson, 2014). Olfactory stimulation in museum contexts also influences behavior, with people becoming much more talkative during and after museum tours, indicating a heightened level of engagement (Spence, 2020c; Verbeek, 2020). Furthermore, blind and partially-sighted people indicate that sounds, tactile impressions and smells help them (re)imagine historical events and point to the utility of (smell-related) objects, which can enhance a sense of inclusivity, accessibility and therefore well-being.

ODOUR POLICY-MAKING AND THE URBAN ENVIRONMENT

The policies for odour control and management across Europe present several patterns. They predominantly address odour pollution caused by waste, traffic, plants, soil and water contamination, landfills, livestock facilities and cooking fumes in food districts that can negatively affect quality of life, causing complaints about smell nuisances similar to noise pollution (Bull, 2018). The policies are disparate and even completely absent in many places and lack common criteria for establishing odour-impact thresholds (Rfenacht et al., 2019). The focus remains on measuring emissions at the source, and methods such as evaluating odour impact on receptors (citizens) (e.g., British Standards, 2016) are time consuming, often expensive and still do not provide real-time information on the discomfort of the impacted citizens (Rfenacht et al., 2019). Overall, a top-down approach is usually implemented that fails to actively involve stakeholders in odour management processes, which Henshaw (2014) suggests should be the first step taken.

Against this backdrop, recent advances in smell research can be identified that address these limitations. Expanding on Henshaw (2014), Xiao (2018) proposes an integrated smellscape design process framework grounded on the understanding of smellscape as a perceptual construct. This framework indicates how the five domains in the existing urban design and planning practice can be integrated to implement a participatory process for the analysis, assessment and planning of smellscapes. Another innovative approach to promoting public participation in odour policy-making is to use citizen science tools. For example, the D-NOSES projects collect data on odour pollution through a free mobile app called OdourCollect that enables citizen participation in odour mapping to foster a bottom-up, multi-level governance model in local decision-making.

Finally, existing policies lack a distinction between pleasant and unpleasant odours, and odour is mainly considered a negative element of the urban environment (Bull, 2018). This is reflected in odour control and management strategies that usually apply masking and deodorisation techniques (e.g., Henshaw, 2014; Bull et al., 2018). Conversely, the positive impacts of smells should also be acknowledged in current policy and urban practice. Smells in fact bring distinct identities to places, connect people emotionally to their surroundings, positively influence human behavior and emotion and evoke memories of the past.

OUTLOOK AND CONCLUDING REMARKS

Smells, either negative or positive, should be considered as an essential aspect of the design and planning framework of public spaces alongside other sensory components, such as sound and lighting, to create a pleasant, healthy environment (Xiao, 2018). Moving from odour nuisance control to smellscapes opens up opportunities to appreciate the benefits of smells in human experiences and well-being. The gaps revealed through our review of the existing literature include a lack of databases and archives of smells; a lack of place-related histories and meanings; a lack of applicable design frameworks, building materials, scenting systems and representation methods; and limitations in how current policy-making considers and manages smells. Given these gaps and limitations, three directions are suggested for future research on smells and the build environment.

Firstly, setting up smell archives and databases may demand a large, collaborative effort and considerable time in the coming years. Records of smells and odorants provide essential information for replicating and creating a smell environment. The cultural and social value of smell is an important part of the history of towns and cities (Reinarz, 2014), so smell maps and oral stories should be collected to gather the information. Benchmarks of odour concentration and composition and measures of smells' emotional impacts on human experience can be tested in controlled experiments (see Maggioni et al., 2020). Engineers, chemists, public health specialists and smellscape researchers should engage in cross-disciplinary conversations and collaborations to establish clear objectives and methodologies for these databases. Involving artists and chemists/perfumers in the process can also contributed to the (re)creation of scents in the built environment, particularly in the heritage and museum contexts (see Verbeek, 2016; Spence, 2020b), where creating an experiential learning environment is essential.

Secondly, addressing social justice in odour control and management in urban planning and design would contribute to reducing odour pollution affecting minority communities, enhancing inclusivity for people who have partially or fully lost the sense of smell and fostering participation in decision-making processes concerned with removing or introducing smells to infrastructures and public spaces. Furthermore, promoting a real-time monitoring system and odour reporting platform—such as the OdourCollect app—would nurture a bottom-up, multi-level governance model. Creative methodologies drawn from artistic approaches could also facilitate participatory processes.

Lastly, research into advanced materials that can store and release natural smells and filter pollutants (i.e., VOCs and SVOCs) would advance the integration of smellscapes into current architectural and urban design practices. For example, recent research on nano materials by Lee and Jeon (2020) has shown the potential of polyacrylonitrile nanofiber membranes to filter gases and citrate smoke from burning cigarette paper to purify the air, thus contributing to safeguarding health and well-being in the built environment. These new materials could be used for the canopies in and around transport hubs, commercial kitchens and bus stops.

In addition to the above, the Covid pandemic has drawn attention to anosmia and parosmia. Initial studies suggest that up to 57% of Covid-19 patients experience some olfactory dysfunction (Agyeman et al., 2020; Moein et al., 2020). Subsequent to anosmia, an altered sense of smell, parosmia, occurs in over 50% of post-viral smell loss patients (Reden et al., 2006). This may result in either an inability or reticence to search for and sniff odours or the opposite (see Mahdawi, 2020; Rimmer, 2020). Köster et al. (2002) point out that a conscious coping mechanism for odours and the environment can potentially contribute to odour memory as a way to reduce the uneasiness experienced by people who experience anosmia. Odour education and the training of olfactorisation skills (ways to gain olfactory experiences via sensory cues beyond smelling) might increase well-being in the context of ongoing smell loss. Further research will be needed on designing an inclusive environment for people who experience a loss or changed sense of smell and on establishing environmental cues for olfactorisation.

AUTHOR CONTRIBUTIONS

JX, FA, and AR: contributed to conception and design of this perspective article. FA: introduction. JX and KM: methodological approaches in smellscape research. LS and CV: rediscovering designed smellscapes. AR: odour policy-making and the urban environment. JX, AR, and KM: outlook and concluding remarks. All authors wrote sections of the manuscript.

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Odors Associated With Autobiographical Memory Induce Visual Imagination of Emotional Scenes as Well as Orbitofrontal-Fusiform Activation

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Specific odors can induce memories of the past, especially those associated with autobiographical and episodic memory. Odors associated with autobiographical memories have been found to elicit stronger activation in the orbitofrontal cortex, hippocampus, and parahippocampus compared with odors not linked to personal memories. Here, we examined whether continuous odor stimuli associated with autobiographical memories could activate the above olfactory areas in older adults and speculated regarding whether this odor stimulation could have a protective effect against age-related cognitive decline. Specifically, we used functional magnetic resonance imaging to investigate the relationship between blood oxygen levels in olfactory regions and odor-induced subjective memory retrieval and emotions associated with autobiographical memory in older adults. In our group of healthy older adults, the tested odors induced autobiographical memories that were accompanied by increasing levels of retrieval and the feeling of being "brought back in time." The strength of the subjective feelings, including vividness of the memory and degree of comfort, impacted activation of the left fusiform gyrus and left posterior orbitofrontal cortex. Further, our path model suggested that the strength of memory retrieval and of the emotions induced by odor-evoked autobiographical memories directly influenced neural changes in the left fusiform gyrus, and impacted left posterior orbitofrontal cortex activation through the left fusiform response.

Keywords: autobiographical memory, functional magnetic resonance imaging, fusiform gyrus, odor, older adults, orbitofrontal cortex

INTRODUCTION

Specific odors can induce autobiographical memories (AM-odor), which are accompanied by the visual experience of a spatial and emotional scene, feelings of "being brought back in time" to a moment in the past, heightened emotional arousal, and the sensation of comfort (Willander and Larsson, 2006). Compared with other sensory input such as auditory and visual cues, memory retrieval induced by a specific odor can induce powerful visual imagery (Herz, 2004). Brain imaging studies have indicated that AM-odors activate the hippocampus (HI) and amygdala (AMG) (Herz, 2004; Masaoka et al., 2012a), and in younger individuals, the posterior orbitofrontal cortex (POFC) as well (Watanabe et al., 2018). Because olfactory information is directly transmitted to the piriform cortex, AMG, and entorhinal cortex (ENT), that is, centers of emotion and memory processing, olfactory input to these areas is directly associated with individual emotional past experiences (Herz and Cupchik, 1992; Masaoka et al., 2012a). The information finally converges in the OFC, which plays a role in olfactory identification and conscious awareness of emotions. Indeed, the level of OFC activation elicited by an AM-odor might be associated with the strength of a particular memory, with parallel activation of the para-HI (Watanabe et al., 2018).

The left POFC plays a role in reward processing (Breiter et al., 2001) and motivation (Roberts et al., 2016). Consequently, activation of the POFC by an AM-odor might influence subsequent behavior or cognition, especially in older adults with declining cognitive function and/or olfactory ability. Olfactory ability is known to decline with age (Doty, 1989). In addition to age-related decline, olfactory impairment has been reported as a first sign of mild cognitive impairment (MCI) (Roberts et al., 2016) and is observed in patients with Alzheimer's disease (Doty, 1989; Hawkes, 2003). Such olfactory impairment may be caused by pathological changes, including the accumulation of senile plaques and neurofibrillary tangles, which appear first in the HI and AMG (Mesholam et al., 1998). These areas are critical for functions of memory retrieval and reaction of emotion. Consequently, episodic memory function declines as people age (Park et al., 1996), and autobiographical memory has been found to be impaired in patients with Alzheimer's disease (Fromholt and Larsen, 1991). In one study that used facial expression stimuli in an emotion recognition task, older people exhibited poorer emotion recognition performance than younger individuals (Grainger et al., 2017). Thus, emotion recognition may be an index of social function, and appears to decline with age. Given the observed age-related decreases in olfactory ability, memory, and social function, the stimulation of emotions and memory *via* olfaction might decrease the rate of cognitive change in older adults. Specifically, an odor associated with an autobiographical memory might stimulate emotion and memory retrieval, with corresponding activation of the AMG, HI, and OFC.

To test this hypothesis in the present study, we had two research objectives. First, we examined the brain areas associated with AM-odor in older adults. If specific odors are strongly linked to episodic and emotional memories, then exposure to these odors may enhance neural responses in specific areas of the brain. By setting these specific brain areas as regions of interest, we examined whether connectivity existed between these areas using psychological interaction analysis (PPI) (Friston et al., 1997). Second, we used path analysis to test how the identified brain areas interacted with subjective scale scores, thus enabling us to create a network model including subjective memory and emotions induced by odor.

MATERIALS AND METHODS

Participants

The study participants comprised 30 older adults who were living independently and had self-reported memory loss and mild cognitive deficits. All subjects were recruited from the Meguro Human Resource Center, Tokyo Japan. An experienced neurologist assessed the subjects using the Japanese version of the Montreal Cognitive Assessment (MoCA-J) (Nasreddine et al., 2005). All participants had normal cognitive function (25.5 ± 2, indicated in **Table 1**; Fujiwara et al., 2010). No participants had a personal history of seizures or head injury, or a diagnosis of a neurological or psychiatric disorder.

We excluded two subjects with cerebral infarction and one subject with a history of subarachnoid hemorrhage. Accordingly, 27 subjects underwent magnetic resonance imaging (MRI). Of these, two subjects were excluded because of technical issues and one resigned during the scanning processes because of discomfort. Thus, the final sample included 24 subjects. All 30 initial subjects took part in experimental sessions on two separate days. On the 1 day, we conducted interviews to determine medical history, olfactory ability, and cognitive ability, and conducted pre-testing to enable odor selection. On the 2 day, which took place 2 weeks after the 1 day, 27 subjects underwent MRI scanning.

All experiments were conducted in accordance with the Declaration of Helsinki https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/. The study was approved by the Ethical Committees of Showa University School of Medicine, and all participants provided written informed consent prior to participation.

Olfactory Ability

We used the T&T olfaction test (Takasago International Corporation, Tokyo, Japan) to measure olfactory detection and recognition levels. This test is often used in the field of otolaryngology to test the ability to detect (able to smell) and recognize (identification or naming of odor) and is well correlated with the Pennsylvania Smell Identification Test (Kondo et al., 1998). The detailed methods are given in previous studies (Watanabe et al., 2018).

TABLE 1 | Demographic data of older adult participants.

Total (M/F), No.	24 (Female, 12/Male, 12)
Age, y	74.4 ± 0.7
Handedness	Right, 22, Left, 2
Years of education	13.9 ± 2.5
MoCA-J	25.5 ± 2
Olfactory detection	0.93 ± 0.74
Olfactory recognition	2.95 ± 1.5

MoCA-J, Japanese version of the Montreal Cognitive Assessment.

Pre-testing for Odor Selection

During the pretest interviews on the first experimental day, we tested five odors to determine whether they would induce autobiographical memory in the participant group. The odors were tatami (Japanese straw mat), osmanthus flower, baby powder, citrus, and incense. These were the five odors that induced the strongest autobiographical memories in a previous study in which 30 volunteers were asked to describe memories and rate the level of emotions evoked by the stimuli (Masaoka et al., 2012b). In the present study, all of the participants were asked to describe the memories evoked by the five odors and to rate the strength of the associated emotions. The odors were presented in a randomized order. The participants were exposed to each odor, and then asked to complete the following questions:

(1) Does this odor elicit a specific memory associated with a person, place, or event?
(2) Which age was associated with the memory induced by the odor (younger than 10 years old, teenage years, 20s, 30s, 40s, 50s, 60s, and 70s)?
(3) Rate the degree of pleasantness felt when recalling the memory induced by the odor and the memory context (1 = very unpleasant; 5 = very pleasant).
(4) Rate the vividness of the memory context (1 = not at all strong; 5 = extremely strong).
(5) How strong was the feeling of being "brought back in time" to the occurrence of the event (1 = not at all strong; 5 = extremely strong)?
(6) How emotionally intense was the memory related to the odor (1 = not at all strong; 5 = extremely strong)?

Of the five odors, the one that induced the most powerful autobiographical memory for each participant was used as the AM-odor for that individual. As in a previous study, β-phenyl ethyl alcohol was used as a control odor (Masaoka et al., 2012a,b; Watanabe et al., 2018). The previous study reported that the odor of β-phenyl ethyl alcohol was similar to that of a rose odor, had the characteristics of a "normal odor," and did not induce memory retrieval but had the same level of pleasantness as one of the AM-odors (Masaoka et al., 2012b; Watanabe et al., 2018).

Imaging Data Acquisition

All imaging protocol were the same as in the previous study (Watanabe et al., 2018). MRI scanning (3 Tesla Magnetom Trio scanner, Siemens, Erlangen, Germany) was conducted at Ebara Hospital, Tokyo, Japan, and sessions took place between 6 and 8 pm on Mondays after a brief clinical examination. The scanner had a 32-channel head coil, and functional imaging was acquired with multiband accelerated gradient-echo echo planar imaging. To increase the temporal resolution, four slices were acquired simultaneously. The fMRI time series comprised 330 whole-brain volumes/session, each comprising 39 axial slices (matrix: 80 × 80; TR: 1 s; TE: 27 ms; FOV: 16–22 cm, thickness: 2.5 mm; flip angle: 90°). Anatomical MRI was also acquired using 3D-magnetization-prepared rapid-acquisition-by-gradient-echo T1-weighted sagittal sections.

Statistical analysis for the fMRI data was performed using statistical parametric mapping (SPM12) software (Wellcome Department of Cognitive Neurology, London, United Kingdom). The software was implemented in MATLAB (R2013B; Math Works Inc., Natrick, MA, United States) on a computer running Mac OS X Yosemite. We performed image pre-processing including motion correction, co-registration of functional and structural images, normalization, physiological noise correction (SPM8, Drifter Toolbox), and spatial smoothing with a 6-mm FWHM Gaussian filter.

fMRI for Olfaction

The odor stimuli were delivered using the same custom-designed MRI-compatible system that has been previously described (Masaoka et al., 2014; Watanabe et al., 2018). The system delivers an odorant when the participant breathes in through a nose mask (ComfortGel Blue Nasal Mask 1070038, medium size, Philips Respironics, PA, United States). Each subject wore a nose mask fitted with a one-way valve unit that comprised a valve for inspiration and a valve for expiration. The inspiration valve was attached to three balloon valves, each of which was attached to an odor cassette. The odor cassettes contained the AM-odor, the control odor, and no odor, respectively. The inflation and deflation of the balloon controlled the outside scanner, and when the balloon valve was opened, the odor was delivered to the subject *via* their force of their own inspiration through the odor cassette. Respiratory rate and cardiac output were measured by a respiratory pressure sensor in the nose mask and a photoplethysmogram transducer (TSD200-MRI and PPG100C-MRI; Bio Pac, LA System, Japan), respectively. End-tidal CO_2 was constant throughout the experiment (no-odor baseline, 4.5 ± 0.05, control odor, 4.6 ± 0.02, AM-odor, 4.62 ± 0.03, measured with an O_2 and CO_2 Analyzer, Acro System, Chiba, Japan). Respiration, cardiac output, and end-tidal CO_2 data were stored in LabChart on PowerLab (ML846, AD Instruments, Aichi, Japan), and respiration and cardiac data were used to eliminate physiological noise in the preprocessing of the fMRI data.

As in our previously report, we conducted two fMRI sessions for each participant, one in which the AM-odor was interspersed with unscented air (no-odor baseline), and one in which the control odor (rose) was interspersed with unscented air (baseline). Each session comprised five unscented and five scented 30-s blocks. We designed our study to have 30-s presentations of scented and unscented air to minimize adaptation to the olfactory stimuli.

Subjective Data Analysis

We compared scores on subjective scales measuring the degree to which the stimuli were perceived as pleasant and comfortable, as well as the arousal level, vividness of the memory, level of memory retrieval, and the degree to which the participant felt "brought back in time" between the AM-odor and control odor *via* non-parametric Mann-Whitney tests.

fMRI Data Analysis

We generated SPM contrast images (first-level) by comparing the AM-odor and no-odor baseline condition, and the control-odor and no-odor baseline condition. At the group level for whole brain analysis, we performed one sample t-tests for the *AM-odor vs. no-odor baseline* and *control odor vs. no-odor baseline* comparisons. For this analysis, we applied voxel-wise correction with $P < 0.05$ and family-wise error (FWE) correction for the whole brain volume. We inferred the difference between the AM-odor and control odor conditions using a paired t-test within the whole brain mask and corrected multiple comparisons (FWE-corrected $p < 0.05$) based on minimum cluster-extent thresholds estimated using the AlphaSim (AFNI; National Institutes of Mental Health, Bethesda, MD, United States) permutation procedure. Cluster-extent probability distributions were estimated based on 1,000 permutations of simulated Gaussian noise with a spatial smoothness of 9.2, 9.1, and 8.9 within the analysis mask. The permutation procedure resulted in a minimum required cluster-threshold of 3,821 voxels.

For exploratory analysis, we conducted psychophysiological interaction (PPI) analysis with SPM 12 to investigate the functional connectivity between activated areas. As in our previous report, the posterior orbitofrontal cortex (POFC) was activated during the AM-odor trials, so the voxels corresponding to this region (MNI coordinates: $x = -38$, $y = 22$, $z = -10$, sphere 6 mm) were set as voxels of interest. Then, we performed PPI analysis to explore the functional connectivity between the left POFC and all other voxels. PPI analysis was first performed for individuals, and then the resulting contrast images were entered into a group analysis with a one sample t-test for testing *AM-odor > no-odor baseline* and *control-odor > no-odor baseline* comparisons across the whole brain. For all of the above analyses, a FWE-corrected $P < 0.05$ was applied.

Then, we investigated how the subjective scales of comfort, vividness, level of memory retrieval, and level of being "brought back in time" interacted with the activation level of the target areas. The activation areas that were statistically significant in the fMRI analysis and PPI analysis were the left POFC and left fusiform gyrus. We conducted path analysis to examine the causal connections between the BOLD signal of the left POFC, that of the left fusiform gyrus, and the subjective scale scores.

Raw mean BOLD signals were extracted from a 10-mm sphere at the MNI coordinates $x = -38$, $y = 22$, $z = -10$ (left POFC) and $x = -20$, $y = -66$, $z = -14$ (left fusiform gyrus) for AM-odor PPI. For this analysis, we used the MarsBaR ROI toolbox (SPM 8),[1] and entered the data into SPSS Statistics (IBM SPSS Statistics, Version 23.0, IBM Corp, Armonk, NY, United States). Before the path analysis, a number of analyses were performed to refine the model. We determined the Pearson correlations between the BOLD signals from the left POFC, the left fusiform gyrus, and the scores on the subjective scales, and conducted a multiple regression with interaction analysis.

Path analysis is similar to multiple regression analysis except that path analyses can be used to estimate the relative importance and significance of hypothesized causal connections between sets of variables. The statistical significance of the path coefficients was determined using a function in a structural equation modeling (SEM) program (IBM SPSS Statistics Amos, Version 23.0, IBM Corp, Armonk, NY, United States). Because our purpose was to create a causal model with observed variables, we employed path analysis instead of SEM, which takes into account the effect of latent variables on observed variables. We assessed the path model variability according to the goodness of fit index (GFI) and the Bollen-Stine bootstrap method. A GFI close to 1 and a Bollen-Stine bootstrap P value >0.05 were adopted for the model.

RESULTS

Demographic Data and Subjective Scales

Demographic data are given in **Table 1**. We confirmed that the olfactory detection and recognition scores were all in the normal range for older adults based on the data with that from age-matched patients with neurodegenerative disorders from our previous report (Masaoka et al., 2013). There was an equal amount of participants of each sex (men, 12, women, 12). A comparison between the AM-odor and control odor (**Figure 1**) indicated that the AM-odor significantly increased ratings of comfort ($z = -2.1$, $P < 0.05$), vividness ($z = -2.52$, $P < 0.01$), level of memory retrieval ($z = -2.9$, $P < 0.001$), and level of being "brought back to the past" ($z = -0.32$, $P < 0.001$) compared with the control odor. There were no differences in the degree of pleasantness ($z = -0.56$, $P = 0.57$) or arousal level ($z = -1.84$, $P = 0.06$) between the AM-odor and control odor trials.

fMRI Results

In the *AM-odor > no-odor baseline* comparison, the AM-odor trials had activation in the left POFC, right inferior frontal cortex, and bilateral fusiform gyrus (**Figure 2** top left and **Table 2A**). In the *control odor > no-odor baseline* trials, we observed activation in the bilateral fusiform gyrus (**Figure 2** top right and **Table 2B**). When comparing the AM-odor and control odor trials, the AM-odor significantly activated the left POFC compared with the control odor at corrected significance thresholds corresponding to the whole-brain mask (FWE-corrected $p < 0.05$) (indicated peak cluster in **Figure 2** bottom and **Table 2C**, other cluster indicated in **Supplementary Figure 1**). The PPI analysis confirmed that activation of the left POFC area was associated with increased connectivity with the areas surrounding the left POFC, right POFC, and bilateral fusiform gyrus in the AM-odor trials, and that this was especially the case for the left fusiform gyrus (**Figure 3**). In the control odor trials, the left POFC appeared to be positively connected with the right POFC and the areas surrounding the bilateral POFC but not specifically the left fusiform gyrus. All cluster sizes, z scores, MNI coordinates, and brain regions associated with the PPI analysis are given in the **Supplementary Table 1**.

[1] http://marsbar.sourceforge.net

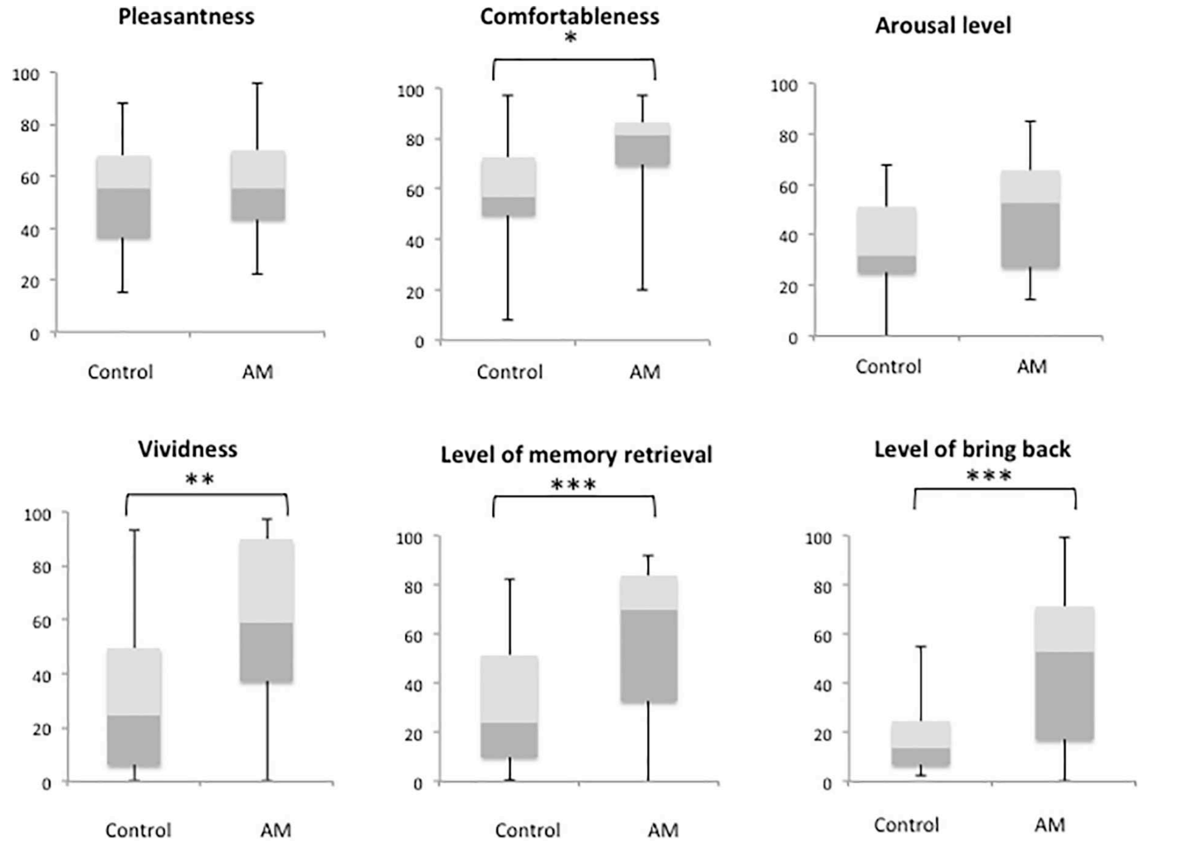

FIGURE 1 | Comparison of subjective scale scores between trials with a control odor and those with an odor associated with an autobiographical memory (AM). *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Path Analysis

According to above results, we analyzed the data from the left POFC and the bilateral fusiform gyrus using the following path analysis.

To investigate how the BOLD signals at the left POFC and the fusiform gyrus interacted with the subjective scales, we first tested our hypothesis. BOLD signals were extracted from the left POFC and the left fusiform gyrus in the AM-odor and control odor trials. Before the path analysis, we conducted Pearson correlation and multiple regression analysis to examine the relationship between each area in which we observed BOLD signal and the subjective scale scores. The statistical results of these correlation analyses are given in **Supplementary Table 2** (AM-odor) and **Table 3** (control-odor). In brief, in the AM-odor trials, we observed correlations between the BOLD signal in the left POFC and that in the left fusiform, and between the BOLD signal in the left fusiform gyrus and the level of memory retrieval and level of being "brought back in time." The level of memory retrieval was correlated with the degree of comfort, vividness, and the level of being "brought back in time" (all $P < 0.01$). In the control odor trials, there was no correlation between activity in the left POFC, activity in the left fusiform gyrus ($P > 0.05$), and the subjective scale scores. The multiple regressions with interaction analysis revealed a significant interaction between the AM-odor and control odor trials in terms of the relationship between the left fusiform BOLD signal and the level of memory retrieval ($\beta = 0.72$, $t = 1.96$, $P < 0.05$), and between the left fusiform gyrus BOLD signal and the level of being "brought back in time" ($\beta = 0.71$, $t = 1.95$, $P < 0.05$) (**Supplementary Figure 2**). We observed no interaction for the relationships between activity in the left fusiform gyrus and vividness ($\beta = 0.5$, $t = 1.6$, $P = 0.1$) or degree of comfort ($\beta = 0.9$, $t = 1.68$, $P = 0.09$).

For path analysis, we first tested the full model including the path between the following variables: the left POFC, left fusiform gyrus, memory retrieval, degree of comfort, vividness, and level of feeling "brought back in time" for each the AM-odor and control odor trials.

After eliminating non-significant paths, we determined the final path to have a GFI value of 0.9 with the Bollen-Stine bootstrap method, $p = 0.24$. **Figure 4** shows the path diagram with a significant direct path for AM-odor. All statistical details are given in **Table 3**. The degree to which the participant felt they had been "brought back in time" had a significant path to memory retrieval ($r = 0.8$, $P < 0.0001$). Further, memory retrieval impacted the left fusiform gyrus ($r = 0.44$, $P < 0.05$), and the left fusiform gyrus had a direct path to the left POFC ($r = 0.69$, $P < 0.0001$). In terms of covariances, we found a correlation between the degree of comfort and the level of feeling "brought

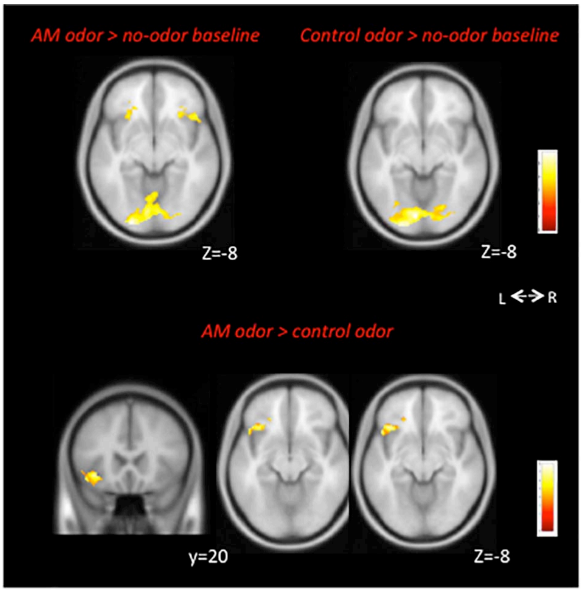

FIGURE 2 | Top: Neural correlations in AM-odor (*AM-odor > no-odor baseline*, left) and control odor (*Control odor > no-odor baseline*, right) trials. Bilateral fusiform gyrus activation was common for both odors. Both results corresponded to FEW-corrected $P < 0.05$. We used $P < 0.001$ with 3,000 voxels for visual purposes. Bottom: The AM-odor significantly activated the left POFC compared with the control odor (bottom) at corrected significance thresholds corresponding to the whole-brain mask (FWE-corrected $p < 0.05$) (indicated peak cluster). L, left; R, right.

TABLE 2 | Contrast fMRI data.

A: AM odor > no-odor baseline

Cluster	Z scores	Peak voxel coordinate x	y	z	Regions
6	4.94	−24	−94	−8	L. fusiform
4	4.98	−18	−76	−18	L. fusiform
4	4.98	−28	22	−8	L. POFC
2	5.04	56	20	2	R. inferior frontal cortex
1	5.01	42	−62	−30	R. fusiform

B: Control odor > no-odor baseline

Cluster	Z scores	Peak voxel coordinate x	y	z	Regions
14	5.04	−8	−82	−10	L. fusiform
10	4.96	26	−90	−2	R. fusiform
7	4.93	−18	−94	−6	L. fusiform

C: AM odor > Control odor

Cluster	Z scores	Peak voxel coordinate x	y	z	Regions
4391	3.27	−36	21	−9	L. POFC
	3.2	−36	40	−4	L. inferior frontal
	3.2	−42	26	−8	L. inferior frontal

POFC, posterior orbitofrontal cortex; L, left; R, right.

back in time" ($r = 0.61$, $P < 0.05$), between the degree of comfort and vividness ($r = 0.74$, $P < 0.01$), and between the level of feeling "brought back in time" and vividness ($r = 0.8$, $P < 0.01$). The other scales of pleasantness and arousal level were not statistically significant in the direct path results, and we found no significant direct path from the left POFC to pleasantness ($r = 0.34$, $P = 0.08$). However, given that the POFC was previously associated with pleasant emotion (Gottfried et al., 2002), we expected to find an indirect path from the variables.

Figure 5 shows the same diagram as in **Figure 4** but includes the significant indirect path of AM-odor. The statistical results of the indirect path are given in **Table 4**. The level of vividness had an indirect effect on activity in the left fusiform gyrus through memory retrieval (blue dotted line). Further, the level of vividness was connected *via* an indirect path to the left POFC through memory retrieval and activity in the left fusiform gyrus (orange dotted line) and also had an indirect effect on pleasantness through memory retrieval, activity in the left fusiform gyrus, and activity in the left POFC (purple dotted line). The degree of memory retrieval had an indirect effect on activity in the left POFC through the left fusiform gyrus (green dotted line), and impacted pleasantness through the left fusiform and the left POFC (pink dotted line). Activity in the left fusiform gyrus also had an indirect effect on pleasantness through the left POFC (pale blue dotted line).

For the control odor, we found an direct path between the subjective scale scores but no significant direct or indirect path to the left fusiform gyrus (**Supplementary Figure 3** and **Supplementary Table 4**).

DISCUSSION

In this study, we examined the relationship between activity in different brain regions and subjective emotional scale scores for acquired odors *via* functional imaging of the left POFC and the left fusiform gyrus during olfactory memory scanning sessions. We found that activation of the left POFC was associated with increased connectivity with the left fusiform gyrus, and path analyses indicated that these two regions were associated with memory retrieval and the feeling of being "brought back in time" during AM-odor trials. Notably, the subjective level of memory retrieval, vividness of the memory, and the associated degree of emotional comfort impacted the level of activation of the left fusiform gyrus and left POFC. Finally, the path model indicated that high subjective memory and emotion scale scores in the AM-odor trials were associated with activity in the left fusiform gyrus and the left POFC, as well as the degree to which the odor was rated as pleasant.

The role of the left POFC has been previous established in terms of reward processing (Breiter et al., 2001), response to attractive human faces (Aharon et al., 2001), and responses to pleasant odor stimuli (Gottfried et al., 2002). The left POFC is connected to the AMG, and the interaction between these

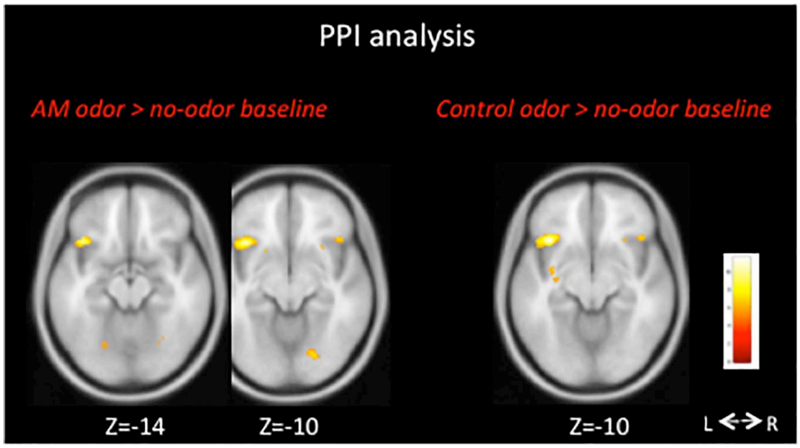

FIGURE 3 | We performed PPI analysis to explore the functional connectivity between the left POFC and all other voxels. In AM-odor stimulation, activity in the left fusiform gyrus increased with activation of the left POFC (left). FWE corrected $P < 0.05$ was applied. L, left; R, right.

two areas may involve emotional perception and awareness of enhanced emotions Murray and Izquierdo, 2007). In non-human primates, the caudal OFC is structurally connected to the AMG (Barbas, 2007), and the OFC receives input from temporal visual areas (Barbas, 1993). Indeed, in a human study, Frank et al. (2019) reported that an enhanced BOLD signal in the AMG was connected with activity in the OFC as well as the fusiform gyrus while participants viewed photos of an emotional scene. During this visual emotional perception, the neural response of the AMG was correlated with that of the fusiform gyrus, which is known to be a critical region for vision. These non-human primate and human studies support our path model, and the most interesting finding of the present study was that activation of the fusiform gyrus (as indicated by the BOLD response) was elicited not by visual but olfactory stimuli associated with autobiographical memory.

Odors are known to induce strong mental imagery (Herz and Cupchik, 1992). Further, an fMRI study reported that the visual perspective during retrieval of autobiographical memories activated the posterior part of the visual areas (St. Jacques et al., 2017). According to these studies, fusiform activation might also be associated with odor-induced visual imagery. Although our results indicated that the control odor also activated the fusiform gyrus, we expect that the connection between the POFC and fusiform gyrus would more strongly increased during memory retrieval and the feeling of being "brought back in time" during exposure to the AM-odor vs. the control odor. The odors in this study evoked imagery of autobiographical memories, including emotional episodic scenes and emotional special scenes, and the strength of these experiences was associated with the activation of the left fusiform gyrus and left POFC. Indeed, most of the subjects reported detailed descriptions of the evoked memories, for example, a memory of being a child playing with friends in a green field and smelling asmanthus flowers, or a memory of talking with their grandmother on a tatami mat, and so on. The fusiform gyrus is in the occipitotemporal gyrus, which is well known to be involved in the visual processing of human faces (Weiner and Grill-Spector, 2012), bodies (Peelen and Downing, 2005), and the perception of stimuli with high spatial frequency. Compared with the experience of recalling the memories without an odor, the scenes in the odor trials might have had an enhanced sense of realism and vividness, reflecting an enhanced fusiform-POFC connection.

One concern is that the anterior cingulate cortex (ACC) was not activated in our study. The ACC, POFC, and the anterior insula have previously been observed to exhibit activation at the same time as the primary olfactory cortex (Poellinger et al., 2001). García-Cabezas and Barbas (2014) suggested that the ACC might become activated at the same time as the primary olfactory cortex to mediate the process of rapid attention to olfactory stimuli, and to integrate this information with other sensory modalities *via* the POFC and anterior insula. In the present study, subjective feelings regarding the retrieved memories and the vividness of the memories were related to the strength of the activation of the fusiform gyrus and POFC. These results suggest that the subjects may have attended more to the retrieved memory than to the olfactory stimuli itself. Indeed, in a previous study, the HI and AMG were activated during retrieval of autobiographical memories *via* a specific odor (Herz, 2004). These data provide information regarding how the ACC integrates inhibition and

TABLE 3 | Statistical results for the direct path in AM-odor trials.

Path	*r*	*P* value
Bring back — memory retrieval	0.83	$P < 0.0001$
Memory retrieval—L. fusiform	0.44	$P = 0.02$
L. fusiform—L. POFC	0.69	$P < 0.0001$
l. POFC—pleasant	0.33	$P = 0.08$
Comfortableness—bring back	0.61	$P = 0.01$
Comfortableness—vividness	0.8	$P = 0.003$
Bring back—vividness	0.8	$P = 0.003$

Standardized regression weight, p value, correlations of covariances and p value.

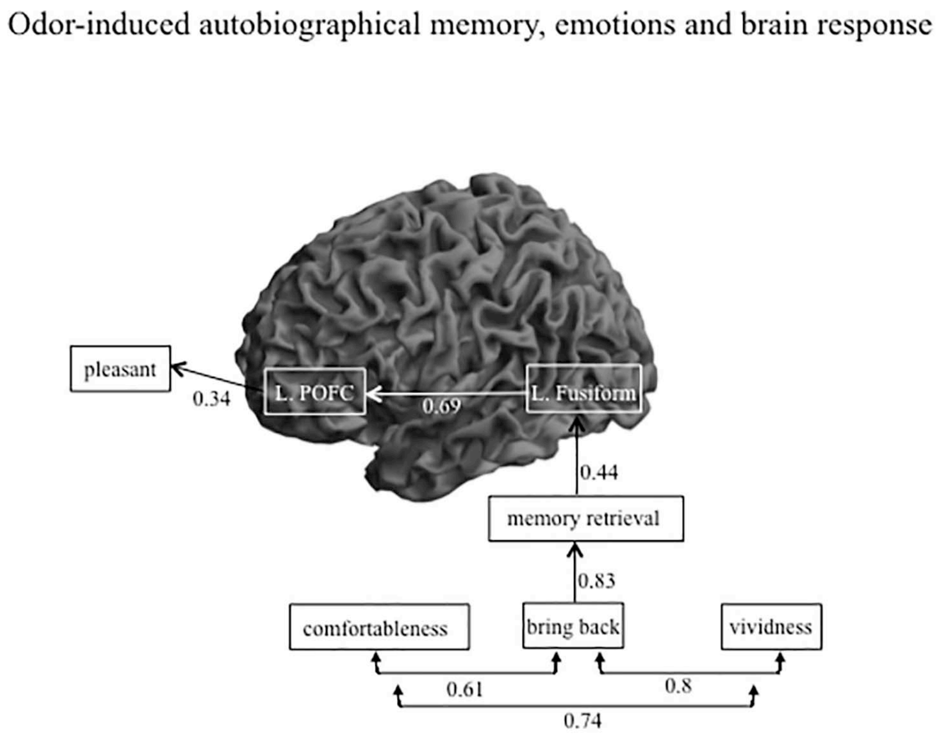

FIGURE 4 | Path diagram showing the significant direct path for AM-odor trials. There were strong correlations among the subjective scales scores, and the level of feeling "brought back in time" had the strongest impact on memory retrieval. The strength of memory retrieval had a direct effect on activation in the left fusiform gyrus, and the level of activation of the left fusiform gyrus directly impacted that in the left POFC.

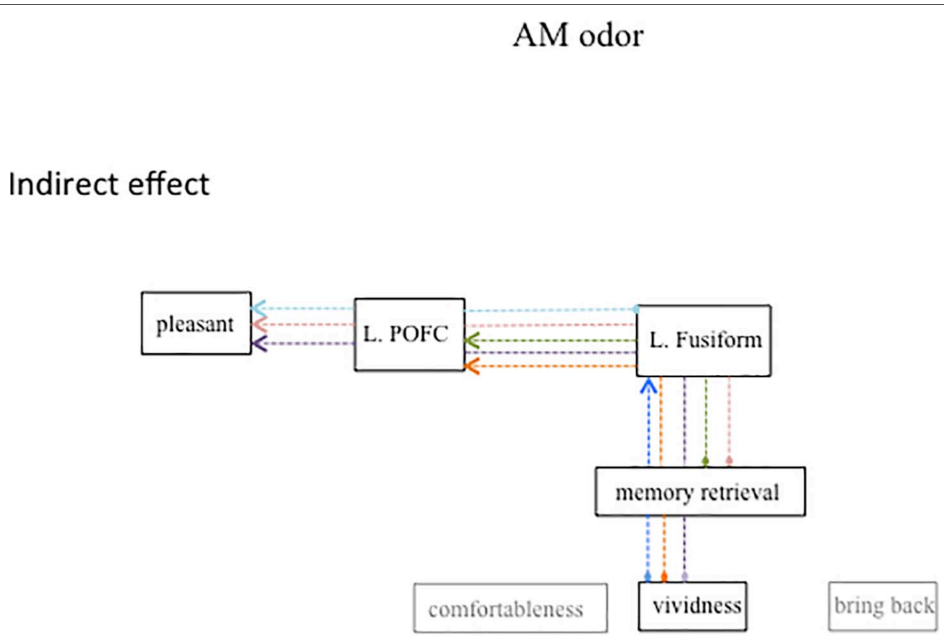

FIGURE 5 | Path diagram showing significant indirect path for AM-odor trials. Each colored dot indicates the starting point of the indirect path and the same colored arrow indicates the final affect variable. Subjective scale scores indirectly affected the left POFC through the left fusiform gyrus. The strength of memory retrieval predicted the degree of pleasantness, which appeared to depend on the level of activation in the left fusiform gyrus and the left POFC.

TABLE 4 | Statistical results for the indirect path in AM-odor trials.

From	To	Lower bounds	Upper bounds	*P* value
Bring back	L. fusiform	0.11	0.59	*P* = 0.01
Bring back	L. POFC	0.03	0.5	*P* = 0.01
Bring back	Pleasant	0	0.25	*P* = 0.05
Memory retrieval	L. POFC	0.03	0.5	*P* = 0.02
Memory retrieval	Pleasant	−0.001	0.3	*P* = 0.05
L. fusiform	Pleasant	−0.01	0.54	*P* = 0.1

Standardized regression weight, p value, correlations of covariances and p value.

excitation with activation of the parahippocampus, HI, POFC, and fusiform gyrus, although further research is needed.

Although the AMG, fusiform gyrus, and OFC had been proposed to have directional interconnectivity in emotional scene perception (Frank et al., 2019), the AMG was not included in the path analysis in our study.

Particularly, the AMG did not survive the GLM analysis with FWE correction. As in the previous study, the piriform cortex, AMG, and hippocampus, which are regarded as the primary olfactory areas, did not reach statistical significance. There are two possible reasons for this. First, in terms of primary olfactory fMRI activation, these regions may rapidly habituate to olfactory stimuli (Masaoka et al., 2014; Watanabe et al., 2018). Specifically, repeated presentation of the same odorant may lead to decreased neural responses in the PIR, ENT, and AMG, and in turn, a decreased BOLD response. Although the primary olfactory areas are known to habituate very quickly, downstream secondary areas of the OFC continue to respond to recurrent odor presentation (Poellinger et al., 2001; Sobel et al., 2001).

The other possibility is that the areas related to conscious awareness of emotion or memory, as well as visual spatial processing, had more powerful responses to the stimuli. Thus, the strong mental imagery might have strengthened the statistical power of activation in the frontal and occipital areas. Further studies that compare activation observed during odor-induced memory or emotion and that accompanied by visual stimuli are needed to more clearly understand the role of AMG activation.

As with previous reports, activation in the left OFC and left fusiform was more significant than that on the right side. Svoboda et al. (2006) indicated in a meta-analysis that autobiographical memory was associated with a network of left-lateralized structures including the medial and ventrolateral prefrontal regions. For instance, the left OFC was dominant during conscious assessment of the emotional quality of an odor (Royet et al., 2003). In terms of left fusiform activation, Spagna et al. (2021) reported that robust activity in the left fusiform gyrus was associated with visual mental imagery. Evidence from patients with brain damage indicates that visual mental imagery is impaired after extensive damage of the temporal lobe, especially that in the left hemisphere (Bartolomeo, 2002). Specifically, a case study of patients with selective damage to the right lingual gurus and left posterior medial fusiform gyrus revealed impaired visual mental imagery. The left fusiform activation observed in our study was located near the medial posterior regions, suggesting that this left fusiform area may be implicated in semantic and lingual processing associated with mental imagery, especially given that with the left OFC plays a role in conscious awareness of memory and emotion.

LIMITATIONS

Several limitations should be noted. First, we analyzed a small number of subjects, and thus studies with a larger number of subjects, including those with MCI, are needed to clarify the path direction of brain activation in terms of subjective memory level and emotions. Second, although we used a subjective scale to measure odor-evoked autobiographical memory, the participants also reported that the odors elicited episodic and spatial memory. Further studies should include evaluations of autobiographical memories (Kopelman et al., 1989), as well as detailed descriptions of the retrieved memories. In addition, future studies should compare neural activities according to the characteristics of the evoked autobiographical memories. Third, we used a careful procedure to clean the odor stimuli from our experimental device, and used only two odors for each participant to reduce the risk that the odors would mix in the valve. In the future, we hope to develop an odor delivery system that enables the presentation of several AM-odors and control odors, as this would enable us to test the relationship between the neural response and subjective scales scores for each odor. Fourth, although we obtained an optimized path model, we could not determine the cause-and-effect relationships between points in the pathway. To investigate this relationship, a method with a higher time resolution such as electroencephalogram (Frank et al., 2019) might be helpful.

SUMMARY

Olfactory abilities are known to decline with age, and olfactory decline may predict further decreases in cognitive and emotional function (Roberts et al., 2016). Our data indicate that in healthy older adults, odors induced autobiographical memories along with activation of the left POFC. This result was consistent with our previous report, which involved young subjects. In older adults, an increased level of memory retrieval and feeling of being “brought back in time” accompanied activity in the left POFC and left fusiform gyrus. Subjective feelings such as the vividness of the memory and degree of comfort impacted the level of left fusiform gyrus and left POFC activation. Our path model suggested that the strength of the memory and emotions elicited by the odor-induced autobiographical memory, which was associated with neural changes in two brain regions, could indirectly impact subjective pleasantness. Activation of the POFC appears to be important for cognitive function and motivation (Watanabe et al., 2018), and retention of these functions is important for older adults. Glachet and El Haj (2019) suggested that odor exposure could be a useful tool for improving the quality of autobiographical memory retrieval and increasing the number of positive memories in patients with Alzheimer’s disease. Taken together, the existing data indicate that continuous stimulation with an odor associated with a strong memory may elicit a continuous neural response in the POFC, and that this neural response could play a role in protecting cognitive function. In the future, we plan to continue to explore how odors associated with autobiographical memory exposure might contribute to the clinical features of neurodegenerative disorders. However, more work is required to investigate whether odors that evoke positive memories and emotions can contribute to healthy aging in terms of all physiologically, cognitive and emotional function.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committees of Showa University School of Medicine. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YM and HS designed the study and conducted experiments. YM analyzed the fMRI data and wrote the initial manuscript. HS analyzed subjective scale data. MY, AY, MH, NK, and KO recruited participants and assisted with scanning. MId assisted with manipulation of the fMRI device. KW, SKu, SKa, and NI performd pre-processing of the fMRI data. YM, HS, and MIz edited the final manuscript. All authors discussed the results.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnins.2021.709050/full#supplementary-material

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Crossmodal Interactions Between Olfaction and Touch Affecting Well-Being and Perception of Cosmetic Creams

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In the present series of studies, we investigated crossmodal perception of odor and texture. In four studies, participants tried two textures of face creams, one high viscosity (HV) and one low viscosity (LV), each with one of three levels of added odor (standard level, half of standard, or base [no added odor]), and then reported their levels of well-being. They also reported their perceptions of the face creams, including liking (global liking of the product, liking of its texture) and "objective" evaluations on just about right (JAR) scales (texture and visual appearance evaluations). In Study 1, women in France tried the creams on their hands, as they would when testing them in a store, and in Study 2, a second group of French women tried the creams on their faces, as they would at home. In Studies 3 and 4, these same two procedures were repeated in China. Results showed that both odor and texture had effects on well-being, liking, and JAR ratings, including interaction effects. Though effects varied by country and context (hand or face), the addition of odor to the creams generally increased reports of well-being, global liking and texture liking, in some cases affecting the "objective" evaluations of texture. This is one of the first investigations of crossmodal olfactory and tactile perception's impacts on well-being, and it reinforces previous literature showing the importance of olfaction on well-being.

Keywords: crossmodal, olfaction, tactile perception, well-being, cosmetics, liking, JARs

INTRODUCTION

Odor and texture are important factors for both the enjoyment and the pleasure gained from cosmetics. The present study focused on the interactions between odor and texture and their effect(s) on well-being resulting from application of face creams as well as liking and perception of the creams' textures. This experience was examined in two contexts, one like in a "store," in which women tested a product by applying a face cream to their hands, and the other like at "home," in which women applied cream to their faces. To explore cultural differences in this experience, similar versions of this study were performed in both France and China.

We usually think of each of our five senses as functioning separately; we hear a sound, smell an odor, or see colors. But more and more studies have found that interactions occur among these senses, influencing these seemingly basic perceptions. Vision can override other senses, causing viewers to believe they hear a voice coming from the mouths of actors on a cinema screen or a ventriloquist's dummy when the voice's real source is elsewhere (see Alais and Burr, 2004, for a discussion of bimodal integration). Taste, smell, texture, appearance, and even sounds can be important in the experience of a fine meal (see Spence, 2010 for a discussion of crossmodal influences on the experience of bacon-and-egg ice cream). Crossmodal associations are strong and pervasive; even when instructed to ignore stimuli from another sense, studies have demonstrated this other sense's influence, for example, of visual stimuli on olfactory perception (Demattè et al., 2009).

Generally, in the study of crossmodal associations, certain senses have been studied more than others. Many studies have examined multisensory perception through vision and olfaction (e.g., Barkat et al., 2003; Österbauer et al., 2005; Demattè et al., 2009; Seo et al., 2010; Zellner, 2013; Guerdoux et al., 2014; Robinson et al., 2015; Nehmé et al., 2016), vision and tactile perception (Duncan et al., 2020), and audition and olfaction (e.g., Belkin et al., 1997; Seo and Hummel, 2011; Crisinel and Spence, 2012). Multisensory integrations between texture and olfaction have been studied together extensively in gustatory/olfactive perception and food texture (e.g., Hollowood et al., 2002; Saint-Eve et al., 2006; Bult et al., 2007; Roudnitzky et al., 2011).

To our knowledge, there have only been three other studies to have examined the multisensory interaction of tactile perception and olfaction outside the domain of food/flavor perception, and these along with a fourth study (the one on vision and tactile perception mentioned above) are especially relevant to the present report. In the first, the authors demonstrated a clear influence of odor on perception of texture: they tested participants' perception of the softness of fabric treated with different chemicals in two separate odor contexts: lemon vs. animal scent (Exp. 1, odor presentation carefully controlled) and lavender vs. animal scent (Exp. 2, odor added directly to fabric) and in both cases the vegetal scent resulted in higher softness ratings of the fabric (Demattè et al., 2006).

The second article to examine odor and tactile perception focused on the influence of taste. One odor was sampled in a viscous solution, a second in a sweet-viscous solution, and a third in water. When later sniffed alone, the odor paired with the sweet-viscous solution was judged as sweeter and thicker than the others, but the odor paired with the viscous solution was not rated significantly differently from the others, though there was a trend toward this (Stevenson and Mahmut, 2011). The authors hypothesized that the experience with the sweet taste may have enhanced learning of the odor-viscosity pairing. The third article to examine olfaction and tactile perception found that a pleasant touch was rated as less pleasant when participants were exposed to a disgusting odor (feces), though a pleasant odor (rose) had no effect on ratings (Croy et al., 2014).

The final study, like the present experiments, focused on perception of viscosity of a skin care product (Duncan et al., 2020), demonstrating clear neurological and behavioral effects of vision on perception of texture. Participants showed brain activation in somatosensory regions in response to visual-only texture cues (a video of the lotion being poured into a petri dish), suggesting early crossmodal perception of texture. Behaviorally, the simultaneous presentation of a more viscous lotion visual cue with lotion application made participants judge the feeling of both the viscous and watery lotion as more moisturizing.

Though tactile perception and olfaction have not often been examined together outside the context of food, olfaction as a domain is particularly rich in crossmodal correspondences, that is, tendencies for an odor to be associated with a feature in a distinct sensory modality. Odor-color, odor-taste, and probably some odor-texture mappings can be explained by associative learning, but others such as common odor-sound associations are more complex (Deroy et al., 2013).

Why Study Tactile Perception and Odor Specifically?

It is interesting to study tactile perception and odor together for two reasons: First, given the prevalence of scented cosmetic products with varying textures, olfaction and tactile perception together offer an ecologically-valid way to examine the impacts of one sensory input on another and multisensory perception on emotion and well-being. Second, both of these senses develop early in gestation, with some markers of system maturity present around the 29th week (Hrbek et al., 1973; Chuah and Zheng, 1987), and, perhaps most importantly, they are *emotionally* important from the beginning. Tactile stimulation and massage can be used to reduce pain and anxiety and increase weight gain in preterm neonates (e.g., Field et al., 1986). And, though the valence of emotional responses to odors appears to be learned (see Herz, 2002 for a review) the olfactory system is fully developed at birth (Chuah et al., 2003) and clear emotional responses to odors are present from this time (Steiner, 1974). The primacy of these senses may be a reason that they are both so closely linked to pleasure and comfort, and through pleasure to well-being, even in adulthood.

According to Aristotle, well-being could be thought of as a combination of at least two components: hedonia (pleasure) and eudaimonia, or finding meaning in life (Berridge and Kringelbach, 2011; Dolcos et al., 2018). Odors act mainly on the former—an odor's experience is difficult to dissociate from its hedonic tone (Schiffman et al., 1995; Rétiveau et al., 2004)—but they are also tightly linked to autobiographical memories (for a review, see Chu and Downes, 2000) and can be even more effective than visual cues for triggering autobiographical memories (de Bruijn and Bender, 2018). A classic example is Proust's madeleine. One might imagine that the recall of autobiographical memories could have an impact on eudaimonia; indeed, a recent review suggests that odor-invoked autobiographical memories can increase positive emotions and reduce negative emotions and stress (Herz, 2016). Even so, odors' main role in well-being is likely to be on the hedonic side.

Multiple examples exist of odors' hedonic influences on well-being. Aromatherapy, a healing technique involving inhaling or using essential oils on the skin, may provide a promising avenue of research for treating psychiatric disorders (Perry and Perry, 2006) and odors themselves have effects on mood, physiology, and behavior (Marchand and Arsenault, 2002; Herz, 2009). Pleasant odors can be used in classical conditioning to positively influence human behavior (Chu, 2008). Unpleasant odors, while not increasing pain intensity, can make the experience of pain more unpleasant (Villemure et al., 2003) and, similarly, sweet odors (note that this result does not extend to all pleasant odors) do not decrease pain intensity but can increase pain tolerance (Prescott and Wilkie, 2007). Marchand and Arsenault (2002) did find a reduction in pain perception, and this effect was gender-specific; pleasant odors reduced pain perception for women but not men, though mood was improved in both groups.

The addition of pleasant odors to cosmetic products has been shown to increase participants' ratings of both pleasantness and arousal (Barkat et al., 2003), though pleasantness ratings can be affected by external factors such as an impression of luxury associated with the odorant (Baer et al., 2018) or the odorant's name (Porcherot et al., 2012). In general, measuring the effect of odors on mood or affect is a challenge; several studies of odor and consumer behavior have reported no positive effects (Ellen and Bone, 1998) or no difference at all between scented and unscented conditions (Morrin and Ratneshwar, 2000, 2003) on self-reported affect. This may be due to changes in mood due to scent being below participants' awareness level (see Rimkute et al., 2016 for a discussion). This implies that direct self-report may not be the best way to evaluate changes in affect or mood in more real-life situations. An alternative explanation is that this lack of effects is due to emotion measurement instruments not being well-adapted to emotions from odors. Researchers in Geneva have investigated the best means to evaluate these emotions, creating Emotion and Odor Scales based on behavioral studies in different countries (Chrea et al., 2009; Ferdenzi et al., 2011) as well as a universal scale combining data from all of these (Ferdenzi et al., 2013a).

The present study attempts to build on previous research in order to investigate the interaction of odors and textures in an ecologically valid, "as in real life" context. When consumers want to choose a new skincare product, they often go to specialized beauty stores or department stores and ask to test the different products that are available. Even if they are products meant to be applied to the face, in general, consumers test them on their hands. We attempted to replicate this experience, though in a controlled environment. We report results from women who tested creams with two different textures (low and high viscosity) and three levels of odor (no added scent, half of the standard scent, and the standard scent level). One group tested these on their hands, as in a store, and another on their faces, as they would after having purchased the product, at home. The participants rated both their liking of the creams and how it made them feel, as well as giving more objective measures such as JARs (Just About Right) of the texture and appearance. Rather than a single identifiable odor such as lavender, anise, or lemon, we used a floral blend comparable to others found in commercially available cosmetics. The proportions of odor tested were also based on those commercially available.

This study is designed to answer questions about the effects of odor and texture on well-being, liking, and JAR ratings of face cream. (1) Does the percentage of added odor affect well-being ratings for a cream after applying it to the skin? Does its effect vary with texture? (2) Does the percentage of added odor affect perception of the product, in terms of liking and "objective" evaluation? How does its effect vary with texture? (3) Do these effects differ depending on whether the cream is applied to the hand or the face? Finally, (4) do we find similar effects across different cultures?

STUDY 1: HAND APPLICATION IN A FRENCH SAMPLE

Materials and Methods

Participants

A group of 60 French-speaking women completed this task ($M_{age} = 45.7$, age range = 31–60). All participants lived in the Paris region. None were pregnant, and none had participated in other cosmetic tests in the previous three months. They all used skincare products on a daily basis, purchased at specialized beauty stores, and they were asked what brand of skincare they use at the beginning of the procedure to verify that they used higher-end or luxury brands. They were recruited by and tested at Eurosyn, a sensory testing laboratory which recruits from a list of participants in the community. The participants were not aware that it was an experiment run by Chanel. Participants were reimbursed for their time with gift cards. All research was conducted according to the principles expressed in the Declaration of Helsinki, and written informed consent was obtained from every participant. All the data collected respond to GDPR requirements (European Chart for General Data Protection Regulation) and all the products tested by the participants were validated by a toxicologist (with a Safety Certificate for each product).

Materials

Creams

The materials used in this study were face creams with two different textures (low and high viscosity), each with three levels of odor, 0% (Base), 0.15% (Half of standard added odor), or 0.3% (Standard added odor). Viscosity of the creams was measured as its elastic modulus using oscillatory rheometry. The high-viscosity (HV) cream had a *G*' of 633 Pa, the low-viscosity (LV) cream had a *G*' of 220 Pa. These two types of viscosity are clearly distinguishable both visually (see **Figure 1**) and by touch for naïve participants. Viscosity did not vary with added odor. The type of odor added to the creams (a proprietary blend with a floral scent) did not vary, only its concentration. However, the Base condition was not neutral; each ingredient of the cream had its own odor, and one of the active components of the cream had a vanilla scent. The odors of these raw materials were modulated by the additional odor in the Half and Standard conditions. These levels of odor were chosen in order to compare the actual scent (Standard) products to the same products without added scent (raw odor), to see if the addition of a scent is beneficial for the perception of the product and the emotions felt with it. The third product version (Half) was chosen in order to compare the Standard products to a product containing less added perfume but in which the raw odor was nonetheless disguised. This allowed us to examine whether a different concentration of perfume would impact the perception of the product and the emotions felt with it.

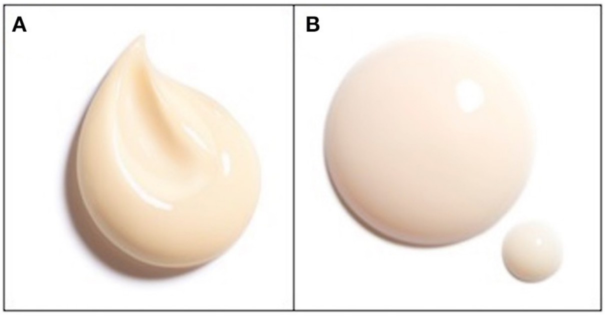

FIGURE 1 | Photographs of two creams showing texture difference. **(A)** high-viscosity, **(B)** low-viscosity.

Questionnaire

The questionnaire (completed only after testing the cream) was presented on a computer using the program Fizz. Participants responded on Visual Analogue Scales by clicking at any point along a line between two extremes, which varied by question. Responses were recorded by the software as values between 0 and 10. The questions discussed here were originally in French but have been translated to English for this report. Questions concerned their liking of the product, Just About Right measures (JARs), and their emotional state (based on the Emotion and Odor Scales [EOS]; Chrea et al., 2009). The questions analyzed for the present report were (1) How much did you like the product? (Not at all—Very much), (2) How much did you like the texture of the cream? (Not at all—Very much), (3) How would you characterize the texture of the cream? (Too light—[Just right]—Too oily), (4) How would you characterize the appearance of the cream? (Too transparent—[Just right]—Too opaque), (5) How strongly do you feel each emotion? (Not at all—Extremely; "well-being" was the emotion analyzed for the present report).

Procedure

As the study aimed to investigate emotional states linked to products, participant fatigue was likely if all 6 products were tested in one session. Therefore, the study occurred over two sessions of 45 mins each, and there was a minimum of 48 h between sessions. In each session, participants tested one of the textures at all three levels of odor concentration. The order of presentation within a session was counterbalanced across participants.

The day of the study, participants were asked to abstain from applying any scented body products or perfume. In each session, participants were told "You will be testing three premium face creams on your hand, as you would when testing it in a store before purchasing it. After each of the three tests, you will respond to several questions concerning the cream you've just tried." The creams were delivered to the backs of participants' hands by an experimenter using pre-filled syringes containing 0.1 ml. This procedure is like what happens in stores, though vendors use a spatula instead of a syringe. All the creams were delivered without any information concerning the product (scent percentage, brand, ingredients, skin benefits), except that it was a "premium facial cream."

After testing each cream, participants filled out the questionnaire, including the questions described above. The instructions for the questionnaire reminded them to keep in mind that the cream was intended for use on the face, even though they had tested it on their hands. They then took a break for 10 mins before trying the subsequent cream; during this time, they were asked to thoroughly wash their hands using unscented soap.

See **Figure 2** for an outline of the experimental procedures for all four studies.

Analyses

Overall analyses were the same for all four studies. The dependent variables of interest were examined using ANOVAs (type III) to compare nested generalized linear mixed models fitted using the statistics program R, version 4.0.3 (R Core Team, 2020), and the package lme4, version 1.1.26 (Bates et al., 2015, R package: lme4, RRID:SCR_015654). Fixed effects variables were TEXTURE and ODOR, and subject was included as a random factor. Additional factors were tested in preliminary models (age, reported skin type), and none of these resulted in better models so they were not explored further. Participants' continuous ratings were quantified on a scale of 0–10. Because the different textures may have changed the odor of the creams, we do not report results on perception of odor, as these would not be possible to interpret. We verified that the addition of odor did not change the viscosity of the cream. Because the factor ODOR had three levels, Standard and Half odor were each compared to the Base odor baseline within the model, and the comparison between Standard and Half odor was done using a pairwise *post-hoc* test using the package lmerTest, version 3.1.3 (Kuznetsova et al., 2017, R package: lmerTest, RRID:SCR_015656) in R. All three of these comparisons are reported including a Bonferroni correction of their *p*-values.

Results

Descriptive statistics (means, SD, ranges) for all the ratings are shown in **Table 1**. Ratings of well-being after trying the product were affected by ODOR, $\chi^2(2) = 45.6, p < 0.001$. The Bonferroni-corrected model showed differences between Standard and Base, $\beta = 2.38$, $SE = 0.38$, $t_{(299)} = 6.25$, $p < 0.001$, and between Half and Base, $\beta = 2.05$, $SE = 0.38$, $t_{(299)} = 5.38$, $p < 0.001$, but not between Standard and Half, $\beta = 0.27$, $SE = 0.27$, $t_{(299)} = -0.99$, $p = 0.64$. There was no main effect of TEXTURE, $\chi^2(1) = 1.38$, $p = 0.24$, nor was there a significant interaction, $\chi^2(2) = 0.71$, $p = 0.70$.

Overall liking of the cream was significantly affected by TEXTURE, $\beta = 5.27$, $SE = 0.29$, $\chi^2(1) = 5.44$, $p = 0.02$, with a preference for the HV cream, and ODOR, $\chi^2(2) = 67.0, p < 0.001$. Using a Bonferroni correction, the model showed significant differences between Standard and Base, $\beta = 2.55$, $SE = 0.34$, $t_{(300)} = 7.42$, $p < 0.001$, and between Half and Base, $\beta = 2.3$, $SE = 0.34$, $t_{(300)} = 6.70$, $p < 0.001$, but there was no difference between Standard and Half odor, $\beta = 0.44$, $SE = 0.24$, $t_{(300)} = -1.81$, $p = 0.14$. There was also an interaction between TEXTURE and ODOR,

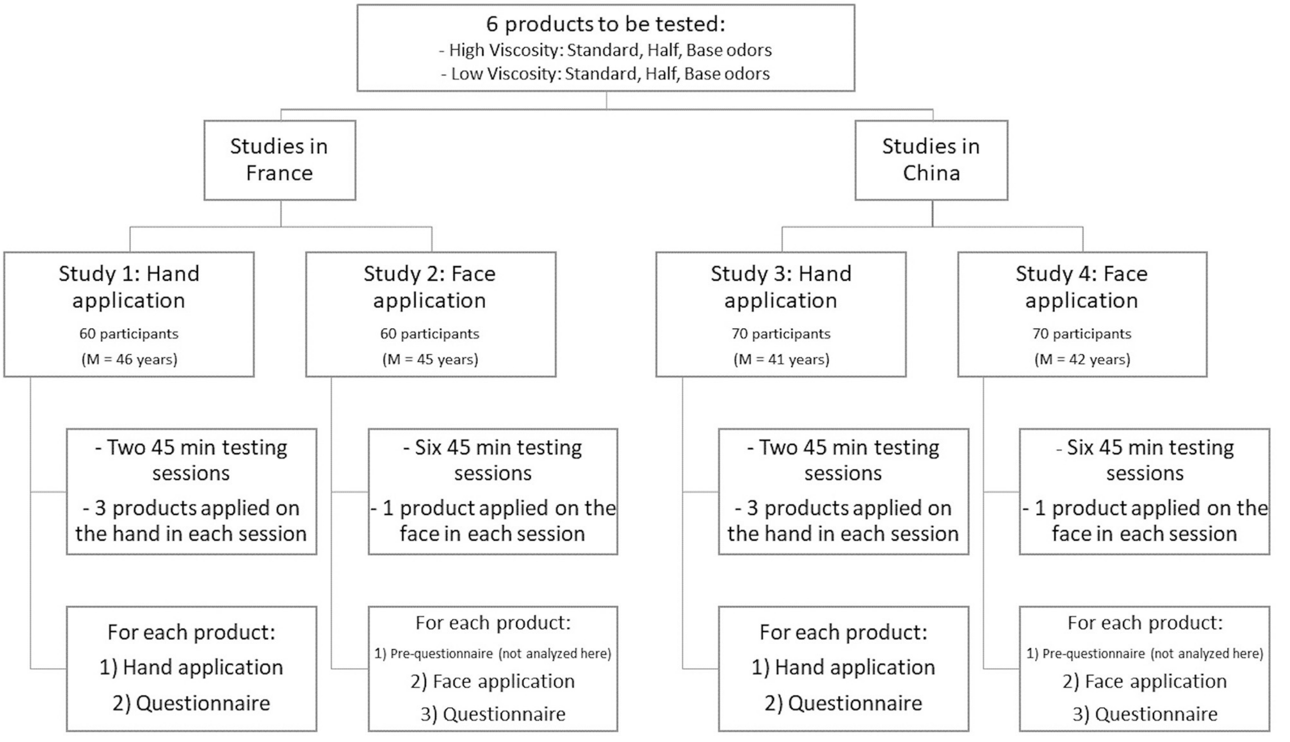

FIGURE 2 | Diagram of the methods for all four studies.

TABLE 1 | Descriptive statistics for each level of viscosity and odor in all four studies.

				Liking				Just about right ratings			
		Well-being		Product		Texture		Oiliness		Opacity	
		Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Study 1: France/Hand application	LV cream	5.62 (3.00)	1–10	6.89 (2.51)	0–10	7.01 (2.43)	0–10	4.64 (1.13)	0–8.7	4.80 (0.80)	0–7.1
	HV cream	5.81 (2.80)	0–10	6.97 (2.38)	0.2–10	6.93 (2.42)	0.4–10	6.02 (1.63)	0.7–10	5.14 (0.88)	1–9.9
	Base odor	4.36 (3.07)	0–9.9	5.67 (2.74)	0–10	6.29 (2.67)	0–10	5.21 (1.93)	0–10	4.77 (1.16)	0–9.7
	Half added odor	6.25 (2.61)	0–10	7.34 (2.09)	0.7–10	7.13 (2.28)	0.4–10	5.36 (1.44)	0.3–9.5	5.07 (0.64)	2.5–8.8
	Std added odor	6.52 (2.51)	0–10	7.78 (1.90)	0.6–10	7.49 (2.14)	0.4–10	5.42 (1.26)	2.7–9.8	5.06 (0.64)	2.7–9.9
Study 2: France/Face application	LV cream	7.23 (1.75)	1–10	7.13 (1.87)	1.1–10	7.37 (2.02)	1.1–10	4.69 (1.26)	0.7–8	4.85 (0.85)	1–7.6
	HV cream	6.36 (2.33)	0–10	5.72 (2.69)	0–10	5.22 (3.08)	0–10	7.38 (1.75)	3–10	5.44 (0.98)	0.6–8.6
	Base odor	6.46 (2.12)	1–10	5.84 (2.43)	0.1–10	5.88 (2.89)	0–10	6.04 (2.18)	0.8–10	5.08 (1.15)	0.6–8.6
	Half added odor	6.82 (2.10)	0.8–10	6.57 (2.36)	1–10	6.24 (2.80)	0–10	6.19 (2.00)	0.7–10	5.20 (0.85)	1.1–8.1
	Std added odor	7.12 (2.05)	0–10	6.87 (2.37)	0–10	6.77 (2.70)	0–10	5.89 (1.91)	1–10	5.15 (0.87)	1.6–8.3
Study 3: China/Hand Application	LV cream	5.27 (2.88)	0–10	6.75 (2.15)	0.8–10	7.33 (1.89)	1.5–10	4.76 (1.04)	0.6–8.2	4.90 (0.87)	1.1–8.2
	HV cream	5.69 (2.78)	0–10	7.53 (1.81)	0.8–10	7.55 (1.87)	0.5–10	5.86 (1.21)	3.8–10	5.35 (0.93)	0.3–9.2
	Base odor	5.19 (2.78)	0–10	6.62 (2.18)	0.8–10	7.13 (1.99)	0.5–10	5.17 (1.15)	1.7–9	5.12 (1.01)	1.1–9.2
	Half added odor	5.62 (2.77)	0–10	7.14 (2.06)	0.8–10	7.43 (1.95)	0.9–10	5.18 (1.07)	1.7–8.8	5.04 (0.86)	0.3–8.6
	Std added odor	5.64 (2.95)	0–10	7.65 (1.69)	3–10	7.76 (1.66)	2–10	5.56 (1.47)	0.6–10	5.21 (0.92)	2.1–9.2
Study 4: China/Face application	LV cream	7.75 (1.42)	3.2–10	7.67 (1.54)	1.9–10	7.86 (1.48)	1.7–10	5.15 (0.73)	2.8–8.7	5.15 (0.70)	1.4–8.3
	HV cream	7.75 (1.51)	2.3–10	7.56 (1.53)	2.6–10	7.47 (1.74)	1.7–10	5.98 (1.19)	3.4–9.2	5.42 (0.93)	1.7–9.5
	Base odor	7.65 (1.58)	2.4–10	7.43 (1.69)	2.2–10	7.54 (1.69)	1.7–10	5.55 (1.16)	2.8–9.2	5.27 (0.88)	1.7–9.4
	Half added odor	7.89 (1.32)	3.4–10	7.70 (1.45)	1.9–10	7.69 (1.64)	1.7–10	5.54 (1.02)	3.4–9.1	5.38 (0.80)	3.7–8.7
	Std added odor	7.71 (1.48)	2.3–10	7.71 (1.44)	2.6–9.7	7.76 (1.56)	2.2–10	5.61 (1.03)	3.7–9.2	5.21 (0.82)	1.4–9.5

with Half and Standard differing from Base, $\beta_{Half} = 0.39$, $SE_{Half} = 0.49$, $\beta_{Standard} = -0.88$, $SE_{Standard} = 0.49$, $\chi^2(2) = 7.14$, $p = 0.03$.

Liking of the texture of the cream was significantly affected by its ODOR, $\chi^2(2) = 17.22$, $p < 0.001$. The Bonferroni-corrected model showed differences between Standard and Base, $\beta = 1.48$, $SE = 0.37$, $t_{(300)} = 4.01$, $p < 0.001$, and between Half and Base, $\beta = 1.08$, $SE = 0.37$, $t_{(300)} = 2.93$, $p = 0.008$, but not between Standard and Half, $\beta = 0.36$, $SE = 0.26$, $t_{(300)} = -1.37$, $p = 0.34$. There was no main effect of TEXTURE, $\chi^2(1) = 0.49$, $p = 0.48$, nor was there a significant interaction between TEXTURE and ODOR, $\chi^2(2) = 1.31$, $p = 0.52$. See **Figure 3** for well-being and liking ratings.

Just About Right (JAR) ratings of oiliness and opacity were affected by TEXTURE, Oiliness: $\beta = 1.82$, $SE = 0.23$, $\chi^2(1) = 64.32$, $p < 0.001$; Opacity: $\beta = 0.37$, $SE = 0.13$, $\chi^2(1) = 7.88$, $p = 0.005$, as well as ODOR, Oiliness: $\chi^2(2) = 6.81$, $p = 0.03$; Opacity: $\chi^2(2) = 3.04$, $p = 0.02$. See **Table 2** for the model estimates for these two JAR ratings for ODOR. For Oiliness, there was a significant difference between Standard and Base, but Half did not differ from either, and for Opacity, Standard and Half differed from Base not from each other. The interaction between the factors was not significant for Opacity, $\chi^2(2) = 0.07$, $p = 0.96$, and it approached significance for Oiliness, $\beta_{Standard} = -0.69$, $SE_{Standard} = 0.32$, $\chi^2(2) = 5.42$, $p = 0.07$. See **Figure 4**.

Discussion

Results show that participants gave generally higher well-being ratings to creams with added odor, and there was no difference between the two textures. Participants also gave higher ratings of product liking to creams with added odor relative to those without. It also eliminated differences between textures: for the Base condition, the HV cream was rated higher, but there was no difference between the two textures for Half and Standard odor. Interestingly, for liking of texture, there was no difference between the two levels of viscosity. Only ODOR had an effect, with higher liking for creams with added odor.

The texture and color JAR ratings (oiliness and opacity) were affected by both TEXTURE and ODOR, with higher ratings (i.e., oilier and more opaque) for the HV cream, as expected. What was unexpected was that the addition of odor also resulted in generally oilier and more opaque ratings. Though there were no significant interactions, the interaction between TEXTURE and ODOR for oiliness approached significance. The trajectory of the lines, both moving toward the center of the scale, suggests a tendency for both of the creams' ratings to approach "Just About Right" with added odor.

In Study 2, participants tested these same creams on their faces to evaluate whether this would result in differences in ratings.

STUDY 2: FACE APPLICATION IN A FRENCH SAMPLE

Materials and Methods

Participants

A group of 60 French-speaking women completed this task ($M_{age} = 44.6$, age range = 30–60). The recruitment criteria and testing laboratory procedures were the same as in Study 1. A random selection of 32 participants were chosen to undergo a prosody-measurement task as well, before and after the experimental procedure. This task was performed in order to measure vocal variation while reading a neutral text, which can serve as an indicator of emotional feelings. These data are not analyzed for the present report.

Materials

Creams

The creams used in this study were the same as in Study 1

Questionnaires

Participants completed questionnaires developed specifically for this study before and after product application. As in Study 1, participants responded in the program Fizz by placing a cursor anywhere along a continuous line between two extremes, which varied by question. All questions analyzed in the present study were from the POST questionnaire: well-being, liking and JAR ratings of the face creams, and were the same as in Study 1, with the exception of the well-being question. Given previous research showing that mood states in response to odors may sometimes be below the threshold of perception (Rimkute et al., 2016), we chose to ask more indirectly about well-being. The participants rated their agreement with the statement "With this cream I have the impression of doing myself some good."

Procedure

The study aimed to investigate emotional states linked to products, so in order to prevent participant fatigue, we did not test the products in a single session. The study occurred over six sessions of 45 mins each, and there was a minimum of 48 h between sessions. For each of the six sessions, participants were presented with only one TEXTURE/ODOR combination. The order of presentation was counterbalanced across participants.

The day of the study, participants were asked to abstain from applying any scented body products or perfume. They either arrived without makeup or were asked to arrive early to remove their makeup. In the latter case, a few minutes were left after makeup removal to let their skin rest before the experimental procedure began. They were told, "You will apply a premium cream to your face as you would do at your home. Before and after application, you will respond to different questions."

In each session, $N = 28$ participants began by completing the PRE questionnaire. The $N = 32$ who had been randomly selected for the prosody task began with it (reading a short page of text aloud; these data are not presented in the current paper) and completed the PRE questionnaire after. Before the questionnaire, they washed their hands with unscented soap. At the end of the questionnaire, all participants were asked to look at their skin and overall facial appearance in the mirror.

In Study 1, participants were given a specific amount of cream in a syringe, as if they were trying a sample in a store. In Study 2, to recreate a more home-like experience, the face creams were given to participants in sample sized containers, the HV cream in a round jar with a screw top lid and the LV cream in a jar with a pump. All the jars were "blind lab samples," without any information concerning the product (such as scent percentage,

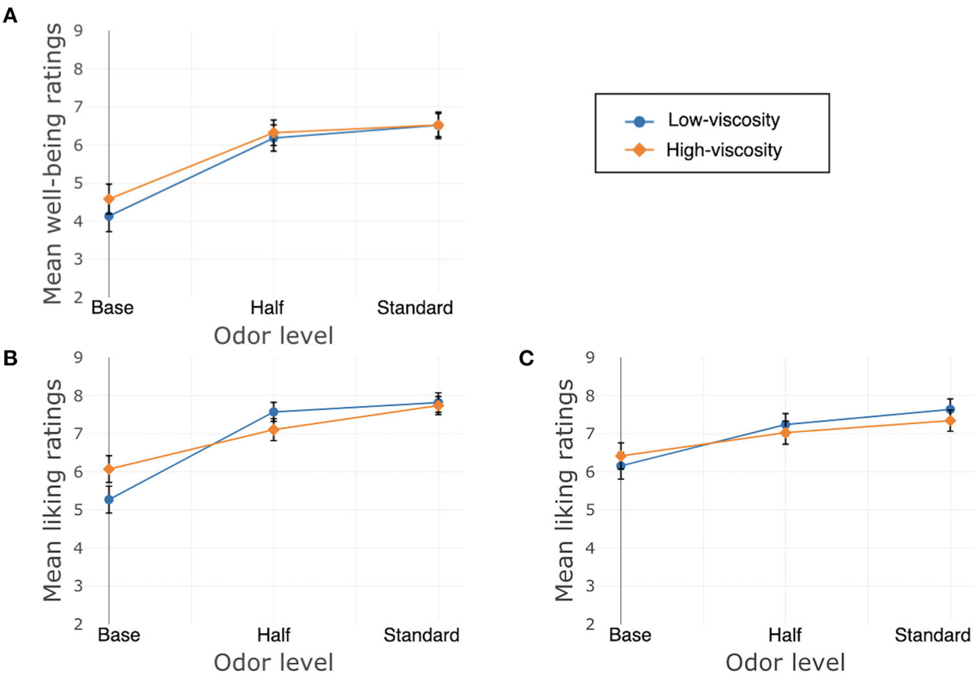

FIGURE 3 | Study 1, France/Hand application, **(A)** well-being, **(B)** liking of the product, **(C)** liking of the texture. Error bars indicate standard error.

TABLE 2 | Study 1, France/Hand application: model estimates of the different levels of odor for each JAR rating.

		β	Std. Err.	*df*	*t*	*p*	Significance
Oiliness	Standard–Base	0.55	0.23	300	2.45	0.03	*
	Half–Base	0.46	0.23	300	2.01	0.09	
	Standard–Half	0.06	0.16	300	−0.37	0.72	
Opacity	Standard–Base	0.30	0.13	300	2.28	0.04	*
	Half–Base	0.33	0.13	300	2.54	0.02	*
	Standard–Half	0.02	0.09	300	0.21	0.84	

*$p < 0.05$.

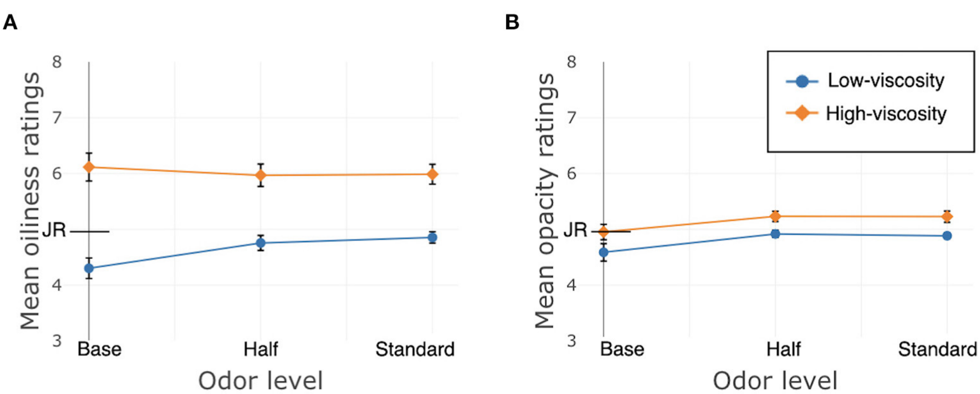

FIGURE 4 | Study 1, France/Hand application, JAR ratings. JR, just right. **(A)** Oiliness, **(B)** Opacity. Error bars indicate standard error.

brand, ingredients, skin benefits), except that it was a "premium facial cream." Participants were asked to apply the cream the same way they would do it at home, and they were free to choose the amount they needed for their face.

The POST questionnaire was completed again after product application. After this, either the session ended (for $N = 28$) or the participant completed the prosody task for the second time ($N = 32$). In the sixth and final session, participants completed the FINAL questionnaire after either the POST questionnaire or after the prosody task, whichever was the final task for the participant.

Results

Descriptive statistics (means, SD, ranges) for all the ratings are shown in **Table 1**. The rating of well-being, "does me some good," was affected by both TEXTURE, $\beta = -0.72$, $SE = 0.29$, $\chi^2(1) = 6.16$, $p = 0.01$ and ODOR, $\chi^2(2) = 6.29$, $p = 0.04$, but the interaction was not significant, $\chi^2(2) = 0.85$, $p = 0.65$. Participants gave higher ratings after trying the LV cream. For the three levels of odor, there were only significant differences between the Standard and Base conditions, $\beta = 0.70$, $SE = 0.29$, $t_{(300)} = 2.40$, $p = 0.04$. Half did not differ significantly from either: for the comparison between Half and Base, $\beta = 0.54$, $SE = 0.29$, $t_{(300)} = 1.84$, $p = 0.14$, and for Standard versus Half, $\beta = 0.31$, $SE = 0.21$, $t_{(300)} = 1.47$, $p = 0.28$.

Overall liking of the face cream was significantly affected by its TEXTURE, $\beta = -1.25$, $SE = 0.36$, $\chi^2(1) = 11.86$, $p = 0.001$, with higher liking ratings for the LV cream, and ODOR, $\chi^2(2) = 10.07$, $p = 0.007$. Using a Bonferroni correction, the model showed significant differences between Standard and Base, $\beta = 1.03$, $SE = 0.36$, $t_{(300)} = 2.82$, $p = 0.01$, and between Half and Base, $\beta = 0.97$, $SE = 0.36$, $t_{(300)} = 2.68$, $p = 0.02$, but there was no difference between Standard and Half, $\beta = 0.30$, $SE = 0.26$, $t_{(300)} = -1.17$, $p = 0.48$. There was no interaction between TEXTURE and ODOR, $\chi^2(2) = 1.24$, $p = 0.5$.

Liking of the texture of the cream was significantly affected only by TEXTURE, $\beta = -2.48$, $SE = 0.44$, $\chi^2(1) = 31.55$, $p < 0.001$, again with higher liking ratings for the LV cream. There was no significant interaction between TEXTURE and ODOR, $\chi^2(2) = 0.87$, $p = 0.65$, and no main effect of ODOR $\chi^2(2) = 2.11$, $p = 0.35$. See **Figure 5** for well-being and liking ratings.

Just About Right (JAR) ratings of oiliness and opacity were affected by TEXTURE. Oiliness: $\beta = 3.05$, $SE = 0.23$, $\chi^2(1) = 173.24$, $p < 0.001$; Opacity: $\beta = 0.71$, $SE = 0.14$, $\chi^2(1) = 25.97$, $p < 0.001$. There were no main effects of ODOR; Oiliness: $\chi^2(2) = 2.20$, $p = 0.33$; Opacity: $\chi^2(2) = 3.04$, $p = 0.22$. Nor were there interactions between TEXTURE and ODOR; Oiliness: $\chi^2(2) = 4.26$, $p = 0.12$; Opacity: $\chi^2(2) = 1.52$, $p = 0.47$. See **Figure 6**.

Discussion

Results from Study 2 showed higher ratings for "does me some good" after trying the creams with added odor and after trying the LV cream.

As in Study 1, overall liking was affected by both TEXTURE and ODOR. The effect of odor was the same, with participants liking the creams with added odor more than the creams without. However, in contrast to Study 1, participants testing the creams on their faces showed a strong preference for the LV cream. This extended to their liking ratings for texture; only TEXTURE influenced these ratings. Participants strongly preferred the LV cream, and the presence of odor did not change their preference.

Participants' JAR ratings were both affected by TEXTURE, with the HV cream generally being rated toward too oily and opaque, and the LV cream's ratings around the center of the scale. Odor did not affect these ratings.

The present study has so far examined the interaction of the perception of odor and texture in different contexts (hand and face). Because odor and texture preferences may vary with culture, we wanted to explore whether the effects we found in France could also occur in China, a country with a culture very different from that of France.

The studies were set up as similarly as possible to the studies in France, with one exception: for reasons unconnected to the present report, the authors wished to test a low viscosity lotion with a slightly different texture than the one tested in France. This is the main reason that these different studies have been reported as such rather than comparing French and Chinese participants in a single study. However, all reported data on liking, well-being, and JARs are from questions to which participants in both France and China responded and which were translated to be as similar as possible.

STUDY 3: HAND APPLICATION IN A CHINESE SAMPLE

Materials and Method

Participants

Participants were 65 women ($M_{age} = 41$, age range = 30–59). All participants lived in Shanghai and spoke Mandarin. Recruitment criteria were the same as in France. They were recruited by and tested at Biofortis (Mérieux Nutrisciences), a sensory testing laboratory which recruits from a list of participants in the community. Also as in France, participants were unaware of Chanel's involvement in the study, they were reimbursed for their time, all research was conducted according to the principles expressed in the Declaration of Helsinki, written informed consent was obtained from every participant, and the safety of the creams was verified by a toxicologist.

Materials

Creams

As in the first two studies, the materials used in this study were face creams with two different textures (low and high viscosity), each with three levels of odor. The HV cream was the same as that used in France, with the same three levels of odor, 0 (Base), 0.15% (Half of standard added odor), and 0.3% (Standard added odor). As mentioned above, the LV cream differed because one aim of the overall study (not reported here) was evaluation of this particular product by women in China. Rather than the lotion with *G'* of 220 Pa, participants in China were presented with a lotion with a *G'* of 70 Pa. The standard level of odor for this product is 0.1%, so that was used as Standard in the study. Half was therefore 0.05, and 0% was Base. As in the previous experiments, the odor itself (the same proprietary blend) did

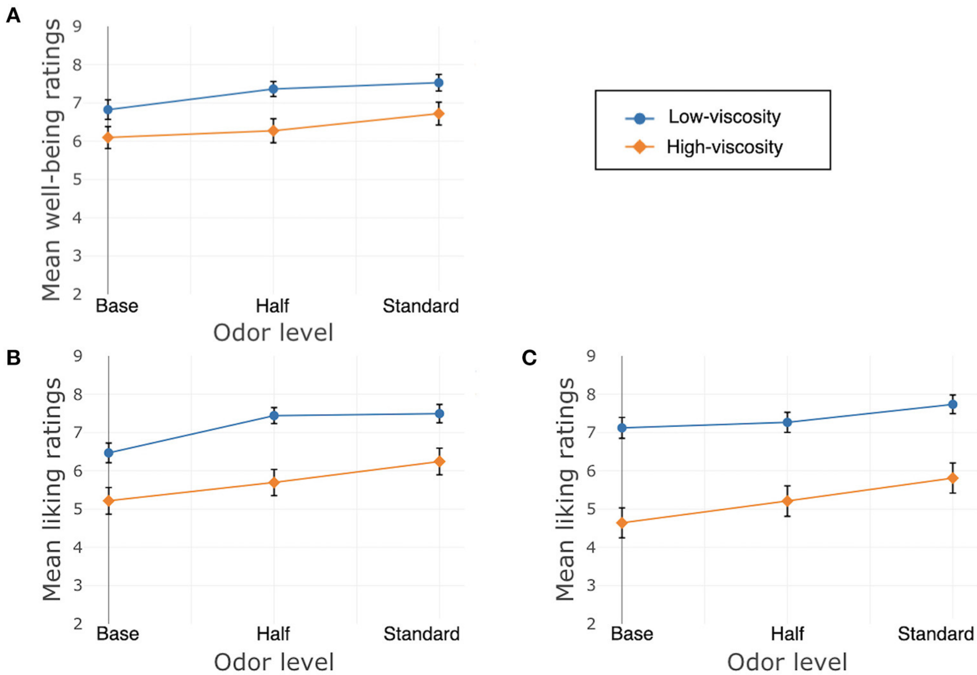

FIGURE 5 | Study 2, France/Face application, **(A)** Well-being/Does me good, **(B)** Liking of the product, **(C)** Liking of the texture. Error bars indicate standard error.

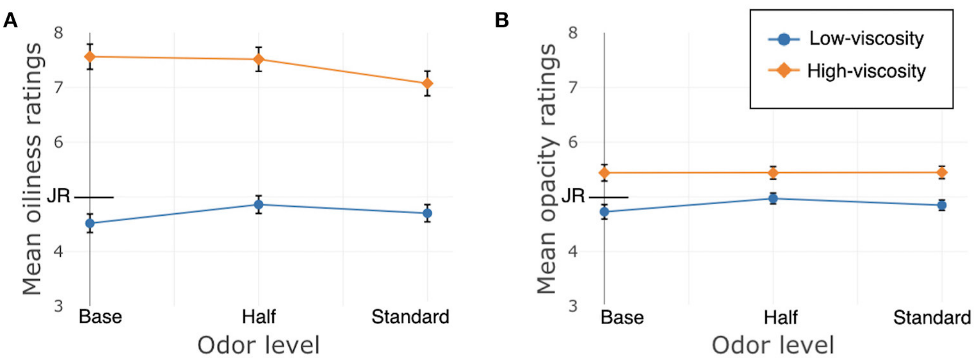

FIGURE 6 | Study 2, France/Face application, JAR ratings. JR, just right. **(A)** Oiliness, **(B)** Opacity. Error bars indicate standard error.

not vary, only its concentration, and the 0% condition was not neutral.

Questionnaires

The questions reported in Study 1: Hand Application in a French Sample were translated to Mandarin for Study 3. The translations were performed by a French/Chinese professional translator and double-checked by the French and Chinese experimenters of the studies.

Procedure

The experimental procedure was the same as in France (Study 1).

Results

Descriptive statistics (means, SD, ranges) for all the ratings are shown in **Table 1**. Ratings of well-being after trying the product were only affected by TEXTURE, $\beta = 0.78$, $SE = 0.39$, $\chi^2(1) = 3.29$, $p = 0.047$. There was no significant main effect of ODOR, $\chi^2(2) = 4.16$, $p = 0.13$, or interaction between TEXTURE and ODOR, $\chi^2(2) = 1.31$, $p = 0.52$.

Liking of the product was significantly affected by TEXTURE, $\beta = 1.56$, $SE = 0.28$, $\chi^2(1) = 30.47$, $p < 0.001$, and ODOR, $\chi^2(2) = 35.56$, $p < 0.001$. Using a Bonferroni correction, the model showed significant differences between Standard and Base, $\beta = 1.66$, $SE = 0.28$, $t_{(325)} = 5.89$, $p < 0.001$, between Half and Base, $\beta = 1.06$, $SE = 0.28$, $t_{(325)} = 3.74$, $p < 0.001$, and between Standard and Half, $\beta = 0.51$, $SE = 0.20$, $t_{(325)} = -2.57$, $p = 0.02$. There was also an interaction between TEXTURE and ODOR, with Half and Standard differing from Base, $\beta_{half} = -1.07$, $SE_{half} = 0.40$, $\beta_{standard} = -1.26$, $SE_{standard} = 0.40$, $\chi^2(2) = 11.52$, $p = 0.003$.

Liking of the texture of the cream was significantly affected by TEXTURE, $\beta = 0.68$, $SE = 0.27$, $\chi^2(1) = 6.21$, $p = 0.002$, and ODOR, $\chi^2(2) = 12.50$, $p = 0.01$. The Bonferroni-corrected model showed differences between Standard and Base, $\beta = 0.92$, $SE = 0.27$, $t_{(325)} = 3.40$, $p = 0.002$, and between Half and Base, $\beta = 0.69$, $SE = 0.27$, $t_{(325)} = 2.54$, $p = 0.02$, but not between Standard and Half, $\beta = 0.33$, $SE = 0.19$, $t_{(325)} = -1.74$, $p = 0.16$. There was no interaction between TEXTURE and ODOR, $\chi^2(2) = 4.51$, $p = 0.11$. See **Figure 7** for well-being and liking ratings.

Just About Right (JAR) ratings of oiliness and opacity were affected by TEXTURE; Oiliness: $\beta = 1.05$, $SE = 0.18$, $\chi^2(1) = 34.45$, $p < 0.001$; Opacity: $\beta = 0.51$, $SE = 0.14$, $\chi^2(1) = 13.22$, $p < 0.001$. There were no main effects of ODOR; Oiliness: $\chi^2(2) = 2.93$, $p = 0.23$; Opacity: $\chi^2(2) = 0.22$, $p = 0.90$; nor were there interactions between TEXTURE and ODOR on these ratings; Oiliness: $\chi^2(2) = 1.3$, $p = 0.52$; Opacity: $\chi^2(2) = 4.52$, $p = 0.10$. See **Figure 8**.

Discussion

Well-being ratings were only affected by TEXTURE. There were overall higher ratings for the HV cream. Results on liking of the product and of its texture showed that, though without added odor participants showed a preference for the HV cream, this preference disappeared once odor was added. One important finding was that, even though the LV cream in China had a viscosity that differed from that in France, we still found, as in France, that the addition of odor had a positive effect on ratings of liking. Similar to well-being, JAR ratings were only affected by TEXTURE. Average ratings were near the center of the scale, with the HV cream receiving ratings more in the direction of oily/opaque and the LV cream receiving ratings in the other direction.

STUDY 4: FACE APPLICATION IN A CHINESE SAMPLE

Materials and Methods

Participants

A group of 65 Chinese women completed this task ($M_{age} = 42$, age range = 30–59). Recruitment procedure and criteria and obtaining informed consent were the same as for Study 3. As with Study 2, 32 women were randomly selected to participate in the prosody portion of the study.

Materials

Creams

The same two creams were used as in Study 3.

Questionnaires

The questionnaires were the same as in France (Study 2), translated to Mandarin.

Procedure

The experimental procedure was the same as in France (Study 2).

Results

Descriptive statistics (means, SD, ranges) for all the ratings are shown in **Table 1**. For the ratings of "does me some good" there was a main effect of ODOR, $\chi^2(2) = 6.56$, $p = 0.04$. There was a significant difference between the Standard and Base odor conditions $\beta = 0.43$, $SE = 0.18$, $t_{(325)} = 2.35$, $p = 0.04$, the difference between Half and Base approached significance, $\beta = 0.38$, $SE = 0.18$, $t_{(325)} = 2.06$, $p = 0.08$, but the difference between Standard and Half was not significant, $\beta = 0.19$, $SE = 0.13$, $t_{(325)} = 1.44$, $p = 0.30$. The main effect of TEXTURE approached significance, $\beta = 0.33$, $SE = 0.18$, $\chi^2(1) = 3.27$, $p = 0.07$, and there was a significant interaction between TEXTURE and ODOR, with Standard and Half differing from Base, $\beta_{Half} = -0.26$, $SE_{Half} = 0.26$, $\beta_{Standard} = -0.74$, $SE_{Standard} = 0.26$, $\chi^2(2) = 8.45$, $p = 0.02$.

Liking of the product was significantly affected by ODOR, $\chi^2(2) = 10.17$, $p = 0.006$. Using a Bonferroni correction, the model showed a significant difference between Standard and Base, $\beta = 0.63$, $SE = 0.20$, $t_{(325)} = 3.19$, $p = 0.004$, but not between Half and Base, $\beta = 0.30$, $SE = 0.20$, $t_{(325)} = 1.51$, $p = 0.26$, or between Standard and Half, $\beta = 0.01$, $SE = 0.14$, $t_{(325)} = -0.08$, $p = 0.93$. There was also an interaction between TEXTURE and ODOR, with Standard and Half differing from Base, $\beta_{Half} = -0.06$, $SE_{Half} = 0.28$, $\beta_{Standard} = -0.70$, $SE_{Standard} = 0.28$, $\chi^2(2) = 7.76$, $p = 0.02$. There was no main effect of TEXTURE, $\beta = 0.14$, $SE = 0.20$, $\chi^2(1) = 0.51$, $p = 0.48$.

Liking of the texture of the cream was significantly affected only by ODOR, $\chi^2(2) = 6.09$, $p = 0.048$. Using a Bonferroni correction, the model showed a significant difference between Standard and Base $\beta = 0.57$, $SE = 0.23$, $t_{(325)} = 2.47$, $p = 0.03$, but not between Half and Base, $\beta = 0.28$, $SE = 0.23$, $t_{(325)} = 1.20$, $p = 0.46$, or between Standard and Half odor, $\beta = 0.08$, $SE = 0.16$, $t_{(325)} = -0.46$, $p = 0.64$. There was no main effect of TEXTURE, $\beta = -0.07$, $SE = 0.23$, $\chi^2(1) = 0.10$, $p = 0.76$, nor was there a significant interaction between ODOR and TEXTURE, $\chi^2(2) = 4.64$, $p = 0.10$. See **Figure 9** for well-being and liking ratings.

Just About Right (JAR) ratings of oiliness and opacity were affected by TEXTURE; Oiliness: $\beta = 0.80$, $SE = 0.16$, $\chi^2(1) = 26.47$, $p < 0.001$; Opacity: $\beta = 0.30$, $SE = 0.13$, $\chi^2(1) = 5.61$, $p = 0.02$. There were no main effects of ODOR; Oiliness: $\chi^2(2) = 0.04$, $p = 0.98$; Opacity: $\chi^2(2) = 0.57$, $p = 0.75$; nor were there interactions between TEXTURE and ODOR on these ratings; Oiliness: $\chi^2(2) = 0.80$, $p = 0.67$; Opacity: $\chi^2(2) = 1.18$, $p = 0.56$. See **Figure 10**.

Discussion

Results show that participants' liking of the product was affected by a combination of the two factors; they preferred the LV cream when there was added odor, but had no preference without odor. Liking of texture showed this same pattern, but only the addition of odor had a significant effect in increasing liking. Similar to liking, ratings of well-being were dependent on the two variables; for the Base odor condition, there was a tendency for higher ratings to be given to the HV cream, but for Standard added odor, higher ratings were given to the LV cream. Here again, even

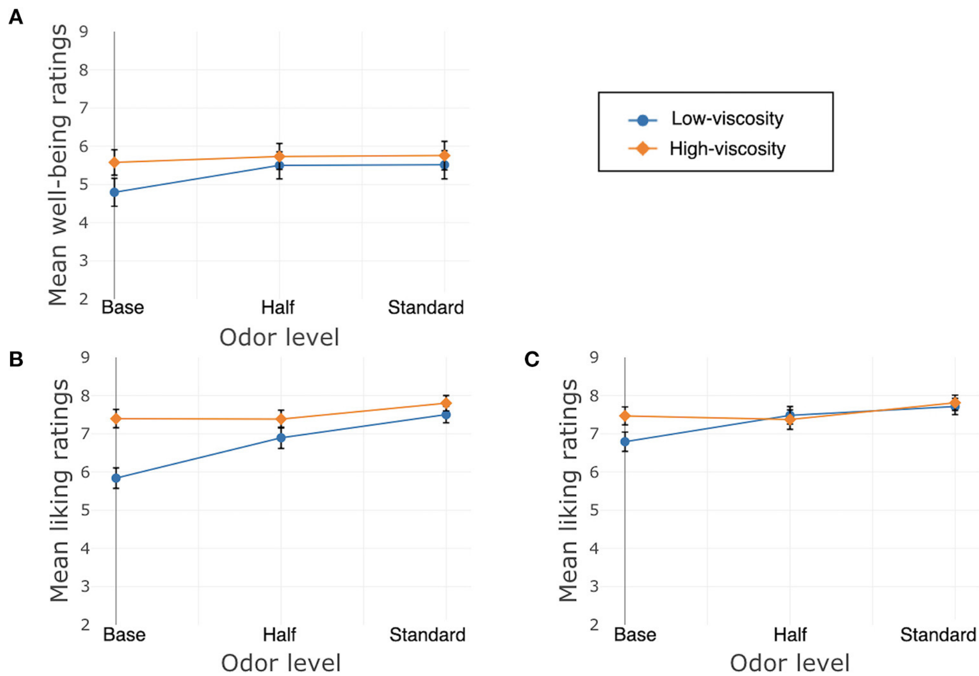

FIGURE 7 | Study 3, China/Hand application, **(A)** well-being, **(B)** liking of the product, **(C)** liking of the texture. Error bars indicate standard error.

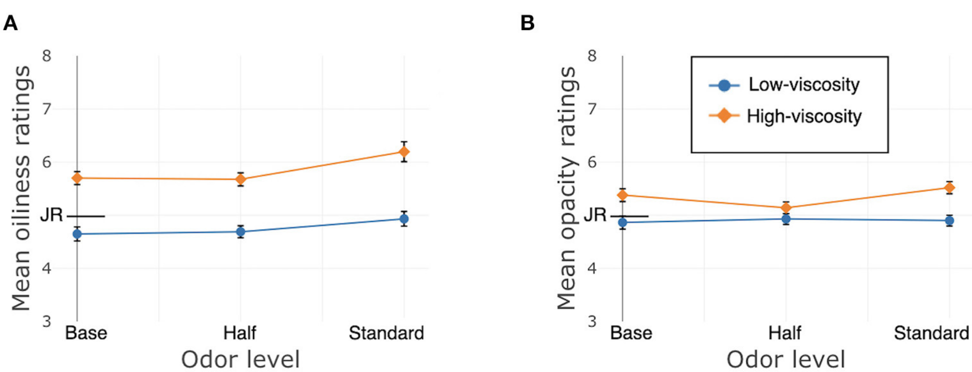

FIGURE 8 | Study 3, China/Hand application, JAR ratings. JR, just right. **(A)** Oiliness, **(B)** Opacity. Error bars indicate standard error.

though the LV cream differed in viscosity from that in France, we found effects that were similar to those in France, with the addition of odor increasing liking and well-being ratings.

For the JAR ratings, however, ODOR had no effect. Only TEXTURE determined ratings, with the HV cream rated as oilier and more opaque.

GENERAL DISCUSSION

The results of the present study show that both viscosity and the addition of odor to facial skin care products have strong effects on ratings of well-being, liking, and perception of the products' textures and colors in two differing cultures, France and China. We did not evaluate the effect of texture on ratings of odor, as the scent is likely to have reacted differently with the different components in the two creams with different levels of viscosity. We did, however, find significant effects of odor on ratings of different textures, though there was no evidence that the addition of odor to the cream changed its texture.

Effects of Added Odor on Well-Being, Liking and JARs

Our first question for the study was how the addition of odor to a cream affected well-being ratings. The addition of odor increased well-being ratings for Studies 1, 2, and 4 (both studies in France and Face Application in China). For the studies in France, this

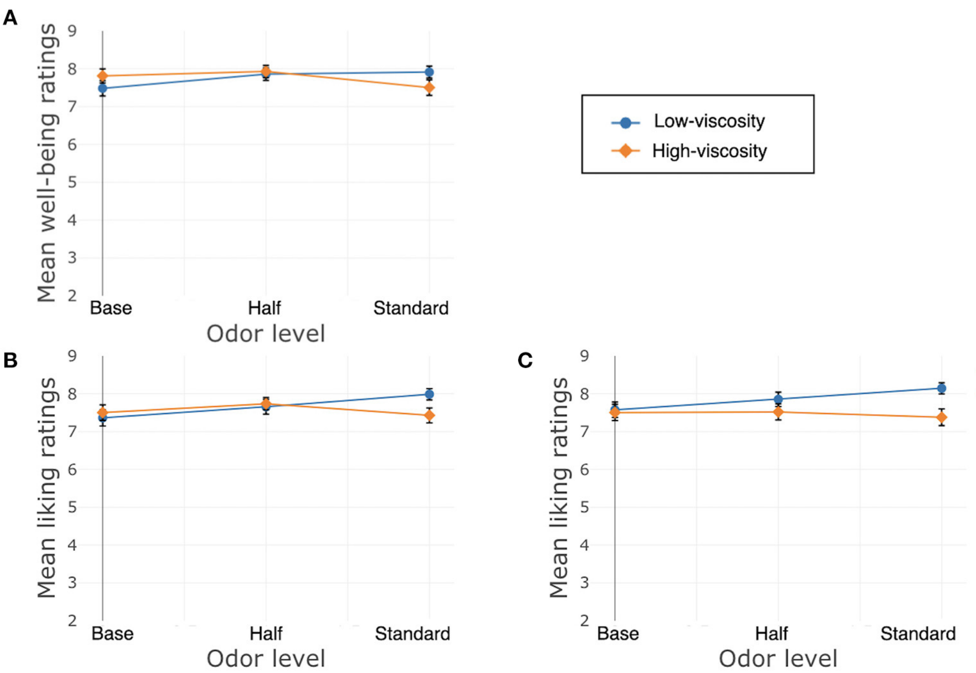

FIGURE 9 | Study 4, China/Hand application, **(A)** Well-being/Does me good. **(B)** Liking of the product. **(C)** Liking of the texture. Error bars indicate standard error.

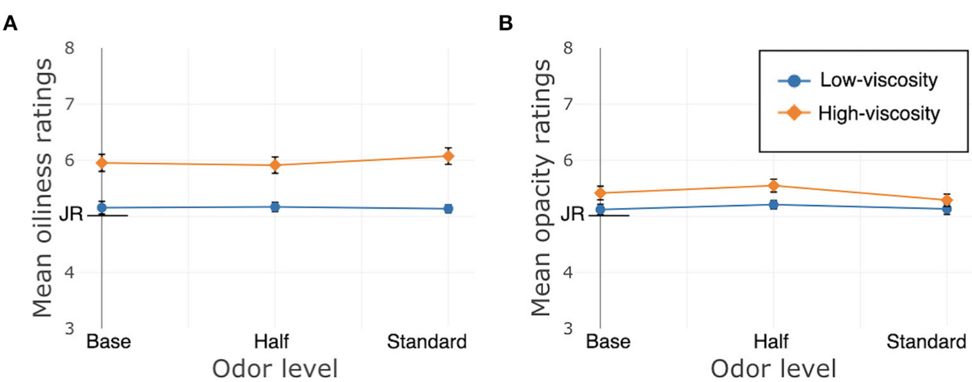

FIGURE 10 | Study 4, China/Hand application, JAR ratings. JR, Just right. **(A)** Oiliness, **(B)** Opacity. Error bars indicate standard error.

effect appeared straightforward, with the Standard level of odor always resulting in higher well-being ratings than Base. In China, perhaps due to the more extreme difference in texture, there were interactions between ODOR and TEXTURE. In Study 4 (Face Application in China), the addition of odor didn't seem to change ratings for the HV cream, while it did change ratings for the LV cream. In Study 3 (Hand Application in China), well-being was much higher after trying the HV cream relative to the LV cream, which may explain why odor did not have an overall effect in this case.

The second main question was about the effect of added odor on product perception, including liking and JARs. For liking of the product itself, there was a consistent effect of added odor increasing liking ratings. This effect was simple in Study 2 (Face Application in France). There was also an interaction between the factors: for both hand application studies (1 and 3), participants liked the HV more than the LV cream when no odor was added, but the two were liked equivalently with added odor. In Study 4 (Face Application in China), the two textures were equivalently liked without odor, and a preference for LV appeared with odor. Both of these demonstrate a greater effect of added odor on liking for the LV creams relative to the HV cream. The majority of these effects appear when comparing the two added odor conditions to the Base cream. With only one exception (Study 3, liking of the product), there were no significant differences between the Standard and Half added odor levels, suggesting a possible threshold for odor perception, after which increases do not result in greater hedonic experience. This points to one possible direction for future investigations: while the scientific value is evident for studying the emotional effects of varying odors' pleasantness or valence, investigations of emotion that vary odor intensity should not be neglected. Neuroimaging studies have demonstrated differential activation in the amygdala and orbitofrontal regions of the brain depending on whether intensity, valence or both are manipulated (Anderson et al., 2003; Winston et al., 2005), and one recent study has shown a nuanced picture of the effect of odor intensity variation on arousal (Baccarani et al., 2021).

In three of the four studies (1, 3 and 4: Hand Application in France and both studies in China), liking of texture increased with added odor as well. The interactions between texture and odor, that is, the differential effects of odor on liking of the two textures, may be the strongest demonstration of crossmodal perception to arise from this experiment. Textures and odors have often been investigated together in the context of food, but they occur together in cosmetic creams as well. Frequent use of these creams may result in an association between texture and odor by our brains—through the fact that they occur together in space and time, or that they are both pleasant (see Spence, 2011 for a review). Previous studies have used dependent variables such as attention (Spence et al., 2001) or associations between particular odors and colors or shapes, (Deroy et al., 2013; Hanson-Vaux et al., 2013) to investigate crossmodal correspondences. In this case, to investigate the result of texture-odor associations while focusing on the hedonic experience resulting from use of cosmetic creams, we found evidence of crossmodal perception using liking and well-being measures, and, it can even be argued, JAR ratings in one study (1, Hand Application in France).

Both JAR ratings concerned the texture and appearance of the cream. In all of the studies, we found the expected results of the HV cream being rated as oilier and more opaque than the LV cream (ratings which reflected its physical properties). In Study 1 (Hand Application in France), however, there was also an effect of ODOR: creams with added odor were rated as oilier and more opaque. A possible explanation is that the addition of odor led to participants perceiving the creams as being more luxurious or moisturizing, and oiliness/opacity are accompanying characteristics of luxury (as in Duncan et al., 2020 when participants rated HV creams as more moisturizing than more watery creams). It could also be attributed to a "halo effect" —the term coined by Thorndike (1920) to describe when one salient aspect influences perception of an entire object. Hence, we suggest that this is another instance of crossmodal association: both added scent and oiliness/opacity were associated with luxury or quality, and therefore associated with each other.

The same effect may not have been found on the face because participants had a preference for the LV cream (or at least less of a preference for the HV cream), meaning the oiliness/opacity were not necessarily associated with positive evaluations on the face. One possible explanation for why this effect was not found in China for the hand application study could be because of the higher difference in texture between the two creams. This should be investigated in future studies.

Comparisons Among Studies

The third question posed in the introduction concerned the differences in ratings between applications on the face and hand. One general difference consistent across both countries was that the participants gave higher liking and well-being ratings after trying the HV cream relative to the LV cream for hands (modulated by odor in France, Study 1) and higher ratings after trying the LV cream relative to the HV cream for their faces (modulated by the presence of odor in China, Study 4).

Even though participants were explicitly instructed in Studies 1 and 3 that they should keep in mind that they were testing a face cream even though it was being applied to their hands, they still showed different liking patterns than the participants in Studies 2 and 4, respectively. Many of these differences could be attributed to physiological differences between the skin of the face and the skin of the hand; for example, the stratum corneum density and barrier are thinner on the face, and the density of nerve fibers is higher than elsewhere on the body (Farage et al., 2014). Sensitivity is also reported more frequently on the face than the hand (Saint-Martory et al., 2008; Berardesca et al., 2013).

Differences between the results of the hand and face studies may in part be due to methodological differences as well. The participants in the hand study only completed two testing sessions and tried three different creams (with varying odor, consistent texture) in each session, whereas the participants in the face study made six separate trips to the testing site and were perhaps less likely to make their ratings based on comparisons with the other levels of odor. They also spent more time completing questionnaires or participating in the prosody study (not reported here), which may have changed their awareness of their own emotional state to be either heightened or fatigued.

Our final question, whether we find similar effects between two cultures, must be answered cautiously given the differences in creams between the studies in the two countries. We can, however, highlight the similarities between the results in the two countries: ODOR has effects on ratings of liking and well-being, and its effects interact with TEXTURE in interesting ways in both places. Additionally, participants generally seem to have a stronger preference for LV creams on their faces and HV on their hands.

Overall, the results showing the influence of odor on well-being are easy to explain in the context of previous research showing the hedonic effects of odor. The results of odor on liking may also be due to these effects, with the odor's hedonic valence influencing liking, even across modalities. An explanation for its interaction with texture is less obvious given the paucity of research investigating these two senses together. In the present sequence of studies, added odor increased liking ratings for the LV cream more than it did for the HV cream. There has been extensive research in the field of cosmetology on sensory perception and preferences for different viscosities of creams (e.g., Bekker et al., 2013; Kwak et al., 2015), but it remains to be further explored how added odor impacts these preferences.

Limitations and Future Directions

A limitation of the present report is the methodological differences among the different studies. The testing length differences between the hand and face study arose for two reasons: first, testing multiple creams on the face in the same day was not feasible; the skin cleansing necessary between two creams would likely irritate the facial skin, negatively impacting all emotional measures. This is not the case for the more robust hand skin. Second, returning to the idea that the hand studies replicate a store experience and the face studies the home experience: in a store, it is common to try multiple creams in one session, whereas at home people only use one at a time. Additionally, the difference in cream distribution (given through a syringe in the hand study and letting participants choose their own amount in the face study, also to reinforce these home/store experiences) may have had unintended effects on ratings. The main difference between the procedures in France and China was the LV cream in China having a lower viscosity than the LV cream in France (for reasons connected to a separate investigation). This is why we strove to be cautious when interpreting these data, keeping the methodological differences in mind. Contrasting results from the two sets of studies, such as the JAR ratings not being affected by odor in China while they were in France, could be due to the viscosity differences in the creams being more pronounced, but we cannot conclude this from the present set-up. Equivalent studies in the two countries could be an avenue for future exploration.

One unavoidable limitation is that the base cream, without added odor, did in fact have an odor due to its chemical composition. This is a necessary evil when testing cosmetics; the ingredients that add odor are essential components of the creams. Without them, the textures of the creams would have been nothing like creams women are used to.

One aspect, which is not necessarily a limitation of the study but should be addressed, is that the participants were informed that the creams were premium, luxury products, and this may have biased their perceptions. This was intentional; we wished to test perception of these products among a group of women who habitually used higher-end cosmetics and hence had specific expectations of luxury products.

This study opens up several avenues of further exploration: for example, future work could shift the balance between laboratory-controlled and ecologically-valid tests. We wanted to explore the effects of odor on well-being in a context like that of a cosmetic store, where participants test face creams on their hands, and in a context like that at home, where participants test them on their faces. However, in the present study, both of these explorations were performed in a laboratory setting in order to be able to control ambient odors, lights, sounds, and other aspects of the experience. It would be interesting to evaluate crossmodal interactions while at the same time pushing this a bit further toward a store context, by adding back some of the background noise that would be present at a cosmetics counter in a department store, and/or by having women try the creams in their homes, as part of their morning routine. It would also be interesting to expand the testing sphere to include participants living in more rural regions. In urban settings, people become accustomed to increased levels of pollution, perhaps changing their olfactory perception and/or skin sensitivity. In addition, consumers in urban settings have and are used to having much more variety of skin care readily available to them; they may be more accustomed to the textures and odors present in luxury skin care products.

One possible direction to further explore and refine the results obtained in this study would be to recruit a new group of participants for more in-depth explorations, including focus groups or user journey mapping exercises. It would also be interesting to document user experiences on other types of scales or using visualization exercises to further explore the emotions accompanying use of the creams. Future studies could also investigate the effect of factors external to the cream, such as packaging design, on ratings.

Other possible directions to further explore include varying the odor itself, examining other senses (by varying the color, for example), or exploring odor and crossmodal perception in men. The present study was restricted because the face creams of the type investigated are much more frequently used by women, but many studies have found differences in odor perception or memory between men and women (Lehrner, 1993; Marchand and Arsenault, 2002; Ferdenzi et al., 2013b), while others have not (Larsson et al., 2000; Bengtsson et al., 2001; Kranz et al., 2019), and this could be an interesting avenue to explore. One of these studies (Larsson et al., 2000) found that personality and semantic memory ability had strong effects on odor identification; it could also be interesting to assess whether crossmodal and emotional responses to odor could be affected by these factors.

Conclusions

The present investigation, the first to our knowledge to examine olfactory-tactile crossmodal perception and well-being, has shown that both odor and texture have effects on well-being and liking of a product, and they interact with each other. Even with variable methodologies, two different cultures, and testing in two different contexts (face/home and hand/store), we found crossmodal effects on well-being, liking, JARs, or a combination of these across all four studies. This means that the effect itself is robust, opening the way for other studies investigating perception of olfactory and tactile stimuli such as other cosmetics or different categories of objects. We also showed that the effects are likely to be context-dependent, given the strong difference in results for HV versus LV creams and the different levels of the odor's influence in the hand and face studies. Future research can build on this study, taking it in numerous different directions to further inform us about olfactory and tactile perception and their interactions.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SC designed and implemented the studies and contributed to the literature review, the statistical analyses and the writeup. AB wrote the manuscript and contributed to the literature review and the statistical analyses. RA performed the statistical analyses, and M-HB supervised the project. All authors contributed to the article and approved the submitted version.

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Smells in Sustainable Environments: The Scented Silk Road to Spending

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Humanity's demand for ecological resources and services exceeds what earth can regenerate in that year, creating an urgent need for more sustainable behavior. Here, the focus is on a particular factor that so far has been overlooked in facilitating sustainable behavior, namely smell. The two-fold aim of this study was (i) to investigate whether ambient scent could enhance customers' subjective experience and spending behavior in a sustainable environment, and (ii) to elucidate the affective and cognitive pathways from scent to spending. To test this, a double-blind field experiment was designed where customers of a second-hand clothing store ($N = 57$) could face one of three conditions: fresh linen scent (pleasant and semantically priming "clean clothing" increasing the products' value), vanilla sandalwood scent (pleasant control odor), or regular store odor (odorless control). Buttressed by prior research, the fresh linen scent was expected to cause the strongest increase in spending behavior due to its positive semantic association with the product (i.e., clean clothing). The results indeed showed that fresh linen scent almost doubled consumer spending vs. the odorless control *and* the pleasant control odor. Other factors potentially affecting consumer behavior (e.g., weekday, weather, odor awareness) were uncorrelated. Whereas a conceptually-driven mediation analysis showed that only fresh linen scent increased mood and evaluations of the store, staff, and products, these variables did not mediate the relation between scent and spending. An explorative structural equation model suggested cognitive priming to be mainly responsible for increasing consumers' spending in the fresh linen condition by enhancing the general store evaluation. Further support is needed to corroborate the indirect findings that specific scents can follow a "cold" semantic road and a "hot" affective road to spending. At minimum, consumers are no "zombies" that empty their pockets in the presence of whatever odor; the smell needs to have a meaningful link to the (sustainable) context at hand to influence consumer behavior.

Keywords: sustainable, consumer behavior, odors, field study, expenses, cognition, emotion

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INTRODUCTION

Earth Overshoot Day (EOD) refers to the date on which humans' demand for ecological resources and services has exceeded what planet earth can regenerate in that year (Earth Overshoot Day, 2021). Alarmingly, this date has been creeping up the calendar every year, from September 23 in 2000 to July 29 in 2019 (Earth Overshoot Day, 2021). As carbon emissions form the largest driver of today's overall ecological footprint and climate change, one can imagine the huge impact of global trade and the shipping of goods like clothing on the environment. One of the most polluting industries in the world is the fashion industry (Howell, 2021). Even before transportation, the production of new clothes involves 1.2 billion tons of greenhouse gasses (Beall, 2020). After "consumption," disposal forms another huge problem. Globally, the 92 million tons of textile waste each year make for one garbage truck full of clothes being unloaded every second (Beall, 2020). Synthetic clothing is especially problematic taking 20–200 years to fully decompose, releasing harmful greenhouse gasses like methane in the process which fuels global warming further (McCarthy, 2018). To overcome these problems and prevent irreversible damage to the environment or loss of function in natural systems, sustainable consumption is needed.

How can sustainable consumption be facilitated? The need for long range shipping and the unsustainable production and disposal of clothing is reduced when more individuals recycle their clothing and buy second-hand clothing in local stores. More and more people seem to become aware of their individual contribution to a more sustainable world, met by a growing number of suppliers of local used products like second-hand clothing. Yet, what factors could persuade people to actually make more sustainable choices in the store?

A deliberate and predictable intervention of changing people's behavior by modifying the cues in the physical and/or social context in which they act is called *nudging* (Thaler and Sunstein, 2008; Marchiori et al., 2017). Nudges are believed to subtly influence consumer behavior by instigating non-conscious processes. As such, stimuli that easily escape awareness may be particularly potent, like smells. Although a number of field studies on scent marketing have demonstrated the potent effects of smells on consumer experience and behavior (e.g., Spangenberg et al., 1996; Fiore et al., 2000; Morrin and Ratneshwar, 2000; Chebat and Michon, 2003; Davies et al., 2003; Bosmans, 2006; Bradford and Desrochers, 2009; Doucé and Janssens, 2011; Morrison et al., 2011; Vinitzky and Mazursky, 2011; Doucé et al., 2014; for reviews, see e.g., Spence, 2015, 2020), *chemonudges* have remained neglected in the context of sustainable consumer behavior and their mechanisms are relatively unknown. This is surprising because through a process called "priming" (Smeets and Dijksterhuis, 2014), smells may activate semantic associations that could facilitate sustainable behavior (cf. Bimonte et al., 2020, for visual priming effects on pro-environmental behavior). If a scent prime proves to be effective in a second-hand clothing store by stimulating customers' sustainable shopping behavior, simple applications like scent diffusers can have a modest yet significant contribution in reducing the urgent environmental problems posed by unsustainable fashion.

Literature Review: Smells in the Built Environment

The business environment is one of fierce competition between companies eager to gain customer loyalty and to maximize sales. In this competitive atmosphere, marketeers continually search for new ways to enhance customers' spending. One way to influence consumption is by creating a pleasant atmosphere by emitting a fragrance (Spence, 2015, 2020). For decades, bakeries, coffee houses, and restaurants have used their food scents to attract customers. Nowadays, an even greater variety of companies work with synthetic fragrances to inspire "consumption" (Emsenhuber, 2009). Marketeers have become increasingly aware of the role scent can play in differentiating brands and improving customers' sense of well-being in marketplace settings (Morrin, 2009), and the term *scent marketing* emerged: "using scents to set a mood, promote products, or position a brand" (Vlahos, 2007). Several large players in the commercial fashion market (like Primark, H&M, Scotch and Soda, and ZARA) have already applied scent marketing (AirAroma Scent Marketing, 2016; MoodMedia, 2016), but the effectiveness of scents in these settings cannot be assessed without scientific publications.

What are the elements that make for a potential effective *chemonudge*? Based on the broader literature reviewed below, smells' potency arguably lies in their capacity to affect our behavior subconsciously, aside from inducing deep-seated emotions and durable semantic associations—mechanisms that are facilitated by the distinct smell brain anatomy.

Smells and Awareness

Before a person consciously notices a scent, molecules have already attached to odorant receptors in the nose and reached among the phylogenetically oldest brain regions conserved in humans to produce an often immediate, instinctive reaction (Zaltman, 2003; Vlahos, 2007). Indeed, the human sense of smell provides the "minimal neuroanatomy for a conscious brain" (Morsella et al., 2010; in Keller, 2011). Smells can thus easily remain beneath the radar of conscious reporting, and its exactly at this stage when our behavior is most affected, as lab studies have shown. Our social preferences (face likeability ratings) are guided most strongly when we are presented with a subliminal positive or negative smell (Li et al., 2007). Li et al. (2007) argued that subliminally presented smells prevent strategic processes like "cognitive discounting" from occurring that could otherwise reduce the smell's influence. Another factor contributing to less conscious attention for smells are neurocognitive limitations making it hard for most (Westerners, at least) to put smells into words (Olofsson and Gottfried, 2015; cf. Majid and Kruspe, 2018). Because of this, smell effects can remain under the hood and be relatively non-distracting. Retailers can effectively take advantage of this by applying scents to enhance customer experience and stimulate purchases (Fiore et al., 2000) without distracting the consumers' attention from other stimuli, like the clothes they are looking at Davies et al. (2003).

Smells and Affect

Smells have an intimate link with feelings that is unique among the senses. There is close structural overlap between brain regions processing smell and those devoted to emotion processing (Gottfried, 2006). Odors also evoke the strongest emotional autobiographical memories (see Hackländer et al., 2019, for a review), and these (memory-related) affective reactions occur before cognitive processes take place. Ample research has shown that scents can alter our mood (Ehrlichman and Halpern, 1988; Baron, 1997; Lee et al., 2011). Other studies have shown that the mood of customers has a positive impact on their evaluation of the store and its staff (e.g., Dawson et al., 1990; Swinyard, 1993; Tice et al., 2001; Arnold et al., 2005; Morrison et al., 2011). Positive affect associated with a pleasant ambient scent also transfers to the items being evaluated (Morrin and Ratneshwar, 2000; Doucé and Janssens, 2011). However, some researchers have argued that for the positive affect to transfer, the scent must be congruent with the product category or at least match in arousing qualities (e.g., Mitchell et al., 1995; Spangenberg et al., 1996; cf. Bosmans, 2006, for a different view). According to *affect-as-information theory*, our subjective feelings can serve as a criterion for our decisions (Schwarz and Clore, 1983; Schwarz, 2011). For instance, if a smell induces a positive feeling, this feeling could transfer to an item within a store and inform a buy decision. However, for affect-as-information to work, individuals typically need to identify their affective state as potential criterion for decision making, while not discounting the influence of affect (Albarracín and Kumkale, 2003). Hence, humans are no zombies that buy every product in a store once a pleasant smell is released—reality is more complex, and cognition plays a role as well.

Smells and Cognition

Because odor processing does not end at the more primitive and emotional limbic system, another possibility is that ambient scents affect consumers through their connection with semantic knowledge (Degel et al., 2001). Lab studies have already shown that certain scents, like the smell of all-purpose cleaner, can activate cleaning-related concepts in our brain and instigate actual cleaning behavior, even without our awareness (Holland et al., 2005). The same phenomenon was replicated in a field setting, as de Lange et al. (2012) found that train passengers produced less litter in citrus-scented train wagons compared to non-scented wagons. In another field experiment, Doucé et al. (2014) found that a pleasant ambient scent had a negative effect on customers' product evaluation in a messy store; yet, this effect disappeared when the pleasant scent was associated with neatness. Learned cognitive associations with a scent are thus likely to influence consumer behavior aside from the more direct emotional effects.

To make matters more complex, it should be noted that peoples' semantic scent-associations have been formed and become reactivated in a particular multisensory context. A recent Virtual Reality (VR) study underlined that odors interact in complicated ways with the context in shaping human behavior (de Groot et al., 2020a). In particular, VR was applied to create a realistic, immersive, yet controlled multisensory context (laundry scenario), which was contrasted with a sterile, non- immersive, traditional lab setting. Using a computer-controlled odor delivery device (olfactometer), participants were exposed to three odors: (i) one odor semantically related to cleaning (detergent smell); (ii) one equally pleasant cleaning-unrelated odor (vanillin); and, (iii) no odor (regular room air). Although positive affect may also fuel a person's motivation (Custers and Aarts, 2005), the results showed that the pleasant odor vanillin could not enhance a persons' motivation to clean (de Groot et al., 2020a). Notably, the multisensory context (a VR laundry scenario) and smell (laundry odor) interacted and both were required to fuel motivated and effective cleaning behavior, objectively and subjectively (de Groot et al., 2020a).

The Present Research

The aim of the current research was to examine whether smells can facilitate sustainable behavior. Given the environmental problems associated with the fashion industry, the setting was chosen to be a second-hand clothing store in a large city in the Netherlands. The results of a pre-test ($N = 79$) revealed that hygiene was the second highest rated factor in a person's decision to buy second-hand clothing (53.2%), after lack of damage (70%), but before style (49.4%) and price (32.9%). Hence, to test whether consumer spending in a second-hand clothing store was related to the mere pleasantness of a diffused odor (affect) or through its positive semantic associations with clean clothing items (cognition), customers could smell a fresh linen scent, an equally pleasant vanilla sandalwood odor, or regular store odor. Based on prior research (e.g., Chebat and Michon, 2003; Holland et al., 2005; de Groot et al., 2020a), the *main* hypothesis was that fresh linen scent would increase spending in a second-hand clothing store compared to vanilla sandalwood and regular store odor, due to a combination of affective and cognitive factors.

Second, although various studies have shown effects of ambient scent on consumer behavior (e.g., Chebat and Michon, 2003; Morrison et al., 2011; Vinitzky and Mazursky, 2011), the precise mechanisms have generally remained elusive (Spence, 2020). Here, I propose a conceptual model (**Figure 1**) rooted in prior research to clarify the pathways from scent to spending in the context of sustainable behavior (hypothesis 2a, 2b, 3). First, an ambient scent like fresh linen (pre-tested to be pleasant and associated with cleanliness, see Materials and Methods) is expected to induce a positive mood (e.g., Ehrlichman and Halpern, 1988; Baron, 1997; Khan et al., 2007; Lee et al., 2011; Haehner et al., 2017; Spence, 2020) vs. the regular store odor. Using their feelings as information (Schwarz and Clore, 1983), this positive mood is believed to mediate the amount of money spent on clothing items (H2a) and to transfer to a better evaluation of the store, staff, and products (H2b) (store and staff: Dawson et al., 1990; Swinyard, 1993; Tice et al., 2001; Arnold et al., 2005; Morrison et al., 2011; products: Morrin and Ratneshwar, 2000; Doucé and Janssens, 2011). Aside from "hot" affective processes, the fresh linen scent is expected to positively affect store, staff, and product evaluation through "cold" cognitive processes (Degel et al., 2001; Doucé et al., 2014), which are expected to mediate the relation between scent and spending (H3).

MATERIALS AND METHODS

Participants and Design

A total of 57 customers between 18 and 65 years ($M_{age} = 42.32$ years, $SD = 14.05$) participated voluntarily in this research. Of the 57 participants, 53 identified as "female," and 4 as "male." This gender imbalance fits with research showing that females are generally more interested in second-hand clothing stores

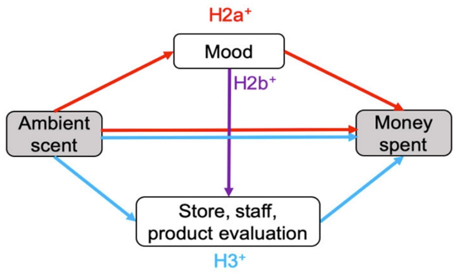

FIGURE 1 | Conceptual model with hypothetical pathways from ambient scent to spending. "Hot" affective route in red and "cold" semantic route in blue.

and vintage stores than males (Cervellon et al., 2012). There were no formal inclusion criteria, and there was no incentive. Participants were asked to fill out a questionnaire directly after having bought an item at the "Green Label Store" (response rate: 16.8%). The Green Label Store is a second-hand store in the city center of Utrecht, the 4th largest city in the Netherlands (357,719 inhabitants), which mainly sells second-hand clothes.

Participants enrolled in a double-blind between-subjects design, with Scent Condition being the sole experimental factor (three levels: fresh linen, vanilla sandalwood, no odor). No evidence was found that age differed significantly across conditions (fresh linen, $n = 21$; $M = 47.43$ years, $SD = 11.85$; vanilla sandalwood: $n = 19$, $M = 41.47$, $SD = 16.06$; no odor: $n = 17$, $M = 36.94$, $SD = 12.61$), $F_{(2, 54)} = 2.85$, $p = 0.067$.

Materials and Measures

Odors

The independent variable in this research was scent. To create the scent conditions, the fresh linen scent and vanilla sandalwood odor were pre-tested for their suitability. During the "no odor" condition, the regular store odor was maintained because no odor was diffused.

Fresh Linen

A pretest was conducted to examine if fresh linen scent would "prime" customers with the idea that products in the second-hand store are hygienic. Participants in this pretest ($N = 22$) were asked to rate odor pleasantness and its association with cleanliness on a 10-point scale. The results revealed fresh linen to be significantly above the midpoint of the scale with regard to pleasantness ($M = 7.55$, $SD = 1.33$), $t_{(21)} = 8.99$, $p < 0.001$, as well as being associated with cleanliness ($M = 8.27$, $SD = 0.99$), $t_{(21)} = 15.49$, $p < 0.001$. Hence, fresh linen scent could influence customers' spending in our field experiment through an affective and/or cognitive semantic priming route. The molecules that made up "Fresh linen" scent are: alpha-Hexylcinnamaldehyde, 4-tert-Butylcyclohexyl acetate, 1-(1,2,3,4,5,6,7,8-Octahydro- 2,3,8,8-tetramethyl-2-naphthalenyl) ethanone, Hexyl salicylate, d-Limonene, 3 and 4-(4- Hydroxy-4-methylpentyl)-3-cyclohexene-1-carboxaldehyde, alpha-Methyl-1,3-benzodioxole-5- propionaldehyde (MoodMedia NL, Almere, the Netherlands).

Vanilla Sandalwood

Prior research indicated that vanilla is perceived as significantly non-fresh (Fenko et al., 2009), and both vanilla (Spangenberg et al., 2006) and sandalwood (Lwin and Morrin, 2012) are perceived a pleasant ambient smell in applied settings. Furthermore, the company ScentAir recommended vanilla sandalwood as a pleasant control scent based on their in-house data (MoodMedia NL, Almere, the Netherlands). The components of "Vanilla sandalwood" were: Vanillin; 1-(1,2,3,4,5,6,7,8-Octahydro-2,3,8,8-tetramethyl-2-naphthalenyl)ethenone; 3-(5,5,6-Trimethylbicyclo[2.2.1]hept-2-yl)cyclohexan-1-ol; 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta-gamma-2- benzopyran; p-t-Butyl-alpha-methylhydrocinnamic aldehyde; alpha-iso-Methylionone. No lab-based pilot test was carried out for this odor, which can be considered a limitation. *Post-hoc*, there were no differences in odor pleasantness between fresh linen and vanilla sandalwood in the field setting (see Results).

Odor Dispersion

The company ScentAir, part of MoodMedia (MoodMedia NL, Almere, the Netherlands) provided the scents and scent diffusion apparatus (**Figure 2**). Both companies have years of experience in real world scent diffusion. The patented scent diffusion system "ScentDirect SDD-4004" (height: 235 mm, diameter: 45 mm) is capable of diffusing scent in an area of 850 m^3, which greatly exceeds the dimensions of the Green Label Store. It features advanced diffusion technology that converts liquid fragrance oil from cartridges (0825 Fresh Linen ON or 1807 Sandalwood Vanilla) into a fine, dry, invisible mist and releases it directly and consistently into the environment. To maximize the efficiency of scent delivery, the airflow in the store was determined by ScentAir. To cover the entire store with scent, ScentAir decided to install the ScentDirect diffuser about half a meter from the entrance. Customers were exposed to the smell during their purchase and during the completion of the questionnaire which was at the counter (located next to the entrance).

Scent Calibration: Awareness and Pleasantness

When a scent becomes too intense, people may become aware that their responses are being influenced by the scent and change their behavior (Bosmans, 2006). Based on their in-house research, ScentAir selected a scent intensity ensuring the scents were not too salient, quantified by ∼25% of the customers noticing the scent and 75% not being aware of its presence. To verify this, a manipulation check was included at the end of the questionnaire. Participants were asked if they smelled a scent which was different from what they expected in the store. If they answered this question with "yes" they were asked to fill in what they thought they smelled. Only three individuals in the fresh linen condition guessed "laundry odor" or "fresh smell," and only three individuals in de vanilla sandalwood condition guessed "sandalwood" or "sweet odor" (∼15% of the sample). In both scent conditions, 27 individuals "*noticed a smell*" and provided smell ratings (of which 19 individuals mentioned the smell was *different from what they expected*). All 27 customers subsequently rated the scent they noticed on 7-point Likert scales. Importantly,

FIGURE 2 | ScentDirect odor diffusion system.

the pleasantness ratings of fresh linen scent ($M = 5.43$, $SD = 1.55$; $n = 14$) was again significantly above the midpoint (3.5) of the scale, $t_{(13)} = 4.66$, $p < 0.001$, and virtually identical to vanilla sandalwood odor ($M = 5.46$; $SD = 1.56$; $n = 13$), $t_{(25)} = -0.05$, $p = 0.957$.

Questionnaire

Aside from asking the participant to report the amount of money they spent in the store, this 13-item questionnaire intended to assess on a 7-point Likert scale the customer's evaluation of the store environment ("Store evaluation"; four items), their evaluation of the products ("Product evaluation"; four items), their evaluation of the staff ("Staff evaluation"; two items), and the mood of the customer ("Mood"; three items). Of these 13 items, five items were selected based on their high factor loadings (>0.80) in a similar study by Chebat and Michon (2003), with the original source cited for each selected item. For "Store evaluation," two items were selected based on prior research ("How boring/stimulating do you find this store"; "How (un)interesting do you find this store?") (Fisher, 1974; cf. Chebat and Michon, 2003). Note, the question about liveliness was omitted; instead, it was asked: "What is your general impression of this store?," and "What is your impression of the messiness of this store?." For "Product evaluation," one item was selected based on prior research ("What do you think of the quality of the products in the store?") (Bellizzi et al., 1983; cf. Chebat and Michon, 2003). This item was complemented by three items that were more specific to the current context: "How hygienic are the products in this store?," "How much trust do you have in the products being sold in this store?," and "Did you doubt about your purchase?" (Product evaluation). Regarding "Mood," two items were selected from prior research ("How (un)happy do you feel at this moment?"; "How annoyed/pleased do you feel at this moment?") (Mehrabian and Russel, 1974; cf. Chebat and Michon, 2003). The items about satisfaction and feeling melancholic/contented were considered as superfluous for the current setting. In an attempt to capture the whole emotion experience (quality and quantity) in one scale, an extra item on "Mood" was added to target the arousal dimension going from relaxed to tense. In retrospect, this item would have better fitted a separate category of arousal (vs. valence) (see Results; Mehrabian and Russel, 1974; Chebat and Michon, 2003). Fourth, "Staff evaluation" was assessed using two items asking about staff friendliness and helpfulness (cf. Simmers and Keith, 2015).

TABLE 1 | Cronbach's α before and after removing items from Store, Staff, Mood, and Product.

Factor	Number of items	Cronbach's α	Cronbach's α if item deleted	Remaining number of items
Store	4	0.458	0.867	3
Staff	2	0.735	0.735	2
Mood	3	0.051	0.730	2
Products	4	0.405	0.692	3

After this 13-item questionnaire, control questions were asked to check if participants were aware that a different scent was diffused in the store and, if so, how they rated this scent on appropriateness, intensity, familiarity, and pleasantness. The final questionnaire can be found in the **Supplementary Material** (Appendix 1: Dutch questionnaire with key terms translated in English; and Appendix 2: the original untranslated questionnaire).

Reliability Analysis

A reliability analysis was done to verify the internal consistency of the originally constructed subscales ("Store evaluation," "Staff evaluation," "Mood," and "Product evaluation"). From the initial 13 items, three had to be deleted from the various subscales to reach acceptable internal consistency levels (**Table 1**) (Gravetter and Wallnau, 2007).

"Store" initially consisted of four items ($\alpha = 0.458$); yet, as the store messiness item (#10) did not correlate well with the other store evaluation items (#1–3: $rs > 0.035 < 0.154$), this item was deleted ($\alpha = 0.867$). "Staff" consisted of two items ($\alpha = 0.735$); these items correlated well ($r = 0.585$) and could be retained. "Mood" initially consisted of three items ($\alpha = 0.051$); yet, the experienced tension item (#5) correlated negatively with the other mood items (#7: $r = -0.154$; #13: $r = -0.134$). After deleting this item, internal consistency was acceptable ($\alpha = 0.781$). Finally, the internal consistency of "Product evaluation" (four items: $\alpha = 0.405$) was raised ($\alpha = 0.692$) after deleting the purchase doubt item (#9), which did not correlate well with the rest (#4, #6, #11: $rs > -0.074 < 0.114$).

Procedure

The experiment was conducted in a second-hand clothing store for seven consecutive weeks. The following scent condition order was maintained: "No odor" condition (week 1), "Fresh linen" scent condition (week 2–3), and "Vanilla sandalwood" scent condition (week 5–7). A person from the company ScentAir arranged proper scent diffusion. A gap week (week

4) was aimed to neutralize the smell to avoid odor mixtures. The experiment was double-blind: experimenters (aware of the study's hypothesis) were not present. Instead, store personnel received a hand-out with general information about the study design. While the staff knew that the regular store odor was altered in the two scent conditions, they were neither aware of the exact content, nor of the study's hypotheses. Employees were instructed to behave as naturally as possible during the experiment, to keep track of how many people entered the store and bought an item, and to ask a customer to voluntarily fill out a questionnaire after a purchase. At the end of each day, an experimenter collected the data.

FIGURE 3 | Mean total amount of money spent by customers in second-hand store as a factor of scent.

Statistical Analyses

Data and analyses are available here: https://osf.io/ax7yp/. The analyzed sample ($N = 57$: fresh linen: $n = 21$; vanilla sandalwood: $n = 19$; regular store odor: $n = 17$) consisted of individuals aged 18–65. By age 65, about half the population has noticeably impaired smell abilities (e.g., Kern et al., 2004; Wolfe et al., 2006). Three individuals self-reported a decreased sense of smell, and analyses were performed with and without these individuals to check for its impact.

Regarding the main effect of ambient scent on the mean total amount of money spent in a second-hand clothing store (hypothesis 1), it was first checked whether data were normally distributed. If so, a one-way ANOVA was conducted with scent condition as the sole factor. Following up on a main effect of scent condition, planned contrasts would verify the nature of the difference.

Regarding the relations from ambient scent to consumer spending (hypothesis 2a, 2b, 3), three questionnaire items had to be rescored because their scales were reversed: Item 5 "How do you feel at the moment?" Relaxed-Tense; Item 9: "Did you doubt about your purchase?"; Item 10: "What impression does the store make on you?" Not messy-messy. To maintain power, missing responses on the questionnaire (4.1%) were imputed in IBM SPSS 27, per scent condition, using regression imputation including a random error term. Then, a reliability analysis was done on all 13 items to check whether the subscales (store, product, staff, mood) were internally consistent (see **Table 1**, Results). To assess relations from the conceptual model (**Figure 1**), mediation analysis was performed with the PROCESS procedure for SPSS (Version 3.5.3) following the method from Hayes (2018). Within the PROCESS macro, model 4 was selected to test hypothesis 2a, 2b, and 3 with simple mediation. The significance of the indirect effect was tested using bootstrapping procedures. Specifically, unstandardized indirect effects were computed for each of 5,000 bootstrapped samples, and the 95% confidence interval (CI) was computed by determining the indirect effects at the 2.5th and 97.5th percentiles. Mediation was present if the 95% CI did not overlap with 0. Second, to explore a possible best fitting model between latent and observed variables in a data-driven way, structural equation modeling was performed in JASP (JASP Team, 2020).

RESULTS

Scent and Amount of Money Spent

The first hypothesis entailed that exposure to a fresh linen scent would cause people to spend more money in a second-hand clothing store compared to no odor (regular store odor) and control odor exposure (vanilla sandalwood). As the data were normally distributed according to a Shapiro-Wilk test (*p*s > 0.126), a one-way ANOVA was conducted with condition (three levels: fresh linen, control, vanilla sandalwood) as between-subjects factor. Because Levene's test indicated significant non-homogeneity of variances, correction of the degrees of freedom was performed using Brown-Forsythe. The ANOVA showed a significant effect of condition, $F_{(2, 44.40)} = 5.23$, $p = 0.009$, $\eta^2 = 0.15$. Planned contrast tests with degrees of freedom corrected (not assuming equal variances) indicated that, on average, customers spent significantly more money in total in the fresh linen scent condition (M = €10.36, SD = €6.44) vs. the no odor condition (M = €5.76, SD = €3.39), $t_{(31.42)} = 2.83$, $p = 0.008$, $d = 0.87$ [0.19–1.53], and vs. the vanilla sandalwood condition (M = €6.72, SD = €3.84), $t_{(33.1)} = 2.20$, $p = 0.035$, $d = 0.68$ [0.04–1.31] (**Figure 3**). No significant differences were found between the two control conditions (no odor vs. vanilla sandalwood): $t_{(34.00)} = 0.79$, $p = 0.432$.

Participants did not only spend more money in the fresh linen condition, but a descriptive analysis (there were not enough data points—days tested—for a formal analysis) also indicated that, with an average amount of 60 customers per day across conditions, the fresh linen scent witnessed a higher ratio of customers that bought an item (23.77 vs. 16%).

Controlling for Potential Confounds

Considering only the scent conditions (fresh linen, vanilla sandalwood), 19 individuals reported to have smelled a different odor than expected in this store, whereas 21 did not. An independent samples t-test revealed that reported awareness of a different-than-expected odor did not significantly impact spending behavior, $t_{(38)} = 0.922$, $p = 0.362$. Three individuals in the fresh linen and three more in the vanilla sandalwood condition correctly guessed the odor. Repeating the ANOVA without these individuals still gave a significant effect of scent condition, despite the smaller sample, $F_{(2, 48)} = 3.41$, $p = 0.041$, $\eta^2 = 0.12$.

Murray et al. (2010) found that customer spending was related to more exposure to sunlight and concomitant decreased negative affect. In the present research, the higher amount of money spent in the fresh linen condition could not be due to extraneous factors like the average outside temperature, hours of rain, or hours of sunshine. A Kruskal-Wallis test indicated significant differences across conditions on all variables [average outside temperature: $H(2) = 36.03$, $p < 0.001$; hours of rain: $H(2) = 32.16$, $p < 0.001$; hours of sunshine: $H(2) = 18.13$, $p < 0.001$]. A Mann-Whitney test indicated that the average outside temperature was lower for the fresh linen condition ($Mdn = 10.1°C$) than for the vanilla sandalwood condition ($Mdn = 17.6°C$), $U = 16$, $p < 0.001$. The no odor control condition yielded the lowest average outside temperature ($Mdn = 8.9°C$) (vs. fresh linen: $U = 99$, $p = 0.018$; vs. vanilla sandalwood: $U = 6$, $p < 0.001$); the highest rain hours ($Mdn = 2.5$) vs. fresh linen ($Mdn = 0$), $U = 99$, $p = 0.018$, and vs. vanilla sandalwood ($Mdn = 0$), $U = 23$, $p < 0.001$; and the lowest sunshine hours ($Mdn = 2.4$) compared to fresh linen ($Mdn = 8$), $U = 31$, $p < 0.001$, and compared to vanillin sandalwood ($Mdn = 13$), $U = 68$, $p = 0.003$. All other comparisons were non-significant. Finally, there were no significant correlations between amount of money spent and average outside temperature, $r(55) = -0.06$, $p = 0.682$, hours of sunshine, $r(55) = 0.16$, $p = 0.242$, and hours of rain, $r(55) = -0.13$, $p = 0.348$.

Data were collected from Tuesday until Saturday and because day of the week could influence spending behavior (e.g., Stewart et al., 2012), weekday was also controlled for (cf. Murray et al., 2010). The analysis revealed that day of the week could not significantly predict spending behavior ($F < 1$; Tuesday: $M =$ €8.45, $SD =$ €6.29; Wednesday: $M =$ €8.37, $SD =$ €4.68; Thursday: $M =$ €8.64, $SD =$ €6.21; Friday: $M =$ €8.78, $SD =$ €3.36; Saturday: $M =$ €5.09; $SD =$ €3.74); adding weekday as a covariate to the main analysis did not eradicate the effect of scent on spending, $F_{(2,53)} = 4.02$, $p = 0.024$, $\eta^2 = 0.12$. The time customers spent in the store may also impact purchasing behavior (e.g., Freathy and O'Connell, 2012); yet, as this factor was not recorded because tracking each customer appeared too difficult in the current set up, it could not be controlled for. Hence, it is possible that customers in the fresh linen condition spent longer in the shop and therefore spent more money, and whether this is driven by the odor is unknown.

Short Summary

Controlling for a number of confounds, customers spent significantly more money in the fresh linen scent condition compared to the vanilla sandalwood and no odor condition, which supports hypothesis 1. For hypothesis 2, a deeper dive into the mechanisms from "ambient scent" (vs. no scent) to spending behavior is required. It should be noted that because a few factors (e.g., customer dwell time) could not be accounted for, and because the sample size was rather small (fresh linen: $n = 21$; vanilla sandalwood: $n = 19$; regular store odor: $n = 17$), the indirect effects reported below should be interpreted with relative caution.

From Scent to Spending: Exploring Hot and Cold Routes Through Mediation Analysis

To test the pathways from scent to spending in the context of sustainable behavior based on the prior literature (hypothesis 2a, 2b, 3), simple mediation analyses were conducted (**Figure 4**).

First, ambient scent (vs. regular store odor) was expected to increase spending through elevating the customer's mood (H2a). Indeed, fresh linen scent significantly increased mood ($b = 0.74$, $t_{(36)} = 2.15$, $p = 0.038$, 95% CI: 0.04, 1.44]), whereas only a trend was found for vanilla sandalwood ($b = 0.62$, $t_{(34)} = 1.94$, $p = 0.061$, 95% CI [−0.03, 1.38]). Whereas the direct path from fresh linen to money spent was significant ($b = 3.99$, $t_{(36)} = 2.17$, $p = 0.037$ [95% CI: 0.26, 7.73]), the indirect path did not reach significance ($b = 0.61$ [95% CI: −0.57, 2.01]). Only 13.19% of the total effect of fresh linen on money spent was explained via (explicit) mood. In contrast, there was no direct effect of vanilla sandalwood on money spent ($b = 1.10$, $t_{(34)} = 0.85$, $p = 0.401$ [95% CI: −1.53, 3.73]; indirect effect: $b = -0.15$ [95% CI: −1.19, 0.49]. In sum, whereas fresh linen scent increased mood and caused a higher amount of money to be spent, mood did not significantly mediate the relation between scent and spending.

Second, positive mood was expected to mediate the relation between scent and evaluations of the store, staff, and products (H2b). Because store evaluation correlated strongly with staff evaluation $r(56) = 0.58$, $p < 0.001$, and with product evaluation, $r(56) = 0.55$, $p < 0.001$, [staff-product: $r(56) = 0.41$, $p = 0.002$]; to prevent that several analyses had to be carried out, mediation analyses were carried using the most strongly correlated and most encompassing variable store evaluation. Aside from the path from scent to mood (presented above) being significant (fresh linen) or just not-significant (vanilla sandalwood), the pathway from mood to store evaluation was neither significant for fresh linen ($b = 0.04$; $t_{(36)} = 0.43$, $p = 0.670$ [95% CI: −0.16, 0.24]), nor for vanilla sandalwood ($b = 0.13$; $t_{(34)} = 1.26$, $p = 0.218$ [95% CI: −0.08, 0.34]). In the absence of significant direct and indirect effects in this model, the conclusion is that there is no evidence that mood mediated the relation between scent and store, staff, and product evaluations.

Third, through semantic priming, the fresh linen scent (but not vanilla sandalwood) was expected to enhance store, staff, and product evaluations, which would mediate the relation between the scent and spending (H3). The path from scent to store evaluations indeed was only significant for fresh linen ($b = 0.52$; $t_{(36)} = 2.60$, $p = 0.013$ [95% CI: 0.11, 0.93]), and not for vanilla sandalwood ($b = 0.11$, $t_{(34)} = 0.54$, $p = 0.592$ [95% CI: −0.31, 0.54]). The paths from store evaluation to spending were not significant (fresh linen: $b = 1.99$; $t_{(36)} = 1.41$, $p = 0.166$ [95% CI: −0.87, 4.85]; vanilla sandalwood: $b = -0.14$, $t_{(34)} = -0.14$, $p = 0.890$ [95% CI: −2.20, 1.92]). For vanilla sandalwood, neither the direct effect ($b = 0.97$, $t_{(34)} = 0.79$, $p = 0.437$ [95% CI: −1.54, 3.49]), nor the indirect effect were significant ($b = -0.02$ [95% CI: −0.73, 0.31]). Despite a significant *total* effect from scent to spending for fresh linen ($t_{(36)} = 0.012$ [95% CI: 1.09, 8.11]), the

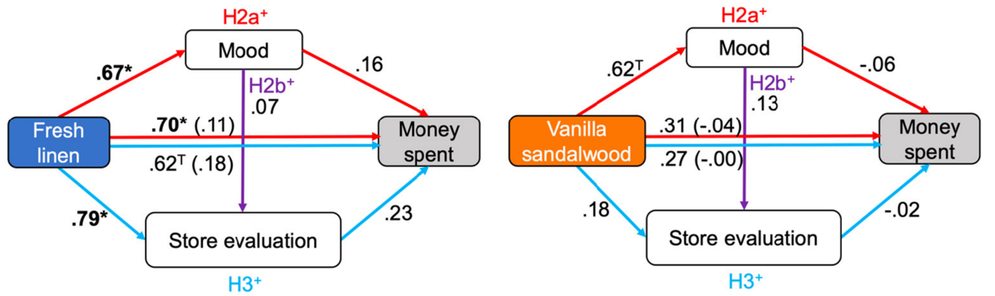

FIGURE 4 | Conceptual model with standardized regression weights and significance indicated**.** Comparisons include fresh linen (left) and vanilla sandalwood (right) vs. regular store odor. *$P < 0.05$.

direct effect became non-significant ($b = 3.55$, $t_{(36)} = 1.91$, $p = 0.064$ [95% CI: −0.22, 7.33]), and the confidence intervals of the indirect effect overlapped with 0, rendering it non-significant ($b = 1.04$ [95% CI: −0.28, 3.25]). Still, in terms of effect size, the indirect pathway explained 22.71% of the significant total effect. In sum, fresh linen scent (vs. control odor, odorless control) did affect store evaluations; yet, these explicit evaluations insufficiently mediated the effect from scent to spending.

For exploratory purposes, structural equation modeling was performed to select the best fitting model from fresh linen scent to spending behavior in a data-driven way (Bollen and Long, 1993). Note that in this model, arousal appears a factor. No a priori expectations were set regarding arousal, but in this data-driven model the possibility for its inclusion was left open. Also, store evaluation, product evaluation, and staff evaluation were decomposed relative to the mediation analysis to see what the model would select as the best fitting predictor of money spent on second-hand clothing. The best fitting model [Goodness of fit Index (GFI) = 0.924; Comparative Fit Index (CFI) = 1.00; Root Mean Square Error of Approximation (RMSEA) = 0.00] (Hu and Bentler, 1999) contained a significant semantic route from fresh linen scent to "store evaluation" ($z = 2.73$, $p = 0.006$) and from "store evaluation" to customers' spending ($z = 2.65$, $p = 0.008$) (**Figure 5**). The results differ from the mediation analysis (**Figure 4**), because no direct pathway from scent to money spent was modeled (cf. Chebat and Michon, 2003), which would otherwise reduce explanatory variance. SEM also showed a significant route from fresh linen scent to mood ($z = 2.26$, $p = 0.024$), and inversely from mood to arousal ($z = -3.69$, $p < 0.001$), reflected by the experienced tension item. The path from arousal to "store evaluation" was not significant ($z = -1.67$, $p = 0.095$). Hence, there was neither a significant direct nor indirect pathway from mood to spending. According to SEM, a fresh linen scent (vs. control) resulted in higher store evaluations and mood, but only higher store evaluations led to more spending.

DISCUSSION

The main aim of this study was to investigate whether the diffusion of ambient scent would increase sustainable behavior in the form of customers spending more money in a second-hand clothing store. The secondary aim was to elucidate the mysterious ways in which ambient scent increases actual spending behavior in this environment, through "hot" affective processes, "cold" cognitive processes, or both. Although various studies have shown effects of ambient scent on consumer behavior (e.g., Chebat and Michon, 2003; Morrison et al., 2011; Vinitzky and Mazursky, 2011), the exact mechanisms from scents to spending have generally remained elusive (Spence, 2020). A field experiment was set up to test this. Based on prior research, a conceptual model (**Figure 1**) was devised to test the pathways from scent to spending in the context of sustainable behavior in a theory-driven way using mediation analysis. Aside from that, a structural equation model was created to explore which model would best fit the data in an unbiased, data-driven way. Mediation analysis showed that only a fresh linen scent (vs. vanilla sandalwood and regular store odor) could increase mood and evaluations of the store; yet, these variables did not mediate the significant link between fresh linen odor and spending. The data-driven model, however, suggested that fresh linen scent mainly influenced customers' behavior through a "cold" semantic route, a direction that warrants further scrutiny in a more powerful experiment using more sensitive, implicit measures of mood and cognition.

The *main* hypothesis was that, due to a combination of cognitive and affective factors, fresh linen scent would cause customers to spend more money in a second-hand clothing store compared to those smelling vanilla sandalwood (pleasant control odor) and the regular store odor (odorless control). Indeed, the results showed a large and medium-to-large effect of fresh linen scent on consumer spending behavior vs. the odorless control and pleasant control odor, respectively. Fresh linen scent almost doubled the amount of money that was spent on second-hand clothing. The reported effects were independent of odor awareness, odor pleasantness, and extraneous factors like day of the week and weather conditions.

The secondary hypotheses were aimed at the specific relations between ambient scent and spending behavior, including a person's mood, their evaluation of the store, staff, and products. Hypothesis 2a stated that compared to the regular store odor, an ambient scent like fresh linen (pre-tested to be pleasant and associated with cleanliness) would induce a positive mood (e.g.,

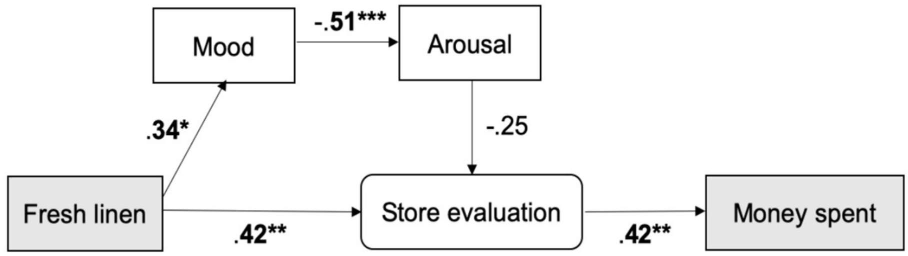

FIGURE 5 | Best fitting model according to structural equation modeling. Store evaluation is a latent variable in this model measured with three items.

Ehrlichman and Halpern, 1988; Baron, 1997; Khan et al., 2007; Lee et al., 2011; Haehner et al., 2017; Spence, 2020), which would mediate the relation between scent and spending following affect-as-information theory (Schwarz and Clore, 1983). Whereas fresh linen scent indeed positively influenced mood (and only a trend was found for vanilla sandalwood, although both odors were not rated differently in pleasantness), there was no evidence that mood mediated the relation between scent and spending. Second, positive mood was believed to enhance evaluations of the store, staff, and products (H2b) (Dawson et al., 1990; Swinyard, 1993; Morrin and Ratneshwar, 2000; Tice et al., 2001; Arnold et al., 2005; Doucé and Janssens, 2011; Morrison et al., 2011). This hypothesis was not supported, as odor-induced mood could not predict higher evaluations of the store, staff, and products. Third, there was partial support for the hypothesis that only fresh linen scent would enhance store, staff, and product evaluations through semantic priming (H3) (Degel et al., 2001; Doucé et al., 2014): whereas fresh linen scent indeed enhanced store, staff, and product evaluations (and vanilla sandalwood did not), there were no significant mediation effects of ambient scent on spending via these evaluations. Explorative structural equation modeling also did not show a significant pathway from scent to spending via mood, whereas fresh linen scent did increase store evaluations, and higher store evaluations caused more money to be spent. These combined results suggest that fresh linen scent may have influenced consumers relatively more through a "cold" cognitive route that is based on semantic associations with the smell. These findings dovetail with Chebat and Michon (2003), who noted that "the cognitive effect of ambient scent [on consumers' spending] primarily passes through the perception of the retail environment".

The results add to a growing number of studies highlighting the importance of cognition and context in shaping (multisensory) perception. Using VR, a recent study has shown that motivated goal-directed behavior as induced by odors is not related to odor pleasantness, but it only works for odors that have a semantic relation to the behavior, and this effect only occurs in a realistic, multisensory context (de Groot et al., 2020a). Prior to that study, others had shown that a cleaning-related odor (citrus) increased cleaning behavior, both in a lab environment (Holland et al., 2005) and in a field study (de Lange et al., 2012). At that point, it was unknown whether this form of semantic odor priming followed a reflex-like stimulus–response mechanism, with prototypical (cleaning) behavior always following (cleaning-related) odor exposure. However, such a perspective fails to account for the top-down mediating role that cognitions ("inspired" by context) have on the link between perception of scent and action. In the present research, this perception-action link was observed to operate via enhanced evaluations of the store, irrespective of mood. Although we cannot rule out effects of increased mood by ambient scents like fresh linen because the absence of evidence does not mean the evidence of absence, it does seem the present findings are best intelligible from situated cognition theory (cf. de Groot et al., 2020b). From this theory (e.g., Barsalou, 2016), scents are expected to fuel goal-directed behavior like buying clothing if the information a scent "communicates" (e.g., cleanliness) matches a person's criteria for buying second-hand clothing (e.g., needs to "feel" new, needs to be hygienic). What the current study thus has in common with more controlled lab studies is that it shows that human consumers are no "zombies" that immediately start spending money once they are exposed to ambient scent, but the smell has to convey a particular meaning in a particular context to be effective, operating through cognitive rather than affective processes, although a combination is not out of the question. This insight has practical implications, but the study also has a few shortcomings that are worthy of addressing.

Limitations

One limitation is the potential constraint on generality posed by the characteristics of the current sample (Simons et al., 2017). The large majority of the sample consisted of females (93%) around the age of 40, who are regular visitors of a second-hand clothing store. Most (48.2%) are monthly or even weekly (28.6%) visitors of this or a similar store. Research has shown that females visit more stores and spend more time in stores then males (Dennis and McCall, 2005) and that second-hand clothing elicits more nostalgic feelings in females causing them to visit these stores more (Cervellon et al., 2012). Females also generally have a slightly better sense of smell than males (Sorokowski et al., 2019) and seem more susceptible to emotions associated with smells (e.g., de Groot et al., 2014). The current population may also differ from customers visiting more traditional commercial clothing stores, in the sense that the current sample may assign more meaning and value to second-hand clothing items (Cervellon et al., 2012). If so, this could have created a ceiling effect, reflected in the absent direct link between fresh linen scent and evaluations of the store, staff, and products; yet, fresh linen could still boost these evaluations in this sample. At present, we do not have evidence that our findings generalize to other populations like males. Yet, we have no reason to believe that fresh linen scent would *not* elicit spending behavior in males, because gender differences in smell abilities yield only small effect sizes (Sorokowski et al., 2019), and the spending behavior is expected to be triggered by representations of clean clothing items that are activated by fresh linen scent through mere association, and males are expected to have these associations as well (cf. Holland et al., 2005, showing all-purpose cleaner smell to induce cleaning behavior in a subsample of males also). However, it could be that individuals who wash more frequently will have a more positive association with clean clothing after smelling fresh linen scent. Although demographics like ethnic background were not collected, it is likely that the present research mainly consisted of Western, Educated, Industrialized, Rich, Democratic (WEIRD) individuals (Henrich et al., 2010). Although the scent priming mechanisms are assumed to be universal, its workings are dependent on the associations members of a certain culture have with a smell in order for it to effectively affect behavior.

Another limitation is in the mode of data collection, via a questionnaire. A questionnaire only taps into explicit process and it is possible that the effects of smells on mood and store evaluations escaped the customers' conscious awareness (e.g., Degel et al., 2001; Holland et al., 2005; de Groot et al., 2020a), making it more difficult to find mediation effects using these explicit measures. Future research could make use of VR techniques, controlled odor delivery, and implicit measures of mood and products aside from the current explicit measures. Also, the questionnaire was quite short to increase compliance, but this came at the expense of reliability. Some subscales consisted of only two items, whereas the appropriate scale length is three items or more. Another aspect concerns questions about mood (and arousal). It was not explicitly stated that the participants should report the level of happiness and tension at that very moment. Some people may have difficulties reporting their own mood (Lineweaver and Brolsma, 2014), causing them to answer the question based on their general mood or arousal from the past day, week or month. In future research the questionnaire should be pre-tested before using it as an instrument. Another notable facet is that on each of the subscales (mood, store evaluation, product evaluation, and staff evaluation), customers scored an average 6 on a 7-point scale, with staff getting an average rating of 6.6. These high scores may be a result of selection bias and social desirability. Regarding the former, only about one in six customers who bought an item at the second-hand clothing store completed the questionnaire. Of these individuals, all 57 reported the intention to come back to the store. It could be that only those individuals that were in a good mood, who had a positive view of the store, its products, and the staff, filled out this questionnaire. The high ratings could also stem from the customers showing social desirability, to please the staff (as the researchers were not present). This is possible since the questionnaires were filled out at the counter in close proximity to the staff. It was deliberately chosen to instruct the staff to point the customer's attention to the questionnaire, because the presence of researchers in the store can have a profound effect on the customers and the store personnel (Wood et al., 2006). Creating as much a realistic and natural setting as possible was precisely the aim of this research. Also, the researchers were aware of the hypotheses and could have modified their behavior to obtain the desired results if they would have been present. The store personnel, however, was indifferent to the hypotheses and the study's outcome and would therefore exert a negligible influence on the results. Hence, the current study was truly double blind.

A third limitation is the study design. Compared to a lab experiment, experimental control is obviously more difficult in a field experiment. It cannot be guaranteed that all individuals have been exposed to the same quantity of odor, for the same duration. Aside from that, customers' smell thresholds were unlikely to be identical, which may have caused that the odor was perceived above threshold by some and below their threshold of conscious reporting by others (Smeets and Dijksterhuis, 2014). Another factor is that smells were presented sequentially. To avoid contamination of the store odor by the diffused smells, the "no odor" condition was first in line, followed by the fresh linen scent and then—after a gap week—the vanilla sandalwood condition. A counterbalanced design would have been more optimal, but not crucial, as spending behavior was unrelated to extraneous factors like significantly better weather conditions in the vanilla sandalwood condition. Given the lower amount of money spent in the vanilla sandalwood condition (vs. fresh linen), it is also unlikely that customers were exposed to a residue of fresh linen smell, as this should have boosted spending. To conclude, higher external validity was traded off for potentially lower internal validity, or at least less experimental control. Yet, building on the numerous lab studies that have highlighted excellent human smell skills under sterile conditions (reviewed in e.g., McGann, 2017; de Groot et al., 2020b), examining the effects of odors in natural settings seems inevitable to discover how important smells are to our everyday lives. Admittedly, even though the effect of fresh linen scent on spending behavior was strong, the sample was small. Of the 300+ customers in the store, $<20\%$ completed the questionnaire, perhaps because there was no incentive and participation was truly voluntary. These issues may be overcome in future research by testing large samples from diverse backgrounds at different locations with incentives and using machine learning approaches to make sense of the rich, complex data, after which effective practical applications tailored to a specific store or situation could be developed.

Implications

Different odors can affect the consumer, and even "nudge" them, in different ways according to the context, which has implications for successful application and ethics. Whereas a context-irrelevant pleasant odor can lift the customer's mood, a context-relevant pleasant odor has the additional benefit of increasing consumer spending by increasing the overall evaluation of the store. As such, the insights from this research can inform marked changes in the application of odors in consumer environments. This also warrants considerations about ethics, because once diffused in the store, smells cannot be avoided (Bradford and Desrochers, 2009; Emsenhuber, 2009). Whereas increasing a person's mood through smell may be a minor ethical issue, it becomes more severe if a smell can actually boost sales, and particularly if this concerns products that are not in line with a person's values (e.g., a non-sustainable purchase). Typically, nudges are subtle rearrangements of the choice architecture (Marchiori et al., 2017), and this could mean customers could be manipulated in a direction they are unaware of. To be ethically acceptable, House of Lords Science and Technology Select Committee (2011) for example have mentioned that people should be told about an intervention directly, which could hamper its effect through strategic control mechanisms on the part of the customer (especially with smells), or an intervention should be just noticeable by a perceptive person (Thaler and Sunstein, 2008; Marchiori et al., 2017). As odor thresholds vary markedly from person to person (e.g., Oleszkiewicz et al., 2019), the concentration of the diffused odor could be set at the average threshold level for a certain population. Furthermore, research has shown that putting a sign on the counter stating "we are helping you to make healthy choices" did not impact a healthy food choice nudge effectiveness (Kroese et al., 2015); therefore, a similar sign replacing "healthy" with "sustainable" could make customers aware of a possible smell intervention, which may (or may not) be in line with their core values (for them to judge). In sum, the greater knowledge on the workings of smells in built environments needs to be coupled to thinking critically about the ethical considerations that are surrounding their application, and these concerns may be different for different scents in different contexts.

CONCLUSION

The current findings are promising for scent marketing in sustainable environments like a second-hand clothing store. A specific ambient scent almost doubled the sales by associating good qualities ("clean," "hygienic") with the products in the store. Contrary to much research, it was shown that consumer behavior is not simply impacted by diffusing a pleasant scent in the air; the smell needs to have a particular meaning with respect to the store or product context in which it is diffused. Hence, by keeping the rest of the store environment exactly the same and simply altering the regular store odor to fresh linen scent, customers could be nudged to buy more in this sustainable environment. Smells were initially neglected as a medium that would successfully contribute to preventing irreversible damage to our environment due to disposal issues; yet, here they were demonstrated effective, although more research is needed to chart smells' effectiveness in case of a *direct* comparison between sustainable vs. unsustainable choices. As the fashion industry is one of the most polluting industries in the world (Howell, 2021), the application of scents to facilitate sustainable behavior could eventually help at least a bit to put Earth Overshoot Day higher up the calendar.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article are permanently available on the Open Science Framework: https://osf.io/ax7yp/.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.718279/full#supplementary-material

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Real and Imagined Smellscapes

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The smellscape is the olfactory environment as perceived and understood, consisting of odours and scents from multiple smell sources. To what extent can audiovisual information evoke the smells of a real, complex, and multimodal environment? To investigate smellscape imagination, we compared results from two studies. In the first, onsite participants (N = 15) made a sensory walk through seven locations of an open-air market. In the second, online participants (N = 53) made a virtual walk through the same locations reproduced with audio and video recordings. Responses in the form of free-form verbal annotations, ratings with semantic scales, and a 'smell wheel', were analysed for environmental quality, smell source type and strength, and hedonic tone. The degree of association between real and imagined smellscapes was measured through canonical correlation analysis. Hedonic tone, as expressed through frequency counts of keywords in free-form annotations was significantly associated, suggesting that smell sources might generally be correctly inferred from audiovisual information, when such imagination is required. On the other hand, onsite ratings of olfactory quality were not significantly associated with online ratings of audiovisual reproductions, when participants were not specifically asked to imagine smells. We discuss findings in the light of cross-modal association, categorisation, and memory recall of smells.

Keywords: smellscape, environment, perception, smell, imagination, memory, crossmodal

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INTRODUCTION

The term 'smellscape' was introduced by Porteous (1985), based on Schafer's (1977) soundscape concept. It refers to the olfactory environment as perceived and understood by a person influenced by memories and past experiences, specific to its context (Xiao et al., 2018, p. 106). When considering living spaces and everyday environments, the quality of the olfactory environment is important both psychologically, e.g., subjective evaluation, and physiologically, e.g., stress recovery (Annerstedt et al., 2013; Hedblom et al., 2019). Thus, an examination of the smellscape may contribute towards our understanding of the relationship between perceptual processes such as odour annoyance as well as general wellbeing (Naddeo et al., 2013). Smells are closely associated with memories (Wilson and Stevenson, 2003; Herz, 2016). As the senses combine to influence our overall experience in everyday environments (Spence, 2020, p. 2) throughout our lives, memories contain cross-modal information that was concurrently encoded. Specifically, auditory, visual, and olfactory memories are interrelated. As olfactory perception exerts a large influence on the subjective evaluation of environments, we posit that when presented with either visual and/or auditory information, smells can be imagined to match this visual/auditory information, which would in turn exert an influence on the subjective evaluation of a particular environment.

SMELL PERCEPTION

Humans have several neurological systems to collect information about the environment (Spence, 2020, pp. 8–9). The olfactory system detects airborne semiochemicals (i.e., odours and scents) in particular in the orthonasal region at the front of the nose; the trigeminal system detects strong irritators (e.g., ammonia or chilli); and the vomeronasal (accessory) system detects chemicals in fluids, including pheromones (Haviland-Jones and Wilson, 2010; Lundström et al., 2011). The number of genes expressing odour detection through the nose constitutes one of the largest gene families in the genome (Buck and Axel, 1991, p. 183), perhaps up to 3% of the total genome which would make it second only to the immune system (Haviland-Jones and Wilson, 2010, p. 236). The human sense of smell compares rather favourably with that of dogs and rats (see McGann, 2017, for a review), and its discriminatory powers might be several magnitudes larger than what was previously believed (Bushdid et al., 2014).

The terminology pertaining to olfactory stimuli is inconsistent in the literature. Terms such as 'odour' and 'smell' sometimes appear to be used interchangeably (e.g., Haviland-Jones and Wilson, 2010; Bruce et al., 2015) and regardless of their valence; however, 'malodour' is specifically negative, while no such negation can be attached to the word 'smell'. Likewise, Belgiorno et al. (2013) define 'odour' as an "organoleptic attribute [property of liquids, air, and other substances, that is] perceptible by the olfactory organ" (p. 15), and elsewhere appear to use 'smell' with the same meaning. Spence (2020) omits 'odour' in favour of 'scent', and in his review of design approaches to the olfactory environment appears to use 'smell' more often negatively, and 'scent' (or 'fragrance') in positively valenced contexts. Discussing olfactory imagery, Young (2020) consistently uses 'smell' when referring to the percept, and words such as 'olfaction' in the context of active sensing of the environment; the latter distinction is also made by Xiao et al. (2018).

Smells communicate. Smells have a strong effect on individuals, and may even induce emotional responses for unattended stimuli in a pre-conscious manner (Haviland-Jones and Wilson, 2010, pp. 237–238). Compared to visual and auditory stimuli, there has been much less of a consensus in quantifying olfactory stimuli for empirical analyses. Naddeo et al. (2013) proposed six parameters for characterising smells: by concentration, perceptibility threshold, intensity, diffusibility or volatility, quality, and hedonic tone. Of interest to the present study are intensity (perceived as strength), quality (or character), and hedonic tone (overall pleasantness or unpleasantness of a smell, and its resultant perceptual 'acceptability'; cf. Dravnieks et al., 1984; Xiao et al., 2018).

The specific quality or character of a smell is often expressed via semantic descriptors, for example 'fruity' or 'medical' (Naddeo et al., 2013, p. 14). As with all sensory channels, olfactory sensation is mediated through individual factors, previous experience, and attention. Language embeds salient experiences and mediates between sensation and cognition, though a distinction needs to be made between different forms of cross-modal correspondences: what Deroy and Spence (2016) labelled statistical, structural, semantic, and hedonic (emotional) mediation mechanisms. If we accept the principle of the Lexical Hypothesis – that socially relevant characteristics of personality are encoded in natural language because this benefits social structures and individual survival (see John and Srivastava, 1999, for a review) – then salient odours in the environments need also to be communicated and understood within a linguistic group or culture for much the same reasons. This approach allowed the development of odour classification schemes, for example McGinley's Odor Descriptors Wheel (McGinley and McGinley, 2002), which was employed in the present study.

People typically describe and categorise smells by perceived source (e.g., fishy, floral) but they also use words that describe the effect a smell has on them (e.g., nauseating, pleasant). Several categorisation studies have observed that people's default mode of perception is ecological; that is, we tend to interpret sensation in terms of causes, as evidence of events and actions in the environment. For auditory perception, ecological conditioning over the lifetime lies behind the default mode of causal (or connotative) listening (Schaeffer, 1966; Chion and Gorbman, 2009; Tuuri and Eerola, 2012; see Lindborg, 2019, for a discussion). In this regard, olfaction appears to work much in the same way as auditory perception (e.g., Bruce et al., 2015; Deroy and Spence, 2016; Xiao et al., 2020) in that both the attributed external source and its subjective affect can be verbalised (Lindborg, 2016). As with causal identification of sound sources, an evaluation of smell sources follows immediately and automatically upon source identification (Waskul and Vannini, 2008; Xiao et al., 2020, p. 11) and probably regardless of whether the identification was correct or not (Herz, 2016). Dravnieks et al. (1984) determined the hedonic score (i.e., pleasantness) of 141 commonly encountered smells from ratings by 429 participants. Note, however, that people often cannot identify or use accurate descriptions to define smells or smell-sources, especially in a de-contextualised condition (Xiao et al., 2020), and that unconscious detection of smells most probably also contributes to the overall perception, though it might depend more on the trigeminal than the olfactory system proper (Jacquot et al., 2004, p. 51).

Congruence between sensory information channels leads to perceptual processing fluency which in turn is associated with positive evaluation (Reber et al., 2004; Spence, 2020, p. 2). It has been suggested that concurrent visual information can increase the ability of smells to arouse emotions, and that visuals without smells might evoke odour-related memories (Ehrlichman and Bastone, 1992). Gottfried and Dolan (2003) revealed neurological evidence for perceptual olfactory facilitation when semantically congruent visual and odour stimuli were presented. Castiello et al. (2006) investigated the cross-modal influence of smells on vision and motor activity. They presented people with a smell and then tasked them to grasp with their hand a virtual visual object. The imagined size of the smelly object influenced the size and shape of the hand as it was moved towards the visual object, showing that odours can cross-modally affect kinematics. Xiao et al. (2020, p. 14) wrote that "smellscapes are representations of individuals' imaginations of places, triggered by smells in a space-time structure". There is evidence that smells can trigger episodic memory recall (Herz, 2016) and that smells congruent with audiovisual displays can generate more positive response behaviour within a context of virtual tourism (Flavián et al., 2021). Might this cross-modal influence from smell to other senses be activated in reverse? Considering a theoretical framework for multi-modal mental imagery, Young (2020) posited that non-olfactory stimuli can trigger smell memories, which are projected as imagined smells.

Considering the above, we investigated if people can make meaningful smell associations when presented with purely audiovisual material. The present article discusses results from two recent studies of the smellscape at a complex multimodal environment, real and imagined. The first is a 'sensory walk' conducted onsite, with participants walking through seven locations while making observations. The observations from the first study functions as a reference or ground truth for the second study, which is a 'virtual sensory walk' conducted online, where the same locations were reproduced with audio and video recordings. Analysis of response data from the real environment provides a baseline against which ratings of the virtual environment were gauged (cf. Annerstedt et al., 2013). The online environments were represented in three conditions: audio-only, video-only, and audiovisual (i.e., movie). We were interested in determining the quality, strength, and hedonic tone of the smellscapes evoked and imagined (Naddeo et al., 2013).

MATERIALS AND METHODS

Sensory Walk

Sensory walk and sensewalk are terms describing an activity whereby people move through a physical environment making observations with a research purpose. A soundwalk focuses on the acoustic environment and a smellwalk focuses on the olfactory environment. All are methods for onsite data collection that allow researchers to systematically investigate how people experience, understand, and utilise spaces (Henshaw et al., 2009, 2010; Bruce et al., 2015; Koseoglu, 2016; McLean, 2017; Xiao et al., 2020). The methodology originates in soundscape studies (Schafer, 1977) and has been broadened out to consider multimodal aspects of environments (Bruce et al., 2015, p. 100; Quercia et al., 2015). Carefully curated smellwalks can take the form of experience design (see Aggleton and Waskett, 1990) or as "walkalong interviews in different contextual spaces" (Xiao et al., 2020, pp. 15–16) that aim to generate an ecologically valid vocabulary for further semantic and cross-modal analysis. Porteous (1985, p. 360) suggested that while a soundscape consists of sound sources evidencing events, a smellscape should be understood as the sum total of numerous smell sources that each may connote cause and effect. While a soundmark is a sound that is intimately linked to a site and carries meaning for its community, a smellmark would correspondingly be a culturally highly important smell.

Tiong Bahru Market

In order to study the perception of smells within a multimodal context, we conducted a sensory walk called "Incomplete City Walks: Coffee Shops and Hawker Centres" (Magiera, 2020) at Tiong Bahru Market in Singapore. Perhaps more than in other countries, open markets (aka 'wet markets') are socially important to Singaporeans because they are spaces for unmediated, non-political interactions (Mele et al., 2015). The history and significance of Tiong Bahru Market in this context was the main reason for choosing the site. Houses and shophouses appeared at the site of current-day Tiong Bahru Market around 1900. A nearby cemetery provided its name: 'tiong' (终) means "to die" in Hokkien (the most prevalent language and culture until the 1980s) and the Malay word 'bahru' means 'new'. By the 1930s roads, drains and culverts had been constructed, and one of the first public housing estates in Singapore was opened at Tiong Bahru in 1936. During this time, the area was also known as Mei Ren Wo, "den of beauties', with musician-entertainers doubling as prostitutes referred to as 'pipa girls'. It was generally considered an unseemly and unhygienic place. The marketplace roof was made up of palm leaves woven together, and the surrounding huts had thatched roofs (National Heritage Board, 2013). Tiong Bahru Market reopened in 2006 after thorough renovations over more than a decade (CPG Consultants, 2005). At present it sports a triangular-shaped architecture in three levels: the ground level has a wet market, shops selling vegetables, flowers, clothing, and hardware, and a green space; the second level has a large food court, a.k.a. a hawker centre; and the rooftop has a Carpark (Bravo, 2021).

Locations

Seven locations at Tiong Bahru Market were identified as having a strong identity in terms of smells and sounds. In the present text, they are labelled (in alphabetical order) Carpark, Flowers and Meat, Food Court, Garbage, Green Core, Stores, and Wetmarket. See photos in **Figure 1** and map in **Figure 2**.

Onsite Sensory Walk

Participants and Procedure

We posted a call on social media to participate in an early morning sensory walk at Tiong Bahru Market, saying *"In this structured sensory walk we explore a public space differently, outside of routines and habits. Moving slowly between locations affects our sense of architecture, spatiality, and time. Standing still and focussing on sound and scent increases our awareness of the physical environment. What do you hear? What do you smell? What do you experience?"*

Fifteen people volunteered. Their mean age was 36 years (SD = 12), in a range between 22 and 53; there were nine females and five males (and 1 'other, or prefer not to say'). As for present occupation, nine self-reported as artists, educators, or researchers, and two were students. They had mixed levels of previous experience with sensory walks or soundwalks: four had 'never tried', five had participated at a similar experience within the past month, and three had done so at an earlier point in time.

The participants gathered at 6.30 am, 3 December 2016, and were informed about the task and signed a consent form. None of the participants was smoking tobacco before or during the sensory walk. The group was divided into three groups of five, each led by the two authors and an assistant. The three groups of five completed the sensory walks among the seven selected locations of the market in a different, pseudo-random

FIGURE 1 | Photos of the seven chosen locations at Tiong Bahru Market.

order. The whole walk took between 70 and 90 min that is, 10–14 min at each location. Moving from one location to the next took a few minutes (especially when walking stairs between levels. Upon reaching a new location, the group leader made sure the five participants stayed relatively close together and within the target area for around 7–8 min. Each participant carried a small support plate (A5 size) with the seven locations on separate pages arranged in the order of visit pre-planned for each of the three subgroups. They marked responses with a pencil while standing; the market did not have any benches to sit down on, except at the Food Court. At each location, the participants spent the first 2–3 min focussing on being still and taking in the environment, then 3–4 min on writing down their impressions, and finally, they were at ease for a few more minutes before the group leader signalled for the group to move on. The participants were admirably concentrated throughout the sensory walk, and a little after 8 am gathered for a debriefing over traditional breakfast.

Annotation Protocol

At each location, the protocol first required an evaluation of the quality of the sonic, visual, and olfactory aspects of the environment. Participants marked a response on a seven-step Likert scale anchored by "Very good" and "Very bad", with "Neutral" in the middle. Secondly, they were required to describe "the most *faint* or *secretive* smell (or sound); the most *loud* or *dominant* smell (or sound); the most *beautiful* or *precious* smell (or sound); and the most *ugly* or *disgusting* smell (or sound)". That is, they were free to annotate sources and events in either of the two modalities, in relation to the four given pairs of adjectives that had been set up as opposites. Third and last, participants were asked to describe, in a few words, their thoughts and feelings while being in the present environment. The above three responses or annotations are the ones of relevance to the present context; other parts of the protocol that related to soundscape will not be further discussed here. A sample page is included in **Supplementary Data Sheet 1**. It should be noted that asking participants to focus on smells (either real or imagined) might mask the full range of odour effects, because verbal explicitation focuses on learned semantic processes (see Haviland-Jones and Wilson, 2010, p. 239 for a discussion). Methods for onsite data collection were approved by the Institutional Review Board of Nanyang Technological University #IRB-2015-10-056.

The raw collected data from the two studies, anonymised, are available in **Supplementary Data Sheet 2, 3**. For convenience, a code script is given in **Supplementary Data Sheet 4** to facilitate retrieval and pre-processing of the data.

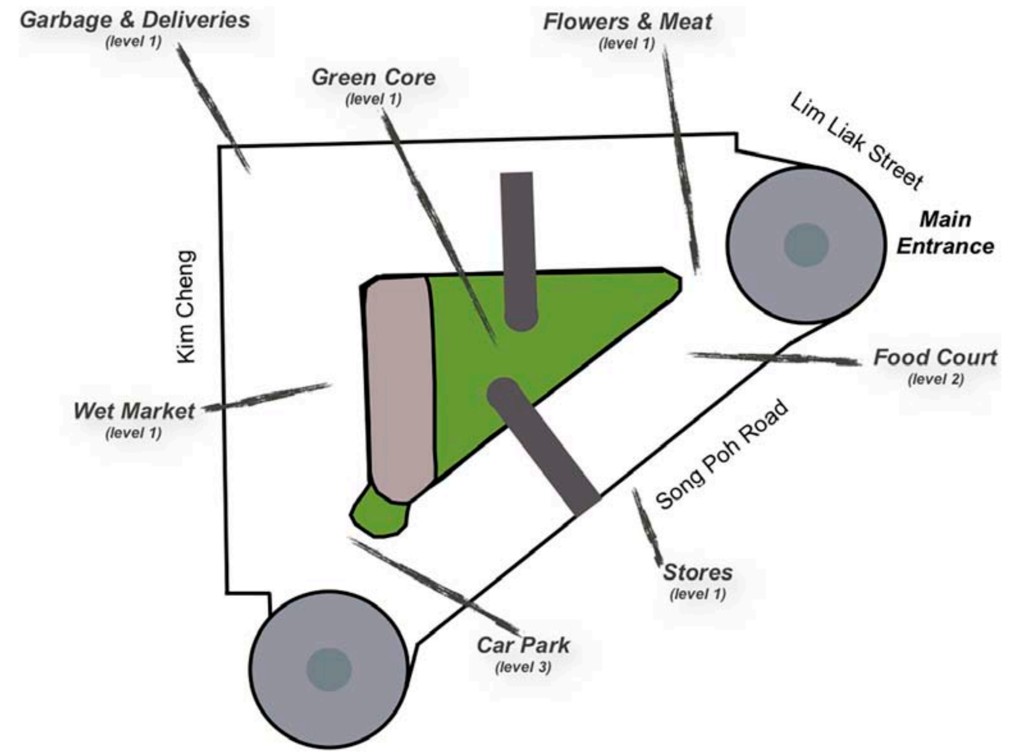

FIGURE 2 | Overview of Tiong Bahru Market marking out the seven locations of the sensory walk.

Online Virtual Smellwalk

Participants

Participants were recruited from Prolific.co and pre-screened for nationality (discussed below), age (minimum 18), and educational level (minimum completed Bachelor degree). Fifty-three valid responses with no duplicates were collected in March and April 2021. Each participant gave their informed consent and received a payment. All reported having no impairment of hearing or vision (wearing glasses/lenses was okay), being in a distraction-free environment during the survey, and using quality headphones (earbuds were discouraged).

Since the environment at Tiong Bahru Market is strongly characteristic of South-East Asia, we chose to recruit participants who may be culturally familiar (see Mele et al., 2014). We first recruited a batch of 25 Singaporean nationals, but upon a stagnation in signup rates, expanded our recruitment criteria to include a second batch of 26 participants from neighbouring Malaysia and Indonesia (that arguably share similar cultural attitudes towards wetmarkets; see Lim, 2004). It should be noted that Prolific.co is a United Kingdom-based company and that it mainly sources its pool of volunteers in Western countries. A minority of the participants were residing in their home country at the time of the survey; all were in countries that are indexed among the first 27 in UN's list of Developed Countries, including Singapore, Malaysia, and Indonesia. For example, 25 participants were based in Great Britain, 8 in Germany, and 6 in Australia. Finally, two Hong Kong residents (not the authors) who had volunteered as beta-testers were included, bringing the total number of participants to 53.

Their median age was 27 years, in a range between 19 and 54; there were 36 females and 17 males. As for present occupation, 19 were employed (e.g., medicine, education, business) and 28 students (similar domains), while the remaining 6 self-reported as homemakers or unemployed. English was the home language for 33 participants, followed by Bahasa for 12 (spoken in Malaysia and Indonesia), while the remaining 8 reported Chinese (the given options included Mandarin, Cantonese, and Hokkien). Probably reflecting behaviours in their current place of residence rather than those of South-East Asia, participants reported infrequently visiting an open-air market (for shopping, eating/drinking, or buying things), with the most common response being "Once a month" followed by "Once a year". As for ethnicity, 18 out of the 25 Singaporeans self-reported as Chinese, while on the other hand only 5 of the 28 other participants considered themselves Chinese (note that the second batch consisted of Malaysian and Indonesian nationals). The median time to complete the survey was 30 min, in a range between 14 and 62. They were paid according to the recommended Prolific hourly rate, which came out to be 6.25 GBP per person.

Materials

Video and sound materials for all stimuli used in the online study were captured at the same time that the onsite study was conducted, that is, in the early morning of 3 December 2016. The first author carried handheld recording equipment which did not detract from the role of (silently) leading the small group of five participants from location to location. Similarly, the Sound Pressure Level (SPL) meter was carried by the second author. In post-production, we edited a representative sequence of each location as a short movie of 90 s duration. Care was taken to create a naturalistic visual representation with an objective point of view, and to keep the sound levels proportional to what had been measured onsite with the SPL meter. We then created 'audio only' and 'video only' sets by replacing the original video with a medium-gray Gaussian blur and the original audio with low-level pink noise. This yielded 21 stimuli, i.e., seven scenes in three modes (referred to as audio, video, and movie). Note the importance of adding low-level yet audible noise to the 'video only' stimuli, since previous research has shown that a realistic visual feature without any sound at all can bias participant perceptions towards fear, and make them expect something dangerous to appear (Annerstedt et al., 2013).

Procedure

A survey was designed using QuestionPro[1]. The 21 stimuli were presented in two parts. First, an individually randomised part containing the seven Audio and the seven Video clips; then, an individually randomised part with the seven Movie clips. In this way the order effect of bimodal stimuli giving unwanted clues to their unimodal versions was avoided. For each stimulus, the participant was requested to go full-screen, start the movie (which could be greyish video with naturalistic audio, or video with low-level noise, or naturalistic audio and video together), and imagine that they themselves were actually in the present environment. The survey constituted an 'onsite virtual sensory walk', which we can compare with the onsite walk (functioning as ground truth). Participants were given three tasks to evaluate the audiovisual environment presented to them.

- The question "Overall, how pleasant is this environment?" was intentionally a broad, multimodal quality evaluation that did not specifically require them to imagine smells. They responded using a seven-step Likert scale anchored by "Very unpleasant" and "Very pleasant", with "Neutral" in the middle.
- The instruction: "In your own words, describe the smells that you imagine", with responses in the form of annotations of free associations, was intended to direct their attention specifically to the smells they might have imagined from audio-visual information.
- The Odor Descriptors Wheel (McGinley and McGinley, 2002) was displayed, in a slightly adapted layout (see **Figure 3**), and the participant was required to "Please click on the smell types that you imagine in this environment". They could mark up to three smells by mouse-clicking (the average number of clicks per stimulus and participant was 2.6).

[1] www.questionpro.com

Note that the first two tasks provided two angles onto the phenomenon of how audiovisuals elicit smell imaginations, which we have suggested can explain the results in the statistical analysis further below. Note that no olfactory stimuli were presented to the participants, who only imagined the smells.

After completing all 21 stimuli participants self-reported demographic information (the group profile is reviewed in the "Participants" section above). Online data collection procedures were approved by the Ethics Committee of City University of Hong Kong, #13-2020-08-E.

RESULTS FROM ONSITE AND ONLINE STUDIES

Onsite: Real Smells

The results from the onsite study functions as a 'ground truth' against which the results from the online study can be interpreted. Therefore it is firstly of importance to explain how the onsite participants ($N = 15$) described their experience at the seven locations. The general experience of the environment was annotated by the onsite participants in free-form verbal descriptions. The locations had clearly different characteristics and we will discuss their olfactory aspects by citing representative annotations verbatim.

- Carpark: this location was described in mostly visual terms, e.g., "View – sense of open space, aerial, above".
- Flowers and Meat: this is a mixed-market area that evoked spatial and olfactory annotations, e.g., "meat – stronger smell", "The smell is totally different in flower to meat area", and "Flowers do not smell as strong as I usually experience @Flower hawkers" highlighting an activity-related expectation.
- Food court: this is a typical Singaporean-style 'hawker stalls' area serving various kinds of local food. It engaged all sensory modalities, though as one participant wrote: "here, smells of foods cooking dominate other senses. Must be ready for breakfast!", while another highlighted the continuous, open-air character of Tiong Bahru Market: "Olfactory, continuous with car park [on Level 3], but not L1 market".
- Garbage: as discussed in the section about environmental quality ratings, it was generally considered unpleasant. However, the smells were not necessarily as strong or bad as some appear to have expected: "It was quite monotonous in the sense that I didn't feel much for that place [Garbage] despite attempting to discover its sounds and smells". Meanwhile, another person tried to "focus specifically to LISTEN [and this] makes it a more pleasant experience, and I didn't notice the smell at all as I normally (probably) would". Lastly, one person remarked that it was "interesting how smells move from place to place, as does sound", highlighting the characteristic spatial pervasiveness and temporal continuity of smell – these characteristics are stronger for smell than for sound, and clearly more so than for light.

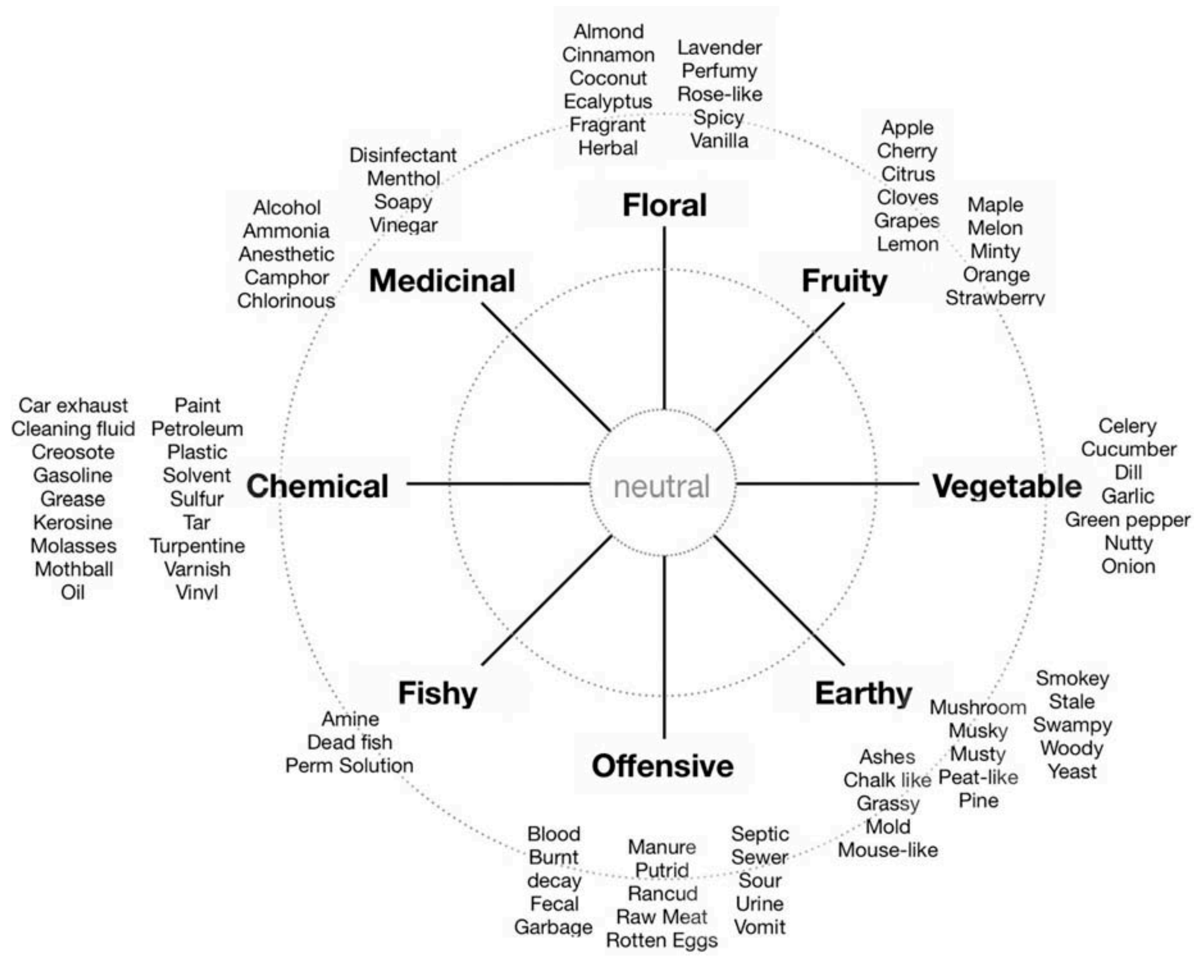

FIGURE 3 | The 'smellwheel' used in the present study (adapted from McGinley and McGinley, 2002).

- Green Core: the small park is at the connecting centre between other locations. Smells and sounds reach it from all directions and cause blurred sensations. One participant characterised it as "...a hot pot of noise. Everything can be heard but cannot be heard clearly at any one time. Nothing makes sense", and the same may have been the case for smells, e.g., "Smell – dense; Busy; Sound – interesting". For at least one participant, their expectation of a 'park smell' was not met: "Wish i could smell the wet grass over the raw meat", perhaps indicating that the smell of raw meat was still dominating even though the row of butchers was some 20 m away.
- Stores: this location is a row of small shops along a street. Here, participants mostly noted sonic elements, such as the background music played in the small shops. One participant reacted strongly to the "SMELL of incense shop at [the] end of [the] row [which] gave me an immediate headache and this created a strong negative association with what had been super-pleasant. The changing music of the stalls, as I walked along, was calming and gave joy".
- Wetmarket: this is an area selling fish and seafood. Annotations revealed marked expectations about the odours, but also that "fish variety of colour doesn't correspond to smell", perhaps indicating that smells tended to blend together. One person annotated a specific 'precious' source (see below) as "Delicate smell of dried scallops, cuttlefish", but to most of the participants in this study the Wetmarket smells were simply generically 'fishy' and did not distinguish themselves. An intriguing observation about social communication habits was that "People seem to talk more with their fishmongers than [with their] butchers". Previous research has noted that the observed activities lead people to expect and imagine particular sounds and smells in certain areas (e.g., Bruce et al., 2015, p. 8).

Environmental Quality

The onsite participants (N = 15) rated the perceived olfactory quality of the environment, as well as the visual and sonic aspects of the environment. Multivariate analysis of variance (MANOVA) revealed that quality ratings (i.e., olfactory, visual, and sonic) differed between the seven selected areas of the open market [Pillai's trace (6 df) = 0.677, F(18,222) = 3.60, p = 0.000003]. This significant result allowed us to follow up with a two-way within-participants ANOVA, taking Quality as the dependent variable and Location and Modality as the independent variables. Each of the independent variables was strongly related to the dependent variable [Location: $F(6) = 8.56$, $p = 0.00000002$; Modality: $F(2) = 10.1$, $p = 0.00006$]. *Post hoc* analysis with Tukey's Honest Significant Difference test showed that Olfactory ratings at the Garbage location were much lower than those at the six other locations, corresponding to as much as two or three steps on the seven-step Likert scale. With the Garbage location removed from the data (keeping the remaining six locations), Olfactory quality ratings were still significantly lower than Sonic and Visual quality ratings, as indicated by Mann–Whitney's rank-based test on paired ratings ($p = 0.031$ for Olfactory vs. Sonic; $p = 0.0006$ for Olfactory vs. Visual). The differences, respectively, corresponded to 0.53 and 0.86 steps on the rating scales, with medium effect sizes (Cohen's $d = 0.33$ and 0.55 SD). The difference in quality between Sonic and Visual aspects of the environment was not significant ($p = 0.88$) across seven locations, though when Garbage was removed, Visual quality was marginally higher than Sonic across the six other locations (0.03 scale steps, $p = 0.041$) with a small effect size ($d = 0.21$) (see **Table 1**, Col. 1–3, and **Figure 4**).

It is not immediately obvious why the olfactory environment received lower quality ratings than both the visual and the sonic aspects. Note that the participants at the onsite sensory walk had been tasked to 'seek out' the smells, and this might have predisposed them to be more critical to smells. However, it is also conceivable that the bias did not originate in the participants' minds but that it reflects something true about the environment at Tiong Bahru Market. For example, the market might simply not be successful in taking care of and promoting the grand variety of its smellscape in a positive way; rather, it is left hanging, as it were. The major renovation (CPG Consultants, 2005), and habits of the vendors, might have paid less than adequate attention to the design of the olfactory environment, which therefore lags behind the quality of visual or sonic aspects of the market. For example, a current website promoting the market (Bravo, 2021) does not highlight its smellscape. Previous research noted that the odours of fish are generally expected and accepted as part of the experience of a wetmarket, regardless of what someone might otherwise think of the smell of raw fish (Bruce et al., 2015, p. 7). In fact, for Tiong Bahru Market, the smell of raw fish is a smellmark (Porteous, 1985). A suitable presentation in marketing material might prepare visitors (e.g., tourists) and thereby enhance the experiences of Tiong Bahru market as a whole, benefitting the larger economy (Henshaw et al., 2016). Attention to the smellscape as part of the intangible heritage has a potential to benefit 'virtual tourism', as shown by Flavián et al. (2021).

Smell Sources

The onsite participants annotated smell sources at each of the seven locations and indicated whether they considered them to be *precious* (or beautiful), *secretive* (or faint), *disgusting* (or ugly), or *dominant* (or loud). We chose the four adjectives because they can be paired two by two, to define bipolar, orthogonal dimensions labelled precious – disgusting and secretive – dominant. Thus, in this analysis, precious smells oppose disgusting smells, and secretive smells oppose dominant smells. The approach allowed arranging smell sources in a circumplex, one for each location, as shown in **Figure 5**. Note that the circumplex spanned by the four adjectives is a simple yet adequate approximation to the more complex smellwheel (**Figure 3**), where the left-right and low-high directions are intrinsically congruent with the dimensions in a standard Valence-Arousal circumplex. That is, high valence corresponds to *more precious*; low valence to *more disgusting*; high arousal to *more dominant*; and low arousal to *more secretive*. However, be aware that the smellwheel does not directly yield information about the valence of individual smells, and can only indirectly be used to indicate the arousal potential (e.g., intensity) of sources by considering the distance between the 'neutral' centre to a distinct smell type (more about this below). In **Figure 5** the seven locations have been placed according to the main types in the smellwheel (compare also with photos in **Figure 1**). This graphical

TABLE 1 | Mean ratings of environmental quality and hedonic tone in the two studies.

	Onsite, environmental quality			Online, environmental quality			Onsite, hedonic	Online, hedonic tone		
	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10
	Sonic	Visual	Olfactory	Audio	Video	Movie	Olfactory	Audio	Video	Movie
Carpark	0.88	1.54	−0.31	0.00	0.26	0.09	−0.52	−0.73	−0.08	−0.69
Flowers and Meat	1.14	2.00	1.42	0.00	0.08	−0.45	0.80	−0.43	−0.03	1.81
Food Court	1.12	1.21	1.05	0.28	0.30	0.83	−0.03	0.35	0.16	1.08
Garbage	1.21	−0.83	−1.54	−1.08	−2.23	−1.75	−2.48	−2.43	−4.87	−5.10
Green Core	1.21	1.23	1.27	−0.09	0.42	0.26	0.30	−0.01	0.72	0.36
Stores	1.27	1.19	0.12	−0.11	0.49	0.34	0.00	−0.81	−0.81	−0.50
Wetmarket	1.71	2.11	0.71	0.04	−0.43	−1.30	−1.44	−0.29	−0.41	−3.03

In Col. 1–3 (onsite) and Col. 4–6 (online), values are means of ratings on seven-point Likert scales (numerically limited between −3 and 3), averaged across 15 participants in the onsite data, and 53 participants in the online data. Values in Col. 7 (onsite, hedonic value, olfactory) were obtained by matching all the onsite annotations of smells in free-form verbal descriptions with smell descriptors and corresponding hedonic scores in from previously published research (Dravnieks et al., 1984). Scores were summed for each location and averaged across the 15 participants. Values in Col. 8–10 were obtained by the same method, from free-form annotations in the online data. They were summed for each location and modality (audio, video, movie), and averaged across the 53 participants in the online study.

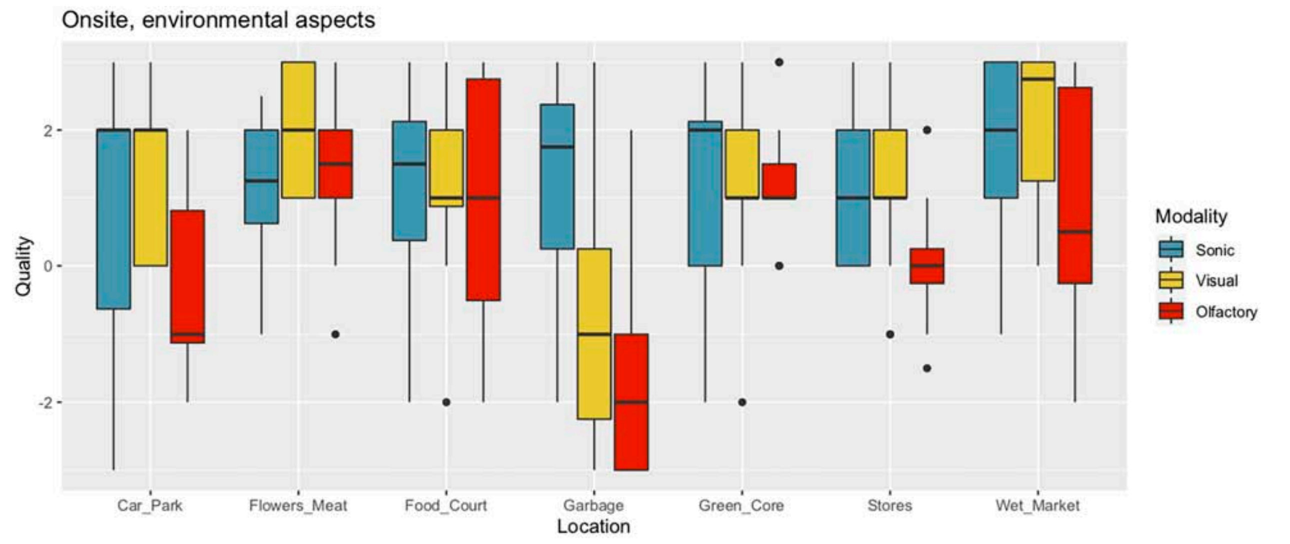

FIGURE 4 | Boxplots of onsite ratings (*N* = 15) of three aspects of environmental quality for seven locations. Quality was rated on a seven-step Likert scale; see the text for details.

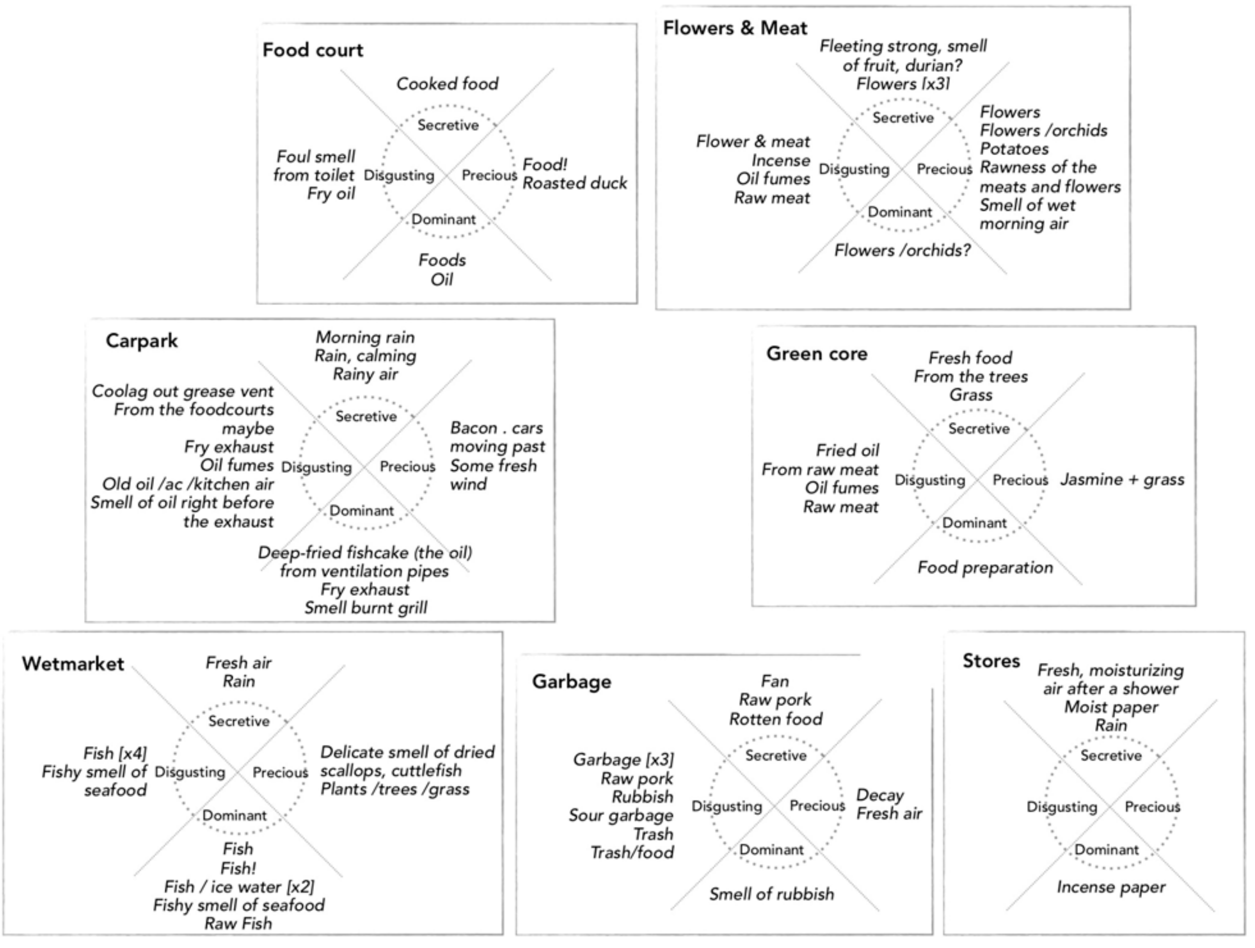

FIGURE 5 | Onsite smell source annotations (*N* = 15) for seven locations; see the text for details.

arrangement supports our interpretation of the locations' general environmental characteristics, and facilitates a comparison with the online responses.

Hedonic Tone

The smell source annotations (in terms of precious – disgusting and secretive – dominant) allow us to infer which locations were more liked or more exciting. To estimate the hedonic tone (pleasantness) for each location, we matched the annotated smells against the list by Dravnieks et al. (1984), which contains 141 commonly encountered smells with hedonic tone rated on a nine-step Likert scale by 429 participants. The listed scores range from −3.75 for "Cadaverous (dead animal)" to 3.53 for "Bakery (fresh bread)". Nearly all of our participants' descriptions could be matched with items in the list. Notable unmatched annotations related to the smells of humidity after rain, fresh air, and wind, all of which likely to have been positively valenced for the onsite participants. It might be debatable to what extent 'fresh air' has a smell of its own, but one should take note of the fact that such usage of semantic labels by laymen is systematic (see also the corresponding analysis of the online data). In the present calculation of hedonic score, these annotations had to be omitted. Summing up within each location yielded the values listed in **Table 1**, Col. 7.

Online: Imagined Smells

Environmental Quality

In the online study, participants (N = 53) rated the imagined environmental quality in terms of pleasantness for each of the 21 stimuli, that is, seven locations and three modalities (audio, video, and movie; see Procedures section). We conducted a two-way within-participants ANOVA with Quality as the dependent variable, and Location and Modality as independent variables. It revealed a strongly significant relation between Quality and Location [$F(6) = 61.3$, $p < 2e\text{-}16$], but not with Modality [$F(2) = 1.632$, $p = 0.20$]. The fact that there were no systematic differences in environmental ratings between presentation modalities (i.e., conditions) suggests that participants were on the whole equally able to judge environmental quality from audio-only and video-only stimuli as they were with movie-stimuli. However, further analysis revealed a strongly significant interaction between Location and Modality [$F(12) = 7.56$, $p < 2e\text{-}13$], which led us to conduct a series of *post hoc* analyses with Tukey's Honest Significant Difference test. Similarly to the onsite study, it was found that the Garbage location was lower rated than all the six others, corresponding to between 1.1 and 2.2 steps on the seven-step Likert scale, with a large-sized effect of 1.37 SD (Hedges' g with correction for different group sizes). Furthermore, the Wetmarket was lower rated than the five remaining locations, corresponding to between 0.44 and 1.1 scale steps, with a medium-sized effect of 0.62 SD (Hedges' g, corrected). Lastly, the Food Court was rated 0.6 scale steps higher than Flowers and Meat, with a medium effect of 0.53 SD (Cohen's d) (see **Table 1**, Col. 4–6, and **Figure 6**). The largely corresponding results between the two studies in terms of perceived environmental quality will be probed further below.

Smell Sources

The smellwheel response interface has 'neutral' at the centre and eight main types of smell evenly distributed in cardinal directions: Vegetable, Fruity, Floral, Medicinal, Chemical, Fishy, Offensive, Earthy. Each of the eight types is exemplified with several subtypes (see **Figure 3**). Participants could mark with a mouse click up to three smells that they imagined in the present environment (audio-only, video-only, or movie). They were asked to "click at the centre (inner circle) if they imagined the smellscape as neutral, and further out (outer circle) if they imagined that smells would be strong".

Participants marked on average 2.6 smells per stimulus; there were 2907 clicks in all. They tended to be placed close to the eight spokes of the smellwheel or at the centre. Within the inner 'neutral' circle, there were 13.9% of the clicks; between inner and mid circles, 54.8% of clicks; between mid and outer circles, 21.8%, and outside the outer circle, 9.5%. The analysis proceeded by interpreting smellwheel responses in terms of smell type (discrete, eight kinds) and smell strength (continuous). In the present analysis, the click's distance from the centre is taken as a proxy for the strength (perceived intensity) of the identified type of smell, its numerical value relative to the radius of the outer circle. For example, a smell strength value of 0.5 means that the participant clicked half-way between the centre and the outer circle. We observed a correlation between the order of clicks and their distance from the centre. The mean distance for the first clicks that participants made was 0.514, for the second 0.505, and for the third 0.468. Analytic tests comparing the distributions of clicks, i.e., 1st versus 2nd and 2nd versus 3rd, were significant in both cases ($p < 0.0001$, Mann–Whitney's rank-based test on paired samples), however the effect sizes were small (0.08 and 0.15 SD, respectively). This order effect can be explained by assuming that the smell that participants imagined to be strongest was also the first one that they clicked on, and for ensuing smells the imagination was less certain, or weaker. Moreover, the number of clicks could also be a useful measure for smell source strength, as shown by the fact that distance from centre and click count (within locations, modalities, and smell types) were highly correlated (distance correlation dcor = 0.59, $p < 0.0002$ for 5,000 bootstrap replications).

Type

Figure 7 illustrates graphically (in the style of Belgiorno et al., 2013, p. 15) the relative intensities of McGinley's eight smell types in the seven locations and three modalities. From inspection, it is clear that one or two smell types were imagined to be dominant at each of the locations, and the three modalities were largely congruent. At the Carpark, the dominant types were Chemical and Earthy; at Flowers and Meat and the Food Court, Vegetable smells dominated; at Garbage, the Offensive smells were dominant; at the Green Core mini-park, Earthy smell types were prevalent; at the Stores, Earthy and Chemical types; and finally at the Wetmarket, the Fishy smells were dominant. This is very similar to the smells detected by the onsite study participants, see **Figure 5**. Note also that the differences between modalities in the online virtual smellwalk were not striking. In the Audio-only condition, the types were more evenly

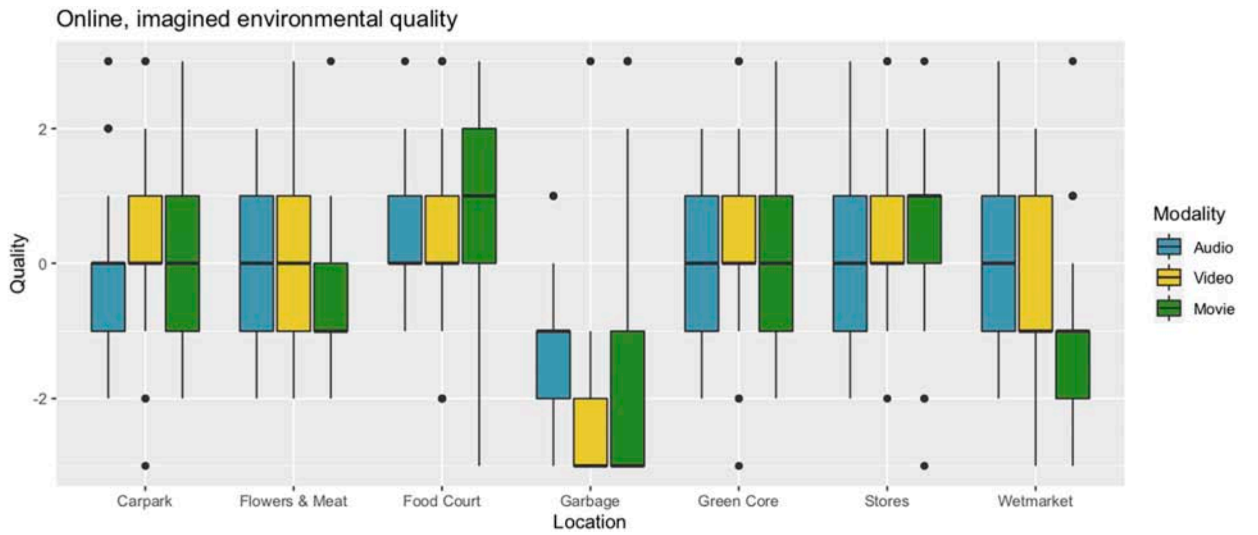

FIGURE 6 | Boxplots of ratings (N = 53) of environmental quality in seven locations, as imagined when presented in three different audiovisual conditions. Quality was rated on a seven-step Likert scale; see the text for details.

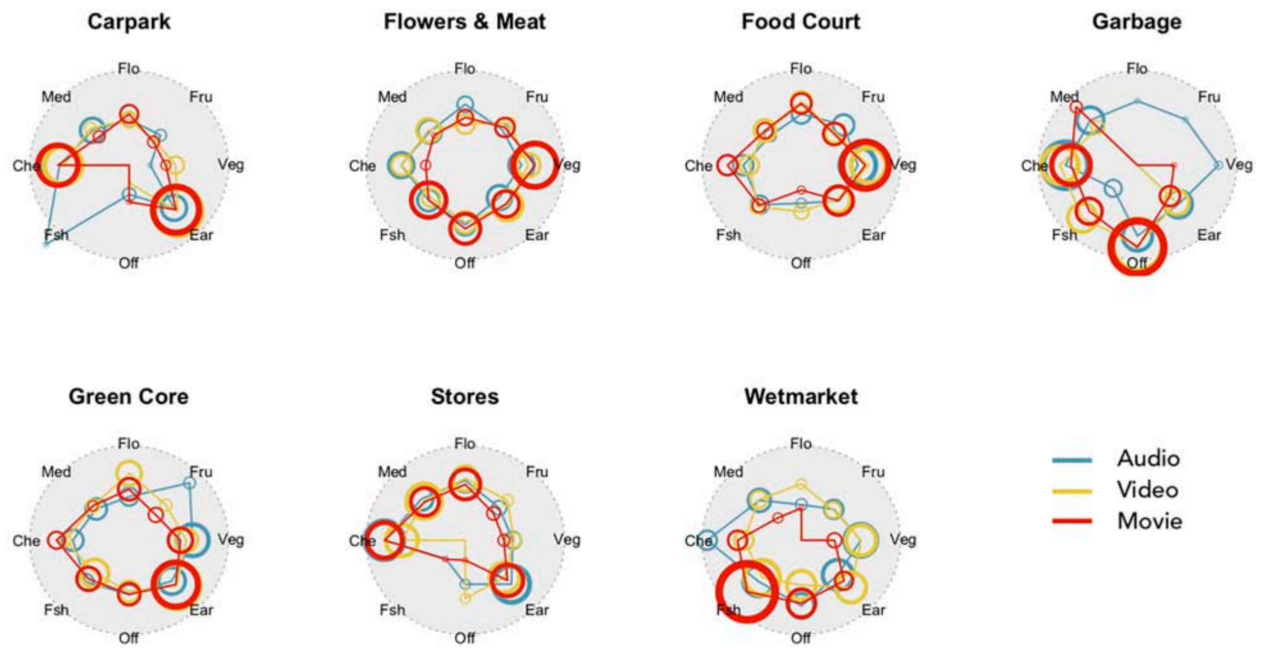

FIGURE 7 | Graphical illustration of smell types (qualities) and intensities in seven locations and in three modalities. Smell types are abbreviated for clarity: Veg, vegetable; Fru, fruity; Flo, floral; Med, medicinal; Che, chemical; Fsh, fishy; Off, offensive; Ear, earthy. Colours refer to modalities, i.e., stimuli conditions. For each smell type and modality, the coloured ring is centred on the mean distance of clicks, and its thickness and size are proportional to the number of clicks made.

distributed, but even at the Garbage location, the participants imagined largely the same kind of smell types as they did when video was present.

Strength

Unsurprisingly, analysis of variance revealed significant differences of imagined smell strength between locations and modalities. This is illustrated in **Figure 8**. For locations, Tukey's Honest Significance test showed that smell strength was higher at the Garbage location than at any of the other six. The difference was on average 0.17 (range 0.12…0.21; recall that strength takes a value from 0 to about 1), with an overall medium-sized effect of 0.54 SD (Hedges' g with correction for different group sizes). It was also significantly higher at the Wetmarket than at Flowers and Meat or Food Court; the difference was about 0.08 for both, with an overall effect size of 0.27 SD. For

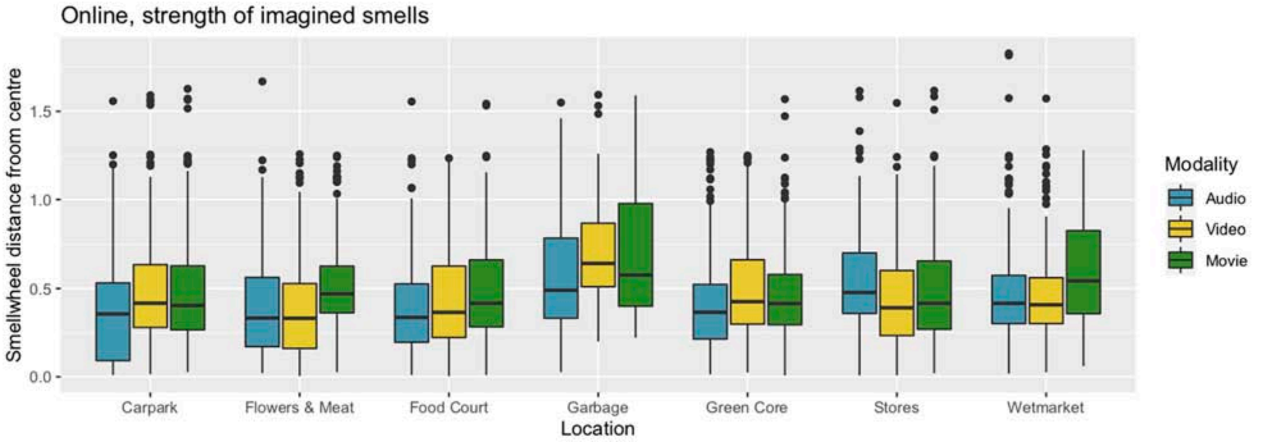

FIGURE 8 | Imagined smell intensity (proxied by mouse-click distance from smellwheel centre; see the text for details) in seven locations and three audiovisual modalities.

modalities, the same test showed that imagined smell strength was higher in the Movie condition than in the two unimodal conditions. The difference between Movie and Audio was 0.08 (Cohen's d = 0.27 SD), and between Movie and Video it was 0.05 (d = 0.17 SD).

Hedonic Tone

The onsite participants were asked to imagine the smells in the represented environment (audio, video, or movie), and describe them using their own words. There were 1113 free-form responses (7 × 3 × 53), each consisting of four words on average. They were pre-processed by removing non-letter symbols (e.g., question marks, citations, parentheses, trailing spaces), transcribing to lowercase, and merging grammatical variations, e.g., singular and plural. There were a total of 2561 individual words, out of which 344 were unique. The 33 most common were: food (6.0%), fish (4.0%), meat (3.9%), grass, neutral (2.5%), raw (2.0%), rain (1.9%), chemical, car (1.8%), exhaust, fresh, vegetables, air (1.6%), earthy, garbage (1.4%), clothes (1.2%), incense, market, musty, smoke, wet (1.1%), damp (1.0%), sweat, cooked, oil, dust, restaurant, humid, trash, humidity, new, rubbish, blood (0.7%). The frequency counts for each of the three modalities (audio, video, and movie) are listed in **Table 2**.

A cumulative score for hedonic tone for each location and modality was calculated from the descriptive words, in a similar way as for the onsite free-form annotations. We matched the 344 unique words from our participants with Dravnieks' list (Dravnieks et al., 1984). For 27% of the unique words a perfect match was available; for 22% a close match was found (e.g., iron → Metallic); for 30% an acceptable match was made by considering the word in the context of its sentence [e.g., car → Gasoline, solvent, or food → Seasoning (for meat)]. For 20% of the words no match could be made (e.g., air, clothes, house). This process yielded a hedonic score for each participant's free-form annotations of smell sources. Scores were accumulated across participants to give an estimate for the hedonic tone of each of the seven locations and three modalities. The distributions are illustrated in **Figure 9**.

Analysis of variance (ANOVA) revealed that there were differences between the locations. *Post hoc* analysis with Tukey's Honest Significant Difference test showed that the Garbage location was lower rated lower than all the six others, corresponding to between 2.9 and 4.7 units (Dravnieks' scale values, accumulated within each participant's free-form response), with a large-sized overall effect of 1.47 SD (Hedges' g with correction for different group sizes). Furthermore, when Garbage was removed from the data, the Wetmarket location was lower rated than the five remaining, corresponding to between 0.54 and 1.8 units, with a medium-sized overall effect of 0.50 SD (Hedges' g, corrected). Tukey's test also revealed that Carpark had lower hedonic tone than Food Court and Flowers and Meat, and that Stores was lower than Flowers and Meat, Food Court, and Green Core, though these differences will not be discussed further. Note that there were no systematic differences in hedonic tone between the three conditions of stimulus presentation.

As was already noted in the analysis of onsite data, some online responses that were frequent (and therefore probably important) could not be satisfactorily matched to Dravnieks' list. For example, the matchings with food-related or rain-related descriptions were only acceptable, and no matching could be made for the relatively frequent descriptions involving [fresh] air or [new] clothes. Furthermore, only 69 of the 141 items were used at all; more than half were not relevant to the present study. This suggests that the overlap is not large between the smells (both real and imagined) perceived at a South-East Asian outdoor market and the smells in Dravnieks' study from almost 40 years ago in Illinois, United States. Future research might pursue a cross-cultural approach to smellscape perception and the categorisation of smell sources.

Comparison and Summary of Results

Finally we analyse the results from the two studies together and compare them in terms of environmental quality, hedonic tone,

TABLE 2 | Most common descriptors for annotations of imagined smells (*N* = 53) at seven locations in three modes of presentation.

	Audio	Video	Movie
Carpark	Neutral (9.4%), car (4.7%), chemical, rain, Air conditioning (3.5%), factory (3.5%)	Grass (14.0%), rain (13.0%), air (8.1%), exhaust (5.9%), car (5.2%), fresh, wet (3.7%), petrol (3.0%), after (2.2%), concrete, dust, open (2.2%)	Grass (15.0%), exhaust (9.8%), car (9.1%), rain, air (4.2%), earthy (3.5%), petrol, after (2.8%), dust (2.1%), fresh, pollution, smoke (2.1%)
Flowers and Meat	Food (11.0%), neutral, fish (4.5%), cooking (3.4%), meat (3.4%)	Food (9.4%), neutral (8.3%), coffee (3.1%), cooked, dust, people, sweat (3.1%)	Meat (19.0%), vegetables (18.0%), raw (10.0%), fish (7.4%), grass (3.7%), market, blood (2.9%), fresh, fruit, earthy (2.2%), food, wetmarket (2.2%)
Food Court	Food (20.0%), restaurant (6.9%), cooked (5.2%), neutral, tea (3.4%), air (2.6%), people (2.6%)	Food (18.0%), crowd (5.4%), restaurant, neutral (4.5%), cooked (3.6%), people (2.7%), sweat (2.7%)	Food (31.0%), cooked (4.6%), oil, garlic (3.8%), oily, cooking (3.1%), hawker (2.3%)
Garbage	Chemical (7.7%), water (4.6%), metal (3.8%), metallic, factory (3.1%), wood, carwash (2.3%), dirty, garbage, machinery, oil, smell, soap, trash (2.3%)	Garbage (13.0%), rubbish (7.1%), trash, rotten (6.2%), pungent (4.4%), putrid, bad (2.7%), chemical, rancid, sour (2.7%)	Garbage (12.0%), trash (6.8%), food (5.3%), putrid (4.5%), rotten, rubbish (3.8%), pungent (3.0%), sewer, fish (2.3%), offensive, rancid, rotting, sour, wet (2.3%)
Green Core	Meat (9.9%), food (9.0%), neutral (6.3%), raw (4.5%), restaurant (3.6%), smoke (2.7%)	Grass (21.0%), fresh (8.7%), meat (7.1%), fish (6.3%), earthy (4.0%), wet, air (2.4%), market, rain, raw, vegetables (2.4%)	Grass (19.0%), meat (9.5%), earthy (6.3%), raw, fish (4.8%), fresh, air (4.0%), food (3.2%), damp (2.4%), greenery, humid, market, wet (2.4%)
Stores	Car (7.9%), exhaust (7.1%), incense, smoke, fumes (3.6%), traffic, medicinal (2.1%), medicine, neutral, street, sweat (2.1%)	Clothes (11.0%), incense (6.9%), new, musty (5.5%), rain, chemical (4.8%), fabric, dust (2.8%), medicinal, air (2.1%), clothing, earthy, floral, humid (2.1%)	Clothes (11.0%), incense (8.1%), new (6.1%), chemical (5.4%), car (4.7%), musty, exhaust (4.1%), fabric (3.4%), floral, plastic (2.7%), Chinese (2.0%), medicinal, shop, smoke (2.0%)
Wetmarket	Meat (12.0%), food (7.9%), fish (4.0%), market, raw, sweat (3.2%), vegetables, blood (2.4%), fruit, hawker, neutral, people (2.4%)	Meat (14.0%), fish (10.0%), food (9.3%), market (5.1%), raw, sweat (4.2%), vegetables, butcher (2.5%), cooked, dust, wetmarket (2.5%)	Fish (45.0%), raw (5.8%), meat (4.9%), damp (2.9%), dead, humid, market (2.9%)

The listed descriptors are those that occurred three times or more in each of the 21 stimuli.

and smell sources. The onsite study represents the 'ground truth', in the sense that the olfactory environment was physically present to the participants even if they might not have been fully able to identify or label the smell sources. In the online study no smell variations existed physically, so all differences in annotations and ratings of smells were imaginary, and evoked by the audiovisual stimuli. Hence, it is of interest to compare results from the two, for those variables that are comparable. In what follows, we report results using Canonical Correlation Analysis (CCA) to compare ratings of environmental quality, and estimates of hedonic tone of the smellscape as constituted by smell sources, respectively. For these multivariate measures results from the two studies are available in numeric form (see **Table 1**). CCA is a dimensionality reduction technique that takes two datasets – matrices with an arbitrary number of columns (variables) – and finds the projection that accounts for the most of the covariance between the two (Thompson, 2000; for an application, see e.g., Eerola and Vuoskoski, 2011). Lastly, we make a summary qualitative comparison based on free-form annotations.

Environmental Quality

A comparison between **Figures 4** and **6** suggests that an association exists between the two studies, in terms of ratings of environmental quality. We ask the Reader to bear in mind that the sonic, visual, and olfactory aspects of the real, multimodal environment and rated during the sensory walk, do not directly correspond to the audio, video, and movie representation modalities that were presented online as a 'virtual sensory walk'. Moreover, in the online situation, participants were asked to make an overall evaluation of how pleasant the environment was imagined to be; they were not specifically required to imagine the olfactory environment. This, as we shall demonstrate, becomes important for how to interpret the results.

First, we use CCA to measure the overall association between the means of onsite overall quality ratings in three environmental aspects and the means of online pleasantness ratings in three presentation modalities (Col. 1–3 vs. Col. 4–6 in **Table 1**). The observed correlation between the first canonical variates from the two matrices is 0.99912. A p-value can be simulated by creating a distribution of correlations between two random matrices of the same sizes (both 7×3), over 50,000 repetitions. Using this bootstrap method, the simulated p-value is 0.107; this means that a spurious correlation as high as the one observed occurs 10.7% of the time. Thereby the data do not support inferring that the two situations are comparable in terms of the ratings for environmental quality. However, we can exclude the onsite olfactory ratings and calculate the measure of association between onsite sonic and visual aspects with the three audiovisual online conditions (Col. 1–2 vs. Col. 4–6 in **Table 1**). The first canonical correlation component is then 0.99869. The bootstrap distribution in this case is created on random matrices of different sizes (2×7 and 3×7), producing

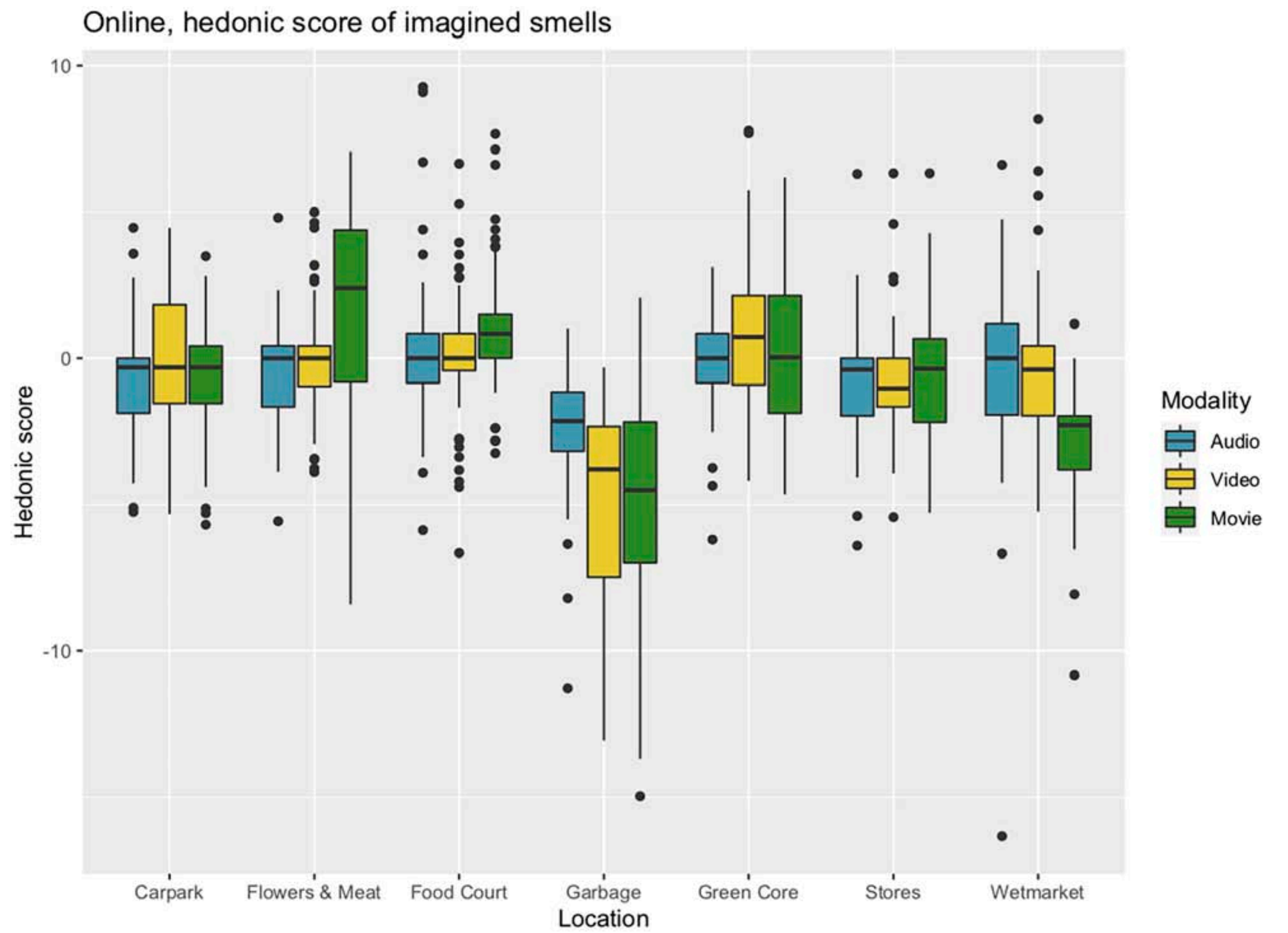

FIGURE 9 | Boxplots of cumulative hedonic scores for seven locations and three modalities, estimated from free-form descriptions of imagined smells by raters (N = 53) matched against previous data (Dravnieks et al., 1984).

a simulated p-value of 0.0074. This is highly significant, and means that a spurious correlation as high as the one observed occurs only 0.7% of the time. Moreover, similarly testing the association between onsite olfactory aspects on its own with the three audiovisual online conditions (Col. 3 vs. Col. 4–6 in **Table 1**), yields a canonical correlation of 0.82494. The bootstrap distribution created on random matrices (1 × 7 and 3 × 7) yields a p-value of 0.28, which is clearly non-significant. These results show that while information about the quality of the sonic and visual environment is transferable from an onsite, real situation to an online, virtual situation, this is not the case for olfactory information. In our study, the online task did not specifically require participants to imagine the smellscape, and the onsite information about the olfactory environment was not spontaneously evoked and reconstituted through the audiovisual information alone.

Hedonic Tone

We run the same analysis between means of onsite hedonic scores and means of online hedonic scores in three presentation modalities (Col. 7 vs. Col. 8–10 in **Table 1**). Note that this comparison does not involve data from McGinley's smell wheel, used in the online study, but only the free-form annotations which had been gathered in exactly the same way in both studies, onsite and online. The scores for hedonic tone were estimated via Dravniek's list (Dravnieks et al., 1984). The observed first canonical correlation is 0.98486. The bootstrap distribution in this case is created on random matrices (1 × 7 and 3 × 7), producing a simulated p-value of 0.0086. This is highly significant, and means that a spurious correlation as high as the one observed occurs only 0.86% of the time. In terms of hedonic tone, an association between the two studies is supported by data. Nevertheless, the critical Reader will want to take into account that the estimates for both sets of data were based on Dravnieks' study, which may or may not be ideal for the smells in the present situation.

Smell Sources

For smell source types and strengths, we interpret the onsite and online results with a qualitative approach without attempting to make strong conclusions. The real, onsite smell sources were distilled from free-form verbal annotations of source categories

(**Figure 5**), while the imagined, online smell sources were those most frequently indicated by the smellwheel responses (**Table 2**).

- Carpark: Across onsite and online situations, descriptions typically refer to grass, cars, car exhaust, and rain. Note the mention of air conditioning in the audio-only condition (noticeable in the recording), through which wafts of smells from the food court on the level below came through.
- Flowers and Meat: The onsite descriptions highlight the mix of smells from flowers, vegetables, and raw meat. Meanwhile, online descriptions do not pick up on the flowers, and emphasise food-related smells, also in the audio-only condition.
- Food Court: In both situations descriptions of food smells abound. Onsite participants also identified foul smells that were not imagined by online participants. In the latter case, mentions of people were fairly common in audio and video conditions.
- Garbage: Here, descriptions onsite and in online video and movie conditions were dominated by words such as trash, pungent, and rotten foods. In the online audio-only condition, the more common words were about chemicals, water, metal, and machinery, and participants appear to have imagined a factory or carwash rather than a garbage handling area.
- Green Core: Onsite descriptions mix food smells and grass, which were also highlighted in the online descriptions in video and movie conditions. The presence of smells from grass, trees, and soil was not imagined in the audio-only condition.
- Stores: The smell of incense paper is annotated as dominant onsite. This was echoed in the online descriptions in all three conditions, which also imagine smells from car [exhaust]. The audio condition did not evoke the smell of clothes, which are clearly visible in the video (and movie) and are the most frequently described.
- Wetmarket: The smell of fish is clearly dominant onsite, and it is imagined in all three online conditions, although the audio-only condition evoked more general terms such as meat and food more frequently than the specific fish association.

In summary, smell source descriptions were in fairly high agreement between onsite and each of the three online conditions for the Carpark, Food Court, Stores, and Wetmarket locations. Notably, the audio-only condition in the online study failed to evoke significant smell imaginations for the Green Core and Stores locations, and most pertinently, the Garbage location did not contain sounds that triggered smell associations in this direction.

DISCUSSION

The olfactory system (in the brain) is closely connected to the limbic system, involving neural regions like the hippocampus, amygdala, and thalamus (Hedblom et al., 2019). Consequently, olfactory perception is also closely tied to emotional and stress processing, and smell-related autobiographical memories with associated emotional encodings are also retrieved with stronger activation of the amygdala, beyond non-emotional memories or emotional memories associated with other modalities (Gottfried et al., 2004; Herz, 2016). Consistently, perceived smells that are not actively attended to are also able to evoke emotional responses in individuals (Haviland-Jones and Wilson, 2010, p. 237). Smells can be incorporated into individuals' schema for places (Tse et al., 2007; Henshaw et al., 2009), with strong connotations with affective and emotional associations. However, despite these emotional linkages, certain behavioural fight-or-flight decisions are often not concluded solely based on olfactory perception. Instead, smells appear to trigger a search for contextual meaning, or confirmation of the odour source, through other (visual or auditory) modalities (particularly for fear-related odours; Haviland-Jones and Wilson, 2010, p. 242), possibly in a bid to match or form new associations from long-term memory. If so, this suggests that cross-modal information is important to olfactory perception. This forms an angle to interpret our current results: we would expect to see systematic differences when people are asked to imagine smells when exposed to either sound- or visuals-only stimuli, or audiovisual (i.e., movie stimuli). Indeed, the highly significant association in terms of hedonic tone (pleasantness) between the online and onsite situations in our data suggests that when online participants were specifically required to imagine smells from audiovisual information, they were successful. They could approximate the types of onsite smell sources and their 'actual' perceived hedonic tone. Imagined smells may thus be a mechanism towards the emotional evaluation of audiovisual environments. By contrast, the analytical results in this study show that ratings of the quality of the olfactory environment (immediately available to onsite participants) did not translate to ratings of environmental quality from audiovisual information only (with no olfactory stimuli present) at least when online participants were not required to imagine smells from audiovisual information.

We may consider the difference between perception and cognition more broadly, and how it might apply in the case of the present study. What does it mean to say that someone has the smell of a fish 'in the nose', or that she has a mental representation of fish smells 'in the brain'? Zach et al. (2018) conducted a study on olfactory, auditory, and visual volitional memory recall of French Fries among a group of mainly teenagers. They found that on-demand olfactory recall was at least to some extent possible for a majority of their subjects (73.2%, 71.0%, and 77.4% in their three groups, respectively). Levels were similar to those for auditory recall but much lower than those for visual recall. However, Zach also states that olfactory recall was harder to do for their subjects, perhaps because smells might take longer time to evoke by volition than sounds or sights. On the other hand, Young (2020) points out that imagination is a broader concept than memory recall: "olfactory imagery seems limited when only considered as the capacity to voluntarily self-generate an experience of olfactory quality in the absence of sensory stimulation. However, a more liberal conception including any experience of olfactory quality in the absence of sensory stimulation widely expands the instances of olfactory imagery by including dream states, hallucinations, autobiographical odour memories, and olfactory memories" (Young, 2020, pp. 3305–3306). In the subjective, free-form annotations in our present work, the evidence of type and strength of olfactory recall – imagining smell on demand and in the absence of stimulation by actual odours – is always going to be reported with different levels of vividness, both because olfactory imagination can be expected to vary greatly across the population, but also because of individual factors unrelated to olfaction (e.g., language abilities, attentiveness). Future research might attempt to validate self-evoked smell percepts through behavioural, physiological, and other external measurements. This reiterates the difficulty of spontaneously imagining smells to match audiovisual environments, since individuals often have to draw on their own familiar (culturally rooted) experiences to do so (Bruce et al., 2015). Referring to fear-odours, (Haviland-Jones and Wilson, 2010, p. 242) noted that "sensing an odour without having a visual or auditory match leads to a slow, cautious search for a match rather than the rapid fear-flight response". This led the authors to propose that "there must be an ongoing, not-quite-conscious match-mismatch system that is correlating bits of information across the sensory systems. It is actively searching for existing associations and making new associations" (Haviland-Jones and Wilson, 2010, p. 245). If such a mechanism exists, we would expect to see systematic differences when people are asked to imagine smells when exposed to either sound- or visuals-only stimuli, or audiovisual (i.e., movie stimuli).

To a certain extent, the significant relationship identified between onsite and online participants in hedonic tone could be facilitated by a shared cultural background (similar schema towards the market). However, in real-world settings, one cannot always control the cultural backgrounds of viewers to a particular video. Given that olfactory perception has a stronger impact on stress reduction and other health-related paradigms (Annerstedt et al., 2013; Hedblom et al., 2019), this may lead to a cultural imbalance in the subjective evaluation of environments (such as through movies or online videos) that present only audio-visual information. Individuals may form incomplete or biased judgements about a location or environment of another (unfamiliar) culture, if presented solely with audiovisual information (e.g., a trailer to an exotic travel destination). This may in turn have implications on tourism strategies in general for a city or country (Henshaw et al., 2016; Spence, 2020, p. 8). The recent study by Flavián et al. (2021) provides evidence that congruent smell presentation as part of a multimodal VR display acts to increase positive behavioural responses in the context of 'virtual tourism'. We refer the interested Reader to their article which also contains an excellent review of recent development in olfactory-extended virtual reality (Flavián et al., 2021).

This issue of schema, memory and association in imagining smells is evident in the discrepancy of descriptions between locations in the study. For example, some locations, such as the Carpark, that were less subject to cross cultural specificity, appeared to have more qualitative consistency between onsite descriptions and online imaginations. By contrast, the onsite descriptions of the Wetmarket frequently featured fish-related smells, as opposed to the imagined meat-related smells that were prevalent in imagined online descriptions. One explanation for this discrepancy could be in the direction of attention. The auditory/visual stimuli forces the viewer to follow a top-down specified path of attention for smell-imaginations, which can be influenced by one's upbringing and culture (Masuda et al., 2020). On the other hand, given the source-confirmation drive often associated with olfactory perception, onsite participants could have first relied on olfactory perception as a preliminary input, before searching for the source through audiovisual confirmation in a bottom-up approach.

LIMITATIONS AND FUTURE WORK

The current findings are limited in that no olfactory stimuli were presented during the online study. The article by Flavián et al. (2021) is exemplary in its design of an experiment with olfactory conditions when a small number of distinct smells are tested. It is inspiring for our further work on the relationship between real smellscapes ('in the nose') and imagined smellscapes ('in the head'), which will be needed in order to test the findings we have reported here. A further limitation is the substantial time gap between conducting the onsite study at Tiong Bahru market, and the online study. We had hoped to carry out a confirmatory second onsite study, in the form of a sensory walk, but unfortunately the COVID-19 restrictions during the summer of 2021 made it impossible. Outlets at the market were closed or working at minimal capacity; e.g., no customers were allowed to sit at food court tables, and no gatherings of people were allowed anywhere. Waiting for restrictions in Singapore to be lifted would delay publication of the present text. Instead, we are turning our energies towards a follow-up project in Hong Kong (where the first author is currently based). It will include a survey of several wet markets, with collection of audio-visual recordings and olfactory measurements together with observations made during sensory walks. An interesting option for an onsite study might be to partially inhibit multisensorial perception, for example by blindfolding some participants, having others wear hearing muffs, and others again with nose clips. Experiments in the laboratory will include a suitable way of replicating the relevant smells of wet markets, for example by presenting olfactory stimuli corresponding to the main parts of the smellwheel (McGinley and McGinley, 2002) by using odour compounds in ceramic vessels or on perfume sticks.

Future work will also pay close attention to different kinds of memory. For example, when asked to imagine smells on demand, the memory one recalls might be semantic ("knowing"; common knowledge shared by others) rather than episodic ("remembering"; a person's autobiographical olfactory experiences). For example, when asked the question "In your own words, describe the smells that you imagine", a participant who has never been to a wet market might still be able to write down words like "fishy", "seafood", and so forth, simply using knowledge they learned in school. In our present online study we enrolled participants from Singapore and neighbouring countries in South-East Asia, allowing the assumption of them having personal experience with Asian-style open air markets. However, it is a limitation of our data elicitation method that it did not make a clear distinction between episodic and semantic memories. In future online studies, it might be of interest to include a 'no external stimulus' condition where participants are required, for example, to recall the last time they were in the specified environment and to describe the smells they imagine based on their lived experience.

CONCLUSION

Analysing perceptions of the built environments, Jean-Paul Thibaud wrote that "urban ambiances are created and experienced as a product of different, sometimes unique, blends of sights, sounds, smells, textures, tastes and thermal conditions" (Thibaud, 1995, p. 204). Smell represents an important dimension of our understanding and design of the everyday environment. In particular, the olfactory environment offers benefits for well-being and restoration both in architecture (Spence, 2020, pp. 6–7) and in the context of calm, green, natural places (Hedblom et al., 2019). To be of optimal usefulness for urban design, research on smellscape perception should consider the olfactory environment in relation to individual factors (Lindborg and Friberg, 2016; Xiao et al., 2018). The urban smellscape indeed forms part of our intangible heritage (Lenzi et al., 2021). It is valuable as culture, and at the same time, it also represents a marketing opportunity (Henshaw et al., 2016), especially for urban servicescapes that contain a multitude of sensorial information (Bruce et al., 2015, p. 6; Lindborg, 2015).

Recent interdisciplinary initiatives show the way towards a 'World Smellscape Project' based on the model of soundscape research (Schafer, 1977). Smellscape measurements and descriptions made by 'nose-witnesses' (Porteous, 1985, p. 360) constitute an archive of experiential descriptions of various smells around the globe. Notably, the Odeuropa project[2], which is involved in intangible cultural heritage and everyday culture, aligns with our present work. Meanwhile, D-Noses[3] focuses on odour pollution control, and GoodCityLife[4] works at improving the urban living environment through parallel smart-city mapping projects. The citizen science approach also doubles up as a resource for the historical archival of locations and places as they develop over time. Through this paper, we present a humble contribution to this larger discourse through a documentation of the smellscape of an area of significance in Singapore's history, while examining cross-modal linkages between olfactory perception and audio-visual perception.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

[2]https://odeuropa.eu/
[3]https://dnoses.eu/
[4]https://goodcitylife.org/

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board of Nanyang Technological University #IRB-2015-10-056, and Ethics Committee of City University of Hong Kong #13-2020-08-E. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PL conceived the study and conducted the analysis. KL and PL collected the onsite response data and PL collected the online data. Both authors collaborated on writing and reviewing all parts of the manuscript. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.718172/full#supplementary-material

Supplementary Data Sheet 1 | Sample page of the protocol used in the onsite sensory walk.

Supplementary Data Sheet 2 | Collected raw data from Study 1, onsite (CSV).

Supplementary Data Sheet 3 | Collected raw data from Study 2, online (CSV).

Supplementary Data Sheet 4 | Code example (R script) for retrieving and pre-processing of the raw data.

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From Smelly Buildings to the Scented Past: An Overview of Olfactory Heritage

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Olfactory heritage is an aspect of cultural heritage concerning the smells that are meaningful to a community due to their connections with significant places, practices, objects or traditions. Knowledge in this field is produced at the intersection of history, heritage science, chemistry, archaeology, anthropology, art history, sensory science, olfactory museology, sensory geography and other domains. Drawing on perspectives from system dynamics, an approach which focuses on how parts of a system and their relationships result in the collective behaviours of the system, we will outline a series of practices relevant to this field and identify the elements, materials and competences involved, as well as the connections and interactions. While research in olfactory heritage is currently growing, much of the knowledge that could advance our understanding of this field is still being developed within disciplinary boundaries, leading to little integration of the knowledge and methods and limited interdisciplinary interpretation of findings. In the first part, we review the methodologies for identifying, researching and preserving olfactory heritage, highlighting methodological opportunities and challenges from diverse perspectives like smellscape research, odour nuisance management or heritage science. In the second part, we review the presentation and communication of olfactory heritage in museums and other heritage spaces, outlining the value of presenting scents to wide audiences for interpretation and engagement purposes. Finally, we discuss challenges associated with historical scent reconstruction, and discuss future directions for the field, such as the potential of mining large digital collections for olfactory data.

Keywords: smell, heritage, olfactory, VOC, sensory, intangible, authenticity, system

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INTRODUCTION

Can we experience a building with our nose? What's the olfactory equivalent of a painting? Traditionally, these questions would not have made much sense, since our engagement with cultural heritage has relied heavily on visual experiences. A number of recent works, however, explore how olfactory aspects play an important role in the way we understand cultural heritage and therefore make sense of our past and present.

In this article, we will profile the study of the olfactory dimension of heritage, an emerging field of research concerning the smells that are meaningful to a community due to connections with significant places, practices, objects or traditions (Bembibre, 2021). Knowledge in this field is produced at the intersection of history, heritage science, chemistry, archaeology, anthropology, art history, sensory science, olfactory museology, sensory geography and other domains. It relates to tangible, intangible and natural heritage; and it is of interest to a variety of stakeholders, including policy-makers.

Drawing on perspectives from system dynamics, an approach which focuses on how parts of a system and their relationships result in the collective behaviours of the system, we will outline a series of practices relevant to this field and identify the elements, materials and competences involved, as well as the connections, disconnections and interactions. The holistic understanding fostered by the systems theory is especially beneficial to mapping the new and complex landscape of olfactory heritage because it provides a new way of studying phenomena that cross disciplinary boundaries (Forrester, 2007).

SYSTEM DYNAMICS AND OLFACTORY HERITAGE

A systems approach has been applied to study various aspects of cultural heritage, including decision-making concerning historic buildings (Claude et al., 2019) and heritage values and conservation (Fouseki et al., 2020). The study of smells as part of cultural heritage can be related to the "sensory turn" in the humanities in the 1980s and 1990s, which involves "a cultural approach to the study of the senses and a sensory approach to the study of culture" (Howes, 2013). In recent years, scholarly work has contributed to our understanding of the role that odours and our perception of them play in experiencing the world. Olfactory heritage assumes the value of smells as expressions of heritage associated with information, meaning and emotion. Here we focus on (a) the identification and research of the olfactory dimension of historic narratives, material artefacts, practices and geographical places, and (b) the presentation and communication of scents in galleries, libraries, archives and museums (GLAMs). We identify the components of the olfactory heritage system, such as a "material" dimension with resources, artefacts and technologies; associated competencies (skills, know-how and techniques); relevant environments and time; as well as links between these elements (**Figure 1**). The smells in this system can be textual or visual references, digital or anchored in material documents, as a mix of odorous volatile organic compounds (VOCs) emitted from an historic object, space or a result of a practice. Additionally, they can also be fragrant solutions intended to be smelled, a diverse category that encompasses perfume, historical scent reconstruction, and pieces of olfactory art, among others.

While valuable reflections on olfactory heritage are taking place, much of the knowledge that could advance our understanding of this field is still developed within disciplinary boundaries. For example, the smell of old books and historic libraries, a scent identified as of heritage value (Bembibre and Strlič, 2017), has proved of interest to chemistry and heritage science (Strlič et al., 2009; Cincinelli et al., 2016), architecture and conservation, psychology and sensory science (Spence, 2020a), literature and cultural studies (Groes and Francis, 2021), sensory geography (McLean, 2017), public engagement (Wiggan, 2020) and olfactory art (Inoue, 2017). In spite of this varied interest, there is little integration of the knowledge and methods involved in these pieces of research, and limited interdisciplinary interpretation of findings.

Therefore, one of the aims of our approach is to identify those domains of interest for this field and ways in which bridges can be built to deepen the understanding of and develop shared methodologies and practices around olfactory heritage.

IDENTIFYING AND RESEARCHING OLFACTORY HERITAGE

A traditional approach to the protection of cultural heritage considers smells to be sensory qualities of the environment, including significant places, and as such worthy of conservation (ICOMOS, 1988). In this sense, the smells of heritage places can be considered part of their identity. By sniffing we develop a relationship with the environment, engaging in an embodied experience of heritage, evoking memories (Simonnot and Siret, 2014) and leading to shared experiences and a sense of cohesion (Gorman, 2017). Scents also provide a sense of wellbeing and dignity to local communities and tourists, as argued by the selection of 100 "fragrant places" of Japan by popular vote, including parks, bookshops and sake breweries (Ministry for the Environment, 2001).

It has been proposed that smells can also undergo a process of patrimonialisation, becoming part of cultural heritage by being officially presented as identity traits of a place, as it happened with the scent of flowers, woods and livestock representing the Swiss Alpine landscape in an international exhibition (Fraigneau, 2021). Olfactory heritage, and the history and meanings it represents, can also be named by legal means, as in the French "sensory law" protecting the smells of the rural landscape (2021), which goes beyond the fragrant to include malodours (Guy, 2021).

In order to understand the role of smells in people's perceptions and interpretations of a space, the concept of smellscape, consisting of a distinct set of odours in an environment (Porteous, 1985), is essential. In the last decade, researchers in urban studies and sensory geography (Balez, Bouchard, Fraigneau, Henshaw, McLean, Xiao, among others), have enhanced our knowledge of smellscapes and developed novel methodologies that account for the temporality and subjective nature of odours, recording associations with place, identity and individual experiences and memories. The resulting data, for example odour descriptors collected during smellwalks, is rich and original, and of interest to sensory and heritage science. One of the challenges is, however, to compare descriptions of smellscape obtained via sensory ethnography methods with those collected through odour nuisance analysis (Suffet and Rosenfeld, 2007) or with instrumentally-generated data (e.g., using gas chromatography-olfactometry), as the vocabularies are not standardised. This is why dedicated concepts such as the Porteus (1990, p. 26) smellmark, an olfactory type of landmark, can be extremely helpful. In this line, a smellmark in Istanbul would be the fragrant spice market, recently recorded by Davis and Thys-Şenocak (2017).

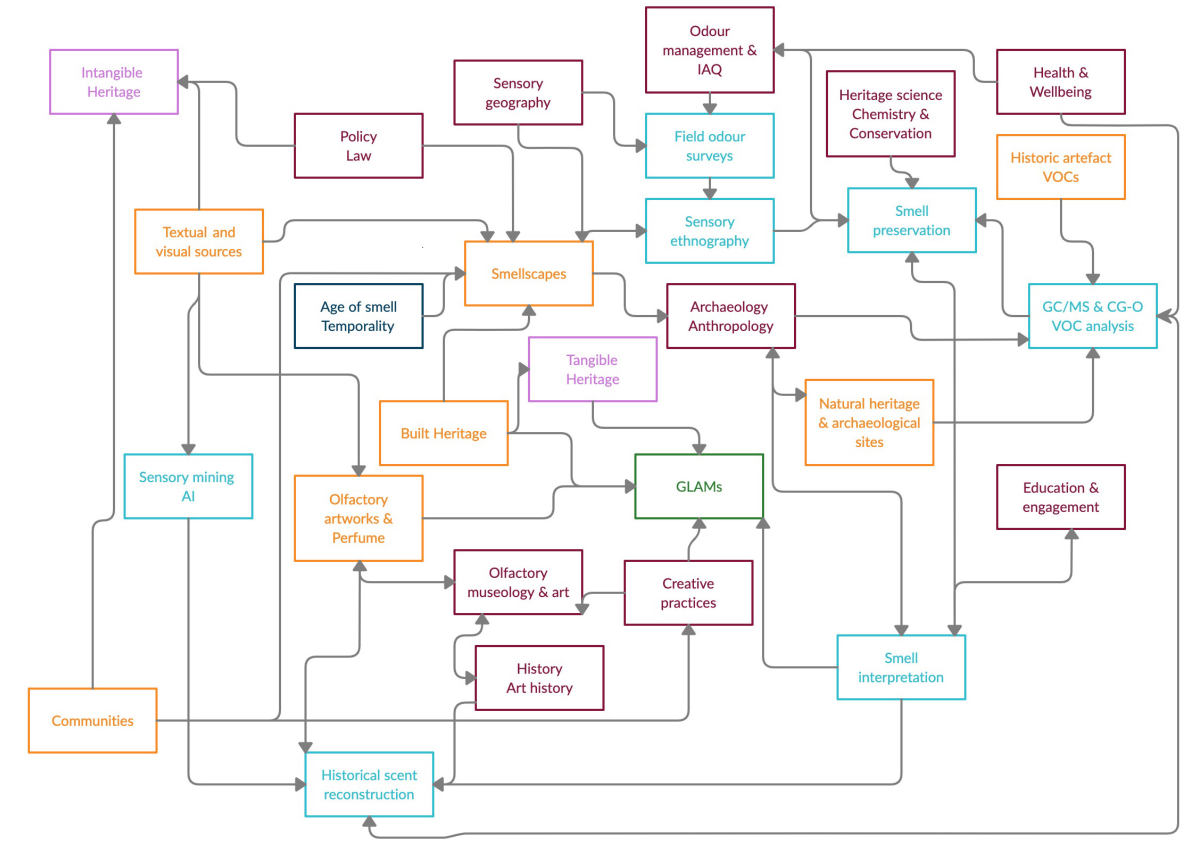

FIGURE 1 | Representation of olfactory heritage as a system, encompassing competences, materials and meanings. The colours indicate dimensions, as follows: maroon: disciplines and knowledge domains; blue: competences and skills; orange: materials, resources and technologies; navy: time; green: environment: purple: heritage approaches. Arrows represent communication and relationship lines.

While the smells of historic buildings are considered part of their significance, other scents of value can be understood from the perspective of intangible cultural heritage (ICH), which concerns "practices, representations, expressions, knowledge, skills" (UNESCO, 2020). In this context, the scents of Grasse, France, are recognised for their connection with the cultivation of perfume plants, the knowledge and processing of natural raw materials and perfume composition (UNESCO, 2018). Grasse's inscription was developed with local museums, recording scents' role in transmitting local knowledge and skills, the involvement of the relevant communities and the need for urgent safeguarding. Learning from the Grasse experience with ICH could prevent meaningful scents from being lost; yet, odours still sit uncomfortably within categories of tangible and intangible heritage, as Boswell (2008) has noted. This is a larger and necessary discussion for those interested in safeguarding olfactory heritage.

Our knowledge of smellscapes and scents of cultural value is informed by research on the sensory worlds of the past. Entering historic sources with an "olfactory gaze," a term coined by Verbeek C. L. (2020) building on the work of scholars such as David Howes and Constance Classen, is key to understand aspects of olfactory heritage. Examples of the value of this approach are new interpretations of (a) archaeological findings, like the preference for accessibility in spite of experiencing malodours in the design of Roman toilets (Koloski-Ostrow, 2015; p. 39), (b) the symbolism of odours in Egyptian culture, where the smell of fish signified stench but could also imply the danger of an unfamiliar place (Goldsmith, 2019), and (c) the historic role of fragrance, such as the a ritual cleaning of women, in the communities of Zanzibar (Boswell, 2008). In the process of revealing alternative historic narratives, these works often provide us with new perspectives to explore and study olfactory heritage.

Textual and visual sources can offer, as we have shown, valuable clues to capturing and interpreting the smells of the past. Sometimes, these clues are supported by material evidence, such as historic artefacts. Heritage science work on the smell emitted by historic objects has traditionally focussed on potential damage of volatile organic compounds (VOCs), the chemicals responsible for most odours, to collections and visitors. Recent research shows, however, that the presence of certain VOCs in a museum, in concentrations detectable by the human nose, does not pose a threat to collections and can provide valuable information on material change (Strlič et al., 2009; Curran et al., 2018). Laboratory analysis of the smells is also of interest to archaeologists, who can use the data, along textual sources, to inform their interpretations of historic objects and as the basis for smell recreations (Verbeek, 2016, 2019; Newstead and Casimiro, 2020).

A stinking artefact can also be a provocation: after smelling a collar reeking of its owner Rex, a decorated rescue dog, conservators at the Imperial War Museum considered eliminating the stench, but agreed that the olfactory dimension of the object "was authentic" and "emitted Rex's aura" (Hetherington, 2020). Historic materials smell as they degrade – as the above example shows, there is a tension between the interpretive potential of a "smelly" object and conservation concerns about material condition, VOC impact and risk. Also at play might be the association of all environmental smells with poor air quality, a notion influenced by the historic miasma theory, which identified odours as carriers of diseases. Although discredited by the end of the 19th century, these beliefs maintained a place into popular culture for many decades (Hsu, 2016).

Once the smells of historic objects are identified as valuable, preserving them enables safeguarding their significance. A first step aimed to build bridges between textual sources, analytical and sensory characterisation, resulting in data which can be co-interpreted by different heritage professionals was recently proposed (Bembibre and Strlič, 2017). Further studies could combine this preservation framework with ethnographic methods involving relevant stakeholders, with the aim of revealing and recording the significance of the characterised smells. Identifying narratives related to odours is also essential to building our understanding of their cultural and historic significance, since smells can be "an important medium for understanding the affective capacities of air" Hsu (2016).

PRESENTING AND COMMUNICATING OLFACTORY HERITAGE

Many museums, which are traditionally vision-centred spaces, are reluctant to introduce an olfactory art element, exhibiting "anosmic cube" mentality (Drobnick, 2005). Other examples of built heritage face similar challenges: projects to conserve the smell of historic buildings are met with resistance around presenting culturally significant historic scents, such as stale cigarette smoke, in the original space (Otero-Pailos, 2008) and a reproduction of a fragrant, historically relevant component (pot-pourri) is kept cordoned off in an exhibition in a historic house preventing the audience from smelling it (Bembibre Jacobo et al., 2017). In these spaces, smells are viewed with suspicion because they disrupt the climate control and sensory calm to interact with and invade artefacts and visitors' bodies in uncontrollable ways, even if, as discussed earlier, concentrations are low and pose no obvious health risks. In this respect, Hsu (2020) notes that one aspect of olfactory art is to allude – and challenge – the idea of toxicity and acceptable risk.

In spite of the tensions between conservation and interpretation of historic scents and the visual tradition of the heritage sector, there is a growing number of institutions which work or would like to work with smell [for some examples of exhibitions see Spence (2020b) and Deramond and Pianezza (2020)].

In museums, smells can be a new strategy to respond to visitors' expectations of immersive experiences that appeal to the audience emotions and senses. Young audiences, in particular, are influenced by ambiance and aesthetics, including temperature, lighting, music and scent (Hyun et al., 2018). In a series of interviews with olfactory museum exhibition designers and visitors, Deramond and Pianezza (2020) noted that the aims of these experiences were to connect artworks, smells and the public, enabling visitors to feel deep attachment to pieces of art and evoke autobiographical memories. As a result, audiences are encouraged to share their experiences of the visit, so smells, and the associated emotions, become a tool to develop and strengthen social bonds.

Odours are also important in heritage interpretation: visitors appreciate the scent of a historic library, imbuing it with symbolic meaning –"inhaling wisdom" – (Bembibre and Strlič, 2017); archives and historic house audiences value the sensory qualities of the documents they access, including the smell (Dillon et al., 2013).

Furthermore, scents are also used to provide alternative ways to engage with collections. In her work at the Rijksmuseum, art historian Verbeek guided an experience of the large painting *The Battle of Waterloo* by Jan Willem Pieneman (1984)[1]. To relate the size of the canvas to her blind audience, she slowly walked its length with audible footsteps. Later, visitors smelled an interpretation of the odour of the battle developed with IFF perfumer, Birgit Sijbrands. A person noted that "the scents really contributed to the stories surrounding the objects, not the artefacts themselves. Being 100% blind I do not feel any connection to – for example – paintings. The scents really made me empathise with people from different eras though" (Verbeek C., 2020).

Presenting and communicating smells with historic and cultural value to wide audiences is a challenge due to the lack of standardised approaches or best practices. Historic perfumes are either reconstructed from the original formula, if such exists (and thousands do, in archives such as the Osmothèque) or, if the formula were inaccessible, recreated from references in texts or images, or from data obtained by analysing historical odour sources such artefacts or materials. In these cases, a growing, and, in many instances, exploratory, practice is being developed at the intersection of academia and industry, which has resulted in many past smells being recreated for the contemporary nose (see Verbeek, 2016, 2019; Barwich and Rodriguez, 2020; Bembibre, 2021; Littman et al., 2021). Discussions around the authenticity of such recreations evidence the tensions between traditional study of history and historic artefacts and approaches which, in a similar way to battle re-enactions, foster affective and sensory experiences, making a distant heritage seem "real and tangible" (Mullins, 2013). Currently, these considerations, along with those around authorship and audience manipulation, tend to take place in the realm of curatorship (Drobnick, 2017). These issues

[1] https://www.rijksmuseum.nl/en/collection/SK-A-1115

could also be usefully explored in relation to the development of smell (re)creations and the public experiencing them. Additionally, the related issue of presenting original historic objects for smelling, or purposedly scented proxies, in a museum context, is one that requires similar investigation.

Fruitful connections could be made by encouraging GLAMs and archaeological sites to document the experiences of visitors in relation to olfactory exhibits, since most of the available data for the use of ambient scent on people's responses to art has been obtained in laboratory studies and may not be directly generalisable to the museum floor (Spence, 2020a). Furthermore, new methods for the development of olfactory narratives would facilitate a "nose-first" approach and new interpretations of existing collections and spaces. In addition, the development, jointly with conservation organisations and industry bodies, of best practices to present and communicate smells, such as indoor air quality (IAQ) standards, smell diffusion methods and public liability disclaimers, would encourage reluctant institutions to engage in sensory work and get a clear understanding of the risks and benefits involved.

Finally, the valuable role of art and creative practices in the development and communication of olfactory heritage is worth noting. For example, the pioneering work of olfactory artists such as Sissel Tolaas and Peter de Cupere, who interrogate the way we experience and discuss scent today; the "Booksniffers Club," a series of workshops funded by Arts Council England where participants smell books in their own collections and share the memories they evoke, leading to conversations about history, culture and identity (Wiggan, 2020) or the "Kitchen Cabinet" sessions by Dutch cultural centre Mediamatic, providing olfactory experiences in which participants learn how the contents of their spice drawers hold meaningful connections to the history of art (Mediamatic, 2021) and the series of lectures and interactive sessions educating about global olfactory practices carried out by the Los Angeles-based The Institute for Art and Olfaction (2020).

FUTURE DIRECTIONS

Access to digital collections of historic texts and images using artificial intelligence techniques has recently enabled the discovery of olfactory references within large data sets, i.e., sensory mining. Tracing historic references to odours in collections, and working with sensory historians to identify and build up the narratives that relate them to the present, is one of the goals of the interdisciplinary project Odeuropa, which focuses on capturing olfactory heritage across multiple European regions and languages from the 17th to the 20th century and then present them in museums (Odeuropa, 2021). In this project, historians, anthropologists and scientists work together, a collaborative mode that could lead to further methodological development and new approaches to co-interpretation. Polish-Slovene project Odotheka also explores semlls in heritage, developing an archive of historic smells from the collections of the National Museum of Krakow, and the National Museum of Slovenia (Odotheka, 2021).

In this article, we've identified some additional directions for future work, which could develop further connections and interactions between elements in the olfactory heritage system, evolving and linking practices. With regards to smell preservation, the integration of analytical work with ethnographic approaches, anchored in written and visual sources when available, would strengthen the process of studying smells in buildings and artefacts, while encouraging discussions around complex historical and social narratives. In order to effectively work with smell in GLAMs for interpretive, accessibility or educational purposes, collecting real world data would validate laboratory studies and deepen understanding. Widening the debate to all stakeholders in this system would enable wider engagement with the ethical dimension of the work. Finally, working with industry and heritage bodies would be beneficial to the development of best practice and safety guidelines around communicating olfactory heritage.

AUTHOR CONTRIBUTIONS

The authors conceived the present review as a reflection of historic discussions between them based on their work in the field. Both authors discussed the literature, contributed to the final manuscript, and approved it for publication.

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Development and Study of Ezzence: A Modular Scent Wearable to Improve Wellbeing in Home Sleep Environments

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Ezzence is the first smartphone-controlled olfactometer designed for both day and night conditions. We discuss the design and technical implementation of Ezzence and report on a study to evaluate the feasibility of using the device in home-based sleep environments. The study results ($N = 40$) show that participants were satisfied with the device and found it easy to use. Furthermore, participants reported a significant improvement in sleep quality when using the device with scent in comparison to the control condition ($p = 0.003$), as well as better mood the following morning ($p = 0.038$) and shorter time to sleep onset ($p = 0.008$). The device is integrated with a wearable EEG and real-time sleep staging algorithm to release scent during specific sleep stages (N1, N2, N3, and REM), which is important for certain use cases (e.g., to study the effect of scent on REM dreams, or to improve memory consolidation with a re-exposure of scent during N2 and N3). Ezzence can be used for several applications, including those that require scent triggered day and night. They include targeted memory reactivation, longitudinal health treatments, therapy, and mental or physical exercises. Finally, this article proposes an interaction framework to understand relationships between scents and environments based on proxemic dimensions and passive or active interactions during sleep.

Keywords: wellbeing (I31), wearables, sleep, odor, olfaction, olfactory interfaces, human-computer interaction

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1. INTRODUCTION

An estimated 50–70 million people in the United States of America suffer from sleep disorders (on Sleep Disorders Research, 2003). Sleep insufficiency and poor sleep quality are correlated with an increased risk of anxiety, diabetes, heart disease, stroke, obesity, and high blood pressure (Liu et al., 2016). Approximately 40% of people that look for medical assistance concerning sleep problems have a psychiatric disorder (Ford and Kamerow, 1989), and more than 70% of depressed patients have insomnia symptoms (Nutt et al., 2008). Insomnia, poor sleep quality, and insufficient sleep is a growing problem in society and is becoming more worrisome due to the COVID-19 pandemic. Poor sleep has been reflected in the increased number of sleeping aids bought globally and rising interest in non-pharmacological sleep interventions (Intelligence, 2018). This article investigates the feasibility of developing scent technologies to improve wellbeing and sleep in naturalistic environments, such as home-based studies. We focus on the use of scent as an intervention during sleep due to the olfactory sense's unique anatomical structure and its privileged connection to memory and the emotional part of the brain, which is especially relevant to develop applications to improve sleep quality and wellbeing. Unlike other sensory modalities, many types of olfactory stimuli can be presented during sleep without awakening (Carskadon and Herz, 2004), as well as during wake time without distracting users from their primary activity, thereby offering novel opportunities for interfaces and applications that extend from wake to sleep time. This research wished to assess the use of scent as an implicit, less conscious stimulus during sleep, that nevertheless has the ability to influence the person's cognition and sleep quality.

2. A FRAMEWORK FOR OLFACTORY INTERACTIONS DURING SLEEP

Human-computer interaction (HCI) has traditionally focused on designing technologies and studying how humans interact with them during wakefulness. However, we almost spend a third of our lives sleeping. Still, most of the technology developed for sleep applications focuses on sleep tracking rather than real-time interventions using non-traditional stimuli such as scent. In comparison to visual, haptic, and audio technologies, olfaction has been less explored in HCI. Human-computer interactions typically require a conscious, explicit input from the user to the system (e.g., typing on a keyboard or touching a screen), and typically the output from the computer to the user assumes that the person is awake (e.g., graphical user interfaces). In contrast, this article proposes computer interventions whose output changes based on minimal or no human input when the person is sleeping or awake. In particular, we explore the process and challenges of developing technology that uses scent as a stimulus in different naturalistic environments with the goal to improving wellbeing during day and night.

Olfactory feedback is an exciting yet to be exploited medium for improving sleep quality and interacting with a sleeping individual without disturbing them. This article proposes an interaction framework to understand relationships between scents for liminal day-night interactions and environments. In the following paragraphs we categorize Olfactory Interfaces (OIs) based on proxemic dimensions (which we will explain in the following section) and passive or active interactions.

2.1. Scent and the Environment: Olfactory Proxemics

Maggioni et al. (2020) described four key features around scent stimuli (i.e., chemical, emotional, spatial, and temporal) and proposed a "*Smell Space*" to use these features in smell-based interactions. In this article, we focus on the spatial features of smell. OIs are fundamentally different from other user interfaces, as scents can linger and disperse in space. Their intensity can very quickly change over time, and they can accumulate or disappear depending on the airflow and dimensions of the area. Like proxemics, scent can be classified based on its presence in a physical environment. Hall (1966) defines proxemics as "*the interrelated observations and theories of humans' use of space as a specialized elaboration of culture*" and classified the social interaction in a physical environment in four distinct zones: (1) intimate space, (2) personal space, (3) social space, and (4) public space. The framework we present expands on his work and applies it to the context of odor delivery and categorizes passive/active scent interactions with computers as Biological, Wearable, and Ambient based on the distance between the origin of the scent-delivery device and the user (as depicted in **Figure 1**).

2.2. Ambient OIs

Ambient scent technology can range from stationary olfactometers that are located at a personal distance, home diffusers that are placed at a social distance to large-scale, architectural scent delivery in public spaces (as described in **Figure 1**). These devices can also be co-located and allow remote synchronization of scent between users over distance. Ambient olfactory interaction can be understood as interaction with ambiently diffused scents (i.e., when a scent is occupying the entire space around, or nearby the user, e.g., examples of this term can be seen in the work by Bodnar et al., 2004; Brewster et al., 2006; Warnock et al., 2013).

2.2.1. Olfactometers Used in Traditional Scientific Research

Olfactometers (or stationary computer-controlled scent delivery machines with nasal cannulas) are among the most widely used instruments for scent delivery in scientific studies. They are a standardized way to study olfaction and are widely referred to as "*olfactometer*" throughout the literature in Psychology, Neuroscience, Psychiatry, and clinical research (e.g., Carskadon and Herz, 2004; Rasch B. et al., 2007; Stuck et al., 2007). However, as per "Oxford Languages," an olfactometer is "an instrument for measuring the intensity of an odor or the sensitivity of someone or something to an odor." Thus, in other fields like Human-Computer Interaction or Electrical Engineering, it is often referred to simply as a scent-delivery device, olfactory interface, or olfactory display. These devices allow for precise administration of odor stimuli and generate a minimum delay between activation and arrival of the odor to the user. Current scent delivery systems for night-time studies consist of nasal masks/cannulas that are connected to large olfactometers via long Teflon tubes (see **Figure 2**).

The scent release device is usually placed in an adjacent room to avoid awakening the user due to the noises generated by the pumps. The technical expert sets up the device and controls the odor's duration and airflow through a computer connected to the device. There are several olfactometers on the market that vary from 3 to over 20 kg, the smallest found with four scent release weighs 4.6 kg and measures 31 L × 20 W × 15 H [cm] (see Scientific, 2019). Some research laboratories choose to build their olfactometers since the devices on the market can be costly (up to 100,000 USD, Lorig et al., 1999), but even the cost of custom ones can surpass 1,000 or 5,000 USD to build (e.g., Lundström et al., 2010; Lowen et al., 2017) and they typically exceed the dimensions of commercial systems. With the aim of creating an accurate olfactometer with smaller size and weight, Risso et al. (2018) created and tested an olfactory device that weighs ≈2 kg and is 50 L × 40 W × 40 H [cm]. As an alternative,

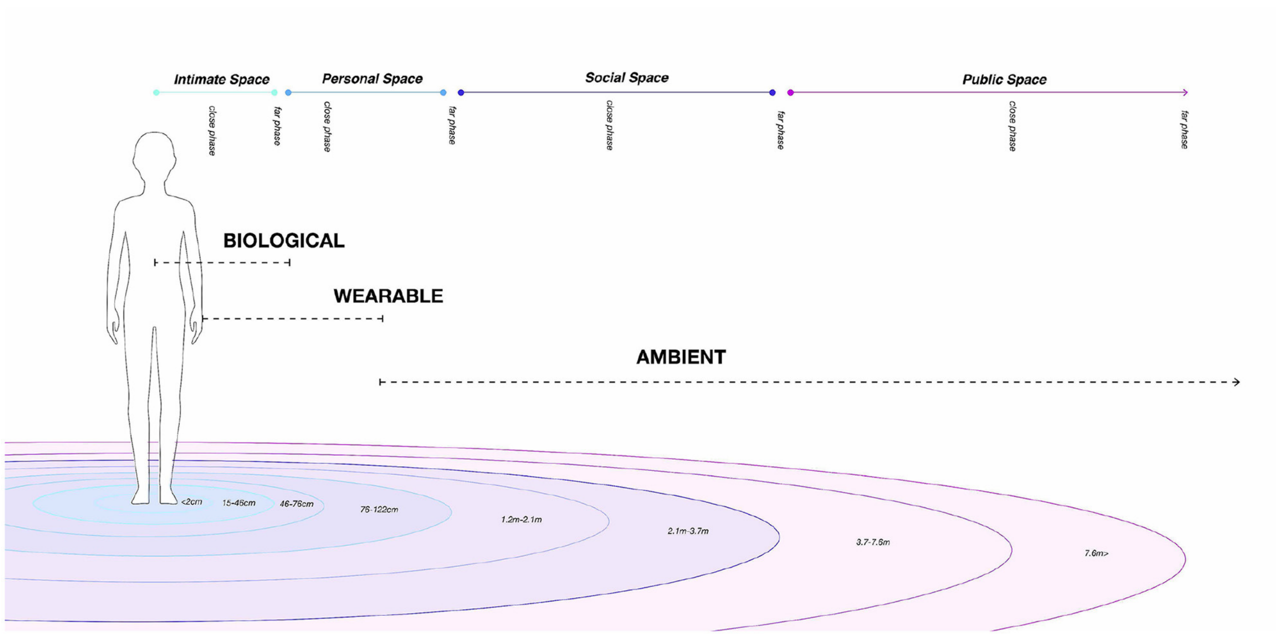

FIGURE 1 | *Olfactory* proxemics. **Ambient**: generated in the environment by a source co-located nearby or far away from the user. The distance can range from a personal space to social space or public space (e.g., home diffusers). **Wearable**: worn by the user in a personal space (e.g., Ezzence wearable). **Biological**: generated in or on the user in an intimate space (e.g., chemosignals, scent hallucinations, synthetic scents).

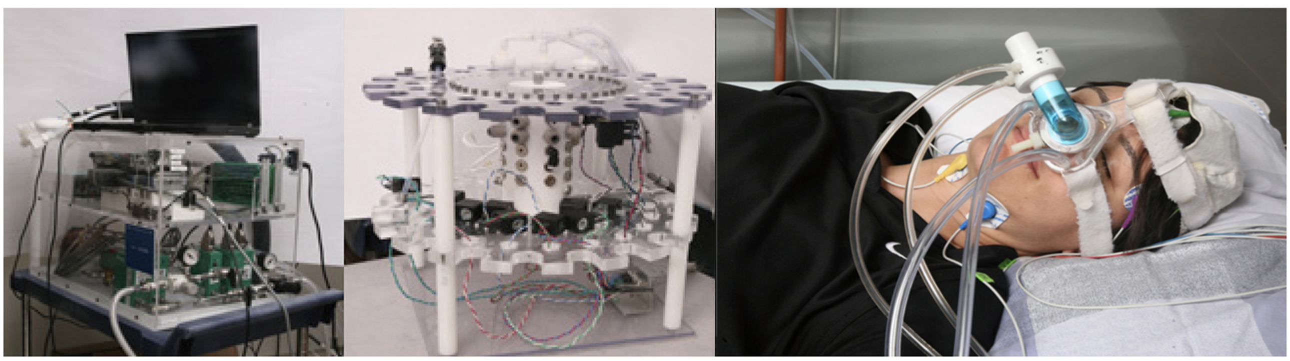

FIGURE 2 | The images depict a typical sleep study using olfactory stimulation. The experiment is conducted in a laboratory with a nasal mask attached to an olfactometer that releases various scents stored in the bottles. Images by (Arzi et al., 2014) (CC-BY).

some experimenters do not use olfactometers but instead hold bottles/vials of scent with their hands and intermittently present it to the participant while carefully controlling the exposure time and proximity to the nose to prevent habituation (see Goel et al., 2005).

Although the ultimate goal of these olfactometers is to provide scent delivery at an intimate or personal space, these scent delivery devices can not be worn and have to be placed on the side of the user due to their size. Therefore, we categorize them as "*Ambient*."

2.2.2. Ambient Scent Technologies in HCI

Some of the most recent advances in scent delivery systems have taken place in the field of HCI. Researchers have looked into designing olfactory technologies for a wide range of day-time applications. These devices tend to be more user friendly, smaller, and cheaper. For example, the prototypes developed by Herrera and McMahan (2014) or Dmitrenko et al. (2017) cost <1,000 USD, which is significantly less than the olfactometers built for traditional science studies. The majority of these scent delivery technologies are stationary, but a few are wearable. Kaye (2001) was one of the pioneers in using aromatic outputs in HCI and developed an automated scent-release mechanism, which facilitated the more objective study of scents for interactive applications. More recently, HCI researchers and product developers have focused on enabling scent to become part of digital communications (e.g., Strong and Gaver, 1996; Choi et al., 2011, 2013; Scentee, 2013; Aromajoin, 2016). Most systems use

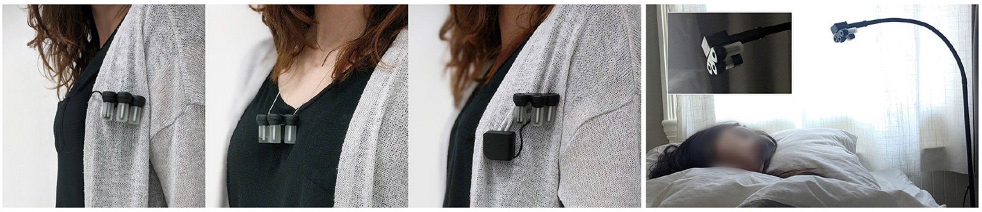

FIGURE 3 | *Ezzence* can be worn during the day and be attached to a bedside holder at night. It can also hook onto pajamas, blankets, necklaces or, inspired by a brooch; each part can be attached separately. The custom holder charges the device and has an adjustable flexible neck. It wirelessly connects to the smartphone application that controls the duration and frequency of the scent bursts and activates odors depending on physiological signals, sleep stage, and the user's preferences.

off the shelf aromas in their prototypes, focusing research efforts on the device itself. For example, the Ophone Ophone (2014) was a commercial product with 32 unique scents that could be combined to create tags for a message or a photograph to be sent through the Internet and reproduced on the other side. A similar idea was Scentee (2013), which emitted a fragrance when a notification is received on the user's smartphone. Some HCI researchers like Ranasinghe et al. (2011) explored the use of scent for digital communication, enabling the sharing of scent over the Internet. Dephemeral[1], explored the future of teleporting flavors and scents through screens in a science-fiction video. Other researchers like Maggioni et al. (2018) have explored the use of olfactory notifications into a messaging application to improve users' confidence and performance in identifying the urgency level of a message. These types of notifications have also been researched for in-car user interfaces by Dmitrenko et al. (2019). Dmitrenko et al. (2016) proposed a three-dimensional framework to compare scent-delivery devices based on the distance, volume, and speed of scent-delivery to guide the design of in-car olfactory interfaces. Scent notifications were perceived as more comfortable, less distracting, and more helpful than visual notifications, which resulted in fewer driving mistakes (Dmitrenko et al., 2018). Related research by Dmitrenko et al. (2020) has also shown that scent of rose and peppermint might be able to calm drivers.

Some researchers have also explored the use of scent in games, like the work by Nakamoto et al. (2008) that lets users "cook" a virtual dish. Others have explored the release of scent though form; Clayodor by Kao et al. (2015) explores the mapping of a malleable tangible interface with scent. Fragrance has also been used to convey data in the work by Patnaik et al. (2018) and Batch et al. (2020).

The devices aforementioned are categorized in our framework as *Ambient* since they are often placed near the user, in a personal, social, or public space (as shown in **Figure 1**). An interesting approach that can be used to move the flow of scent across spaces (e.g., from the social space to personal and even intimate space), is the work proposed by Hasegawa et al. (2018). In their manuscript, they redirect the flow of scent by producing an electronically steerable ultrasound field. This technique has been used in the past to generate mid-air haptic sensations and might be useful to remove odors in the environment and to better control the space between the scent delivery device and the user. Finally, in the context of scents in digital art, Lai (2015) explored the role of an olfactory interface in an art museum to engage visitors around the artwork area.

2.2.3. Large-Scale Scent Delivery for Urban Planning and Architecture

Ambient scent has been widely used throughout history in sacred places in many different religions. Burning incense is still used as an aid in prayer and spiritual practices for meditation and rituals in churches and temples, and probably, after all this use, some of these buildings already have the scent of incense impregnated in their construction materials.

Award-winning architect Peter Zumthor said once that *"Architecture is not about form, it is about many other things. The light and the use, and the structure, and the shadow, the smell, and so on."* In his Bruder Klaus Chapel, layers of concrete were poured on top of a wooden frame that was later set on fire to create the internal structure of the chapel and left behind the scent of the burnt wood reminiscent of the initially formed space.

Beyond architecture, scent-delivery can also be used at an urban scale, although it has not been widely explored. Xiao et al. (2020) studied and proposed a framework around the perceptual process of smellscape perceptions. McLean (2019) creates olfactory landscapes and maps the scents of a city to render with different types of visualizations. Sissel Tolaas, Maki Ueda, and Peter de Cupere have also mapped odors from cities and different areas. Other artists such as Sam Bompas and Harry Parr have explored scent-delivery in large-scale environments and created multi-sensory fireworks, orange-flavored bubbles, and banana-flavored confetti. More recently, Spence (2021) investigated the role of ambient scent in passenger transportation and brought up very relevant areas of exploration such as air pollution, branding, marketing campaigns in the Underground and various forms of public transport, as well as scented terminals and stations.

2.3. Wearable OI

Scent delivery technologies primarily consist of stationary devices that are not designed to be worn. The research on wearable scent delivery technologies is still under-explored and mainly focused on ambient scent delivery rather than personal. There have, however, been a few exceptions described in the following paragraphs.

[1]https://www.youtube.com/watch?v=0MZ9yu3d5bM

2.3.1. Head-Mounted

The history of multi-sensory immersive scent research can be first dated to scents being first released during the viewing of a film, so that the viewer could associate certain scents with scenes of the movie (Smell-O-Vision[2]). In 1962, Morton Heilig patented Sensorama, which could be considered as the first virtual reality system. It was an immersive device, including stereo sound, scent, and tactile stimulation to provide a multi-sensory experience. Since then, researchers and designers have studied the effects of scent on VR experiences (e.g., Flavián et al., 2021) and developed head-mounted displays with wearable scent delivery like the work by Yamada et al. (2006) that uses scent in the outdoor environment, or Choi and Cheok (2015) with Sound Perfume, a pair of 3D-printed glasses embedded with a heating module for releasing the scent at the end of the frames. Other artists like Simun (2014) designed a low-tech artistic piece that is worn around the nose, held like glasses. Narumi et al. (2011) presented a head-mounted display to augment flavors and taste using edible markers for augmented reality. Other head-mounted scent delivery devices have been created, for example, the work by Hashimoto and Nakamoto (2016) and more recently Brooks et al. (2020) used trigeminal odors in VR to simulate temperature illusions (e.g., using eucalyptus for cooling and the chili pepper compound for warmth). Trigeminal odors activate the trigeminal nerve, a sensory nerve responsible for temperature sensations, tactile, pressure, and pain in the nose, eyes, and mouth. There are certain types of odors, such as menthol, Pyridine, peppermint, or capsaicin based fragrances that activate the trigeminal nerve and produce a cold or hot sensation and can cause arousals (e.g., see the work by Badia et al., 1990 or Carskadon and Herz, 2004). Finally, researchers like Ranasinghe et al. (2018) have also combined olfactory and haptic (thermal and wind) stimuli with physiological and subjective measures and proved that these types of VR experiences improve the sense of presence compared to traditional audio-visual feedback.

2.3.2. On-Face OI

The social aspects of wearability are especially relevant when designing devices that are worn on the face. The social impact of non-traditional form factors such as on-skin interfaces located at the collarbone, ears, back of the neck, arms, forearms, and hands have been explored in the past by You et al. (2019). Researchers have developed various interactive technologies and sensors that are attached or worn on the face, such as head-mounted displays (HMD), wearable electroencephalograms (EEG), or nose interfaces for nostril temperature recording (see Kodama et al., 2018). Through the perspective of beauty technology, Kao et al. (2016) designed on-face dynamic color-changing eye shadow to create interactive body decorations. Limited research in the area of on-face olfactory interfaces has been done to date; Wang et al. (2020) describes "On-Face Olfactory Interfaces," a series of form factors for olfactory wearables that are lightweight and can be attached to the skin or to glasses and piercings. The article also compares the user's perception and usability of these devices when pairs of participants interact at a close personal distance.

[2]https://en.wikipedia.org/wiki/Smell-O-Vision

2.3.3. Accessories and Fashion

Smart textiles can incorporate a variety of sensors and actuators; for example, Kan et al. (2015) uses thermochromic dye with conductive thread to reveal or make disappear words on a piece of textile. The t-shirt also has an embedded vibration motor on the neck that is activated when two people are nearby. Other smart textiles that respond when a person is approaching include the "Smoke Dress" by artists (Wipprecht and Casas, 2012) that releases a cloud of smoke. Light and temperature might also trigger changes. For example, "Climate Dress" has an array of LEDs that light up depending on the CO2 levels in the air (Design, 2009). Scientists like Goncalves et al. (2019) have explored the use of scent in textiles and have modified cotton fabric so that in contact with sweat, it releases β-citronellol, a fragrance obtained from the leaves of lemongrass that is commonly used as a mosquito repellent. Some artists have explored the use of scent in fashion such as Tillotson and Andre (2005) or ICT Scent Collar by Tortell et al. (2007), a scent delivery device in the form factor of a collar or bib to use in a virtual environment. There has been other research that focuses on wearable necklaces (Amores and Maes, 2017) or clips (Amores et al., 2018) for wellbeing. Other neck-based wearables have been used to augment mobile notifications by Dobbelstein et al. (2017), and more recently, Lin et al. (2020) created a breath training toolkit that uses a wearable scent-emitting device that is activated with a stress ball. Last but not least, in this article we present an olfactory wearable that can be worn during the day and night coupled with a brain activity sensor to predict sleep stages and release scent at certain stages inprecise quantities.

2.3.4. Intra-Nasal Methods in Medicine

Nasal cannulas and nasal masks are the most common method for scent delivery in hospitals, clinics, or specialized care facilities. Although they are "wearable," they are connected to stationary olfactometers that are computer-controlled and can determine the airflow, odor concentration, and odor duration. Therefore, this method is probably the most efficient to use for stationary, clinical settings but they are challenging to deploy while walking or at home. The nasal cannula delivers small quantities of scent directly to the nasal cavity through the nostrils, and scent lingering in the surrounding space is minimal. This is especially relevant for intranasal medication delivery since it is the fastest way to absorb molecules after intravenous methods (see Patton and Byron, 2007). Close-to-nose interfaces could be used as a complementary or alternative wearable method to nasal cannulas, alleviating the discomfort caused by these intra-nasal devices.

2.4. Biological OI

A "Biological" scent-delivery method is emitted through or within the person. For example, artist (McRae, 2011) created a speculative design fiction called "Swallowable Parfum," a cosmetic pill that makes the skin perspire a fragrance, therefore using the body as an atomizer. Kan et al. (2017) created pH-reactive materials that can change color, odor, and shape. Amongst many other applications, these materials can be applied to the skin and change scent based on sweat or tears, for example, by sensing lactic acid present in sweat. Other biological scent-delivery methods include "bacterial" scent-delivery (delivery of odors using synthetic biology). Finally, biological scent-delivery can include scents that are digitally generated using electrical stimulation or optogenetics. These types of scents are perceived as "real," although they do not exist physically. This exciting research is still under-explored and remains mostly unknown, although some intriguing work has been done in this area, predominantly in rats by Mouly and Holley (1986) and Chong et al. (2020). Other exploratory research in humans has been done by Kumar et al. (2012) and Holbrook et al. (2019). Even though these studies are promising, the methods used are still invasive and require significant development before we can arbitrarily create synthetic scents on demand.

2.5. Passive/Active OIs

Besides the interaction of odor in space, scent can interact with the user in an active or passive manner. We focus on the use of scent in the sleep environment and refer to "Sleep interfaces" or "Sleep UI" as technological interventions in which a person controls a software application or hardware device that can trigger a stimulus like scent while sleeping. These closed-loop systems can monitor physiological signals from the user and generate an output such as a burst of scent, audio, tactile stimulation/feedback, or a light-based stimulus.

2.5.1. Active Sleep UI

We consider an "active" sleep UI a closed-loop user interface that automatically changes according to the user's sleep stage, similar to the system presented in this article. There are other ways to interact with the user during sleep, e.g., using visual, tactile or transcranial magnetic stimulation (which have been used to trigger lucid dreams, see the work by LaBerge and Levitan, 1995; Paul et al., 2014; Voss et al., 2014). Commercial devices such as Night Shift would also fall into this category, by preventing snoring and obtrusive sleep apnea by making the user change their position using haptic feedback. Dormio (Haar Horowitz et al., 2018) tracks when the user is falling asleep (hypnagogic state) and plays a sound or keywords to influence micro dreams in the first stages of sleep.

2.5.2. Passive Sleep UI

Sensorwake is a commercial product that releases bursts of scent to wake people up (some of the scents used are mint, which will activate the trigeminal nerve, in contrast with the odors that we use in this article). The device does not detect any sleep stages or any input from the user; therefore, the user does not "control" it. Thus, it might not strictly be named an interactive or closed-loop "sleep interface," but can instead be categorized as a "passive" sleep UI. Therefore, one might also categorize a sound alarm clock as a "passive" sleep UI since the user does not control it, but the interface will influence the sleeping mind. Similarly, any type of input while sleeping could be categorized as a "passive" sleep UI, such as a humidifier, the bed's stiffness, the texture of the bedsheets, etc. Although the definition of a "passive" sleep UI might seem too broad at first, it could open up new opportunities and ideas to think about how they could transition into an active/interactive or closed-loop sleep interface.

3. DESIGN AND IMPLEMENTATION OF EZZENCE

The goal of our research is to develop an OI that is portable, can be used during wake and sleep state, does not wake the user up, is easy to use and setup at home and can be worn in an ambulatory context during the day. Therefore, our aim is to develop and evaluate an olfactory device that in comparison with previous **HCI** scent-delivery systems:

- Is designed for interactions that extend from wakefulness to sleep.
- Can be deployed in remote human subject studies in which participants sleep in their homes.
- Can release scent in real-time based on specific sleep stages, which is key for applications such as targeted memory reactivation.
- Is modular so it can be worn in many different ways and attached to different surfaces for maximum flexibility and comfort.
- Can release a burst of scent with a duration faster than 1 s, which is important for certain applications.
- Is designed for longitudinal studies.

In comparison with olfactometers used in **scientific sleep studies**, the prototype presented here is:

- Over 700 times smaller and 40 times lighter than the smallest PSG olfactometer (Risso et al., 2018).
- Mobile and usable during sleep and wakefulness.
- Silent enough to be used in the same room as the sleeper without disturbing their sleep.
- Does not require a nasal cannula/mask.
- Controllable wirelessly so that scent release can be customized via a smartphone app.
- Tested outside of a research laboratory in a natural, home context.

As far as we are aware, our device is the only silent wearable olfactometer that precisely releases scent down to microseconds (μs), is designed to be used for both sleep and wake interactions, can release multiple scents, and integrates an automatic sleep staging scent release mechanism. Our device uses ultrasound atomization which has been used in the past and is one of the most silent ways of releasing scent, which is critical for sleep applications. We use piezoelectrics that vibrate at a high frequency to realize a minimum delay between activation and arrival of the scent to the user in comparison with systems that use heat or fans. Our goal was to design a device that people could use comfortably at home, that was silent, portable and that could also be accurate enough for scientists to use in sleep experiments. Given the burden, cost, and difficulties of deploying olfactometers for sleep applications "in-the-wild," sleep research in home-based settings are scarce (we were not able to find any at-home sleep study using these type of technologies).

FIGURE 4 | The "sleep holder" charges the device while the user sleeps. The distance between the prototype and the user's nose can be adapted via the flexible holder head (1). The user can assemble the holder clamped to the nightstand (2) or like a tripod next to the bed (3). On the left, pictures are taken by participants after assembling the prototype to the holder in their homes.

3.1. Technical Description

We designed a prototype that can automatically release scent ranging from microseconds to seconds, generating minimal delay between the activation and arrival of scent to the user. It can be configured prior to sleep via a custom made Android App (see **Figure 5**), in which the user (or an experimenter) can customize the burst duration and timing of multiple scents. The device can release up to three different odors simultaneously, as shown in **Figures 3**, **6**. The user/experimenter can preset triggers and rules for real-time scent release based on changes in sleep brain wave activity (as shown in **Figure 5**), as well as physiological data. The app allows the user to select at what sleep stage scent should be released. If worn on the body, the device can also detect heart rate and respiration and be programmed to release scent accordingly (Amores et al., 2018). Scent can also be delivered based on the user's location and accelerometer information from the phone. The prototype can be adapted to the user and experimenter needs and bedroom settings (see **Figure 4**). The design is modular so that users can wear it according to their preferences. The aim was to design a unisex device that could be portable or wearable, and most importantly, the device had to be close enough to the nose so that small doses of scent could be released into the air without habituating the user. A friendly user interface also had to be created to configure the device easily so participants could use it at home.

3.2. Smartphone App and Real-Time Sleep Staging

An Android smartphone app that connects to the olfactory device via Bluetooth Low Energy (BLE) using UART communication was developed. In the app, the user can control how often and how much scent is released. In "Sleep Settings" (see **Figure 5**), the user can connect to the Muse EEG, so that brain activity information is streamed. The hardware of the EEG is a modification of the original Muse headband by Interaxon. This headband was designed to be used for meditation, not for sleep. Interaxon has recently launched a new EEG headband "Muse S" for bedtime usage, but there is no available API or service to stream sleep stages in real-time. Therefore, the previous SDK and the original Muse headband to stream real-time brain activity were used. The original casing of the EEG was modified to replace Tp9 and Tp10 electrodes with electrodes attached to the skin for better comfort and robustness of the signal while sleeping.

The smartphone app integrates a machine learning model proposed by Supratak et al. (2017) and Koushik et al. (2019) to infer sleep stages in single 30 s epochs by using Time-Distributed Convolutional Neural Networks (CNN) and just one electrode using the Muse EEG headband. The system's accuracy in predicting four sleep stages and wake was reported to be 83.5% on 20-fold cross-validation using the open Sleep-EDF dataset by Kemp et al. (2000). For comparison, inter-rater reliability among sleep-scoring experts is about 80%. A new model was generated

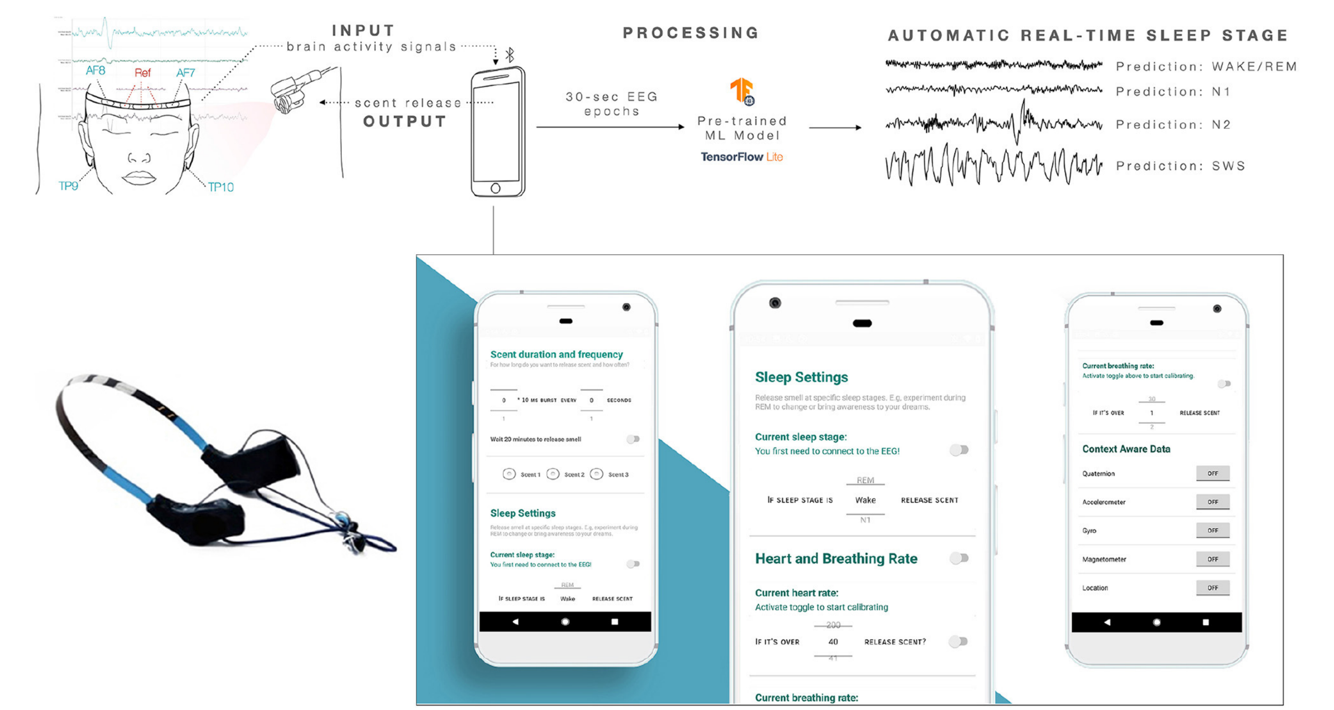

FIGURE 5 | The system reads brain activity signals and sends this information from the EEG to the smartphone via Bluetooth Low Energy (BLE). The app integrates a pre-trained machine learning model that takes 30 s worth of data from the EEG and predicts a sleep stage with a given accuracy. The user or experimenter can customize the duration and frequency of the olfactory stimulation in certain sleep stages using the smartphone app. Scent can be activated manually using a button, or automatically based on physiological signals, such as heart rate and breathing rate. The system can also release scent based on the user's sleep stage, or based on time, e.g., 20 min after going to sleep.

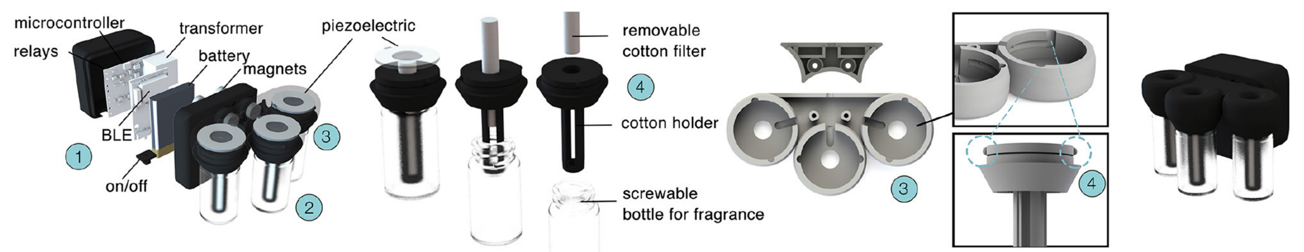

FIGURE 6 | (1) The back case encapsulates the PCB and connects to the front case (2) via a textile thread and magnets. The case holds the piezoelectrics and bottles and has a cavity that connects the textile thread to them (3). The piezoelectrics vibrate at high frequency and release scent when in contact with the cotton filters by soaking the fragrance from the bottle (4). The injection-molded case holds the magnets and wires with two screws. The fragrance can be refilled in two ways: one is by unscrewing the bottle of glass, and the other is by replacing the entire capsule (including cotton filter and cotton holder). The capsule is held using two nubs (4) with an internal mechanism that locks in place by inserting it upwards while rotating 60° (until the nub passes a minor bump in the path).

for this article with data from 20 participants (the training-set is 40 nights in total). The Tensorflow Lite model was imported to the Android App, and a UI was created to let the user pick at what sleep stage scent should be released. When the toggle is activated, the previously set intensity and frequency will be active, and the scent will be released when the accuracy of the predicted sleep stage is over 60%.

3.3. Hardware

The device consists of two main structures (1) and (2) (as depicted in **Figure 6**). They are connected via a textile cable thread and can be magnetically attached and worn with a layer of fabric in between (shown in **Figure 3**). Rare-earth magnets were chosen for their strength and to allow for versatile use of the device.

3.3.1. Electronics and Back Case

The dimensions of the electronics back case are 3.3 cm (L) × 3.8 cm (H) × 2 cm (W) (see **Figure 6**). It has two mounting magnets designed to attract the front case and an on/off piece attached to the PCB. The PCB design was based on previous work (Amores et al., 2018), with variations in the type of piezoelectrics used, transformers, and battery to minimize power consumption and maximize the efficiency and speed of the bursts.

Previous work uses a piezoelectric with a 16 mm diameter, 110 kHz frequency, and an unknown size of microholes. Instead, we were interested in testing different sizes of microholes, which would allow the use of more viscous essential oils. Additionally, controlling the size of the microholes is crucial as it will vary the amount of fluid and power per burst of scent released. For this reason, we visited a piezoelectric company and were able to create our own custom microporous sizes. We created various microhole sizes (e.g., 10, 12, 13 μ) based on the recommendations and limitations given by the manufacturer. Finally, we chose 13 W, 4.5 D microholes with a frequency of 108 kHz (compared to the 110 kHz). These piezo parameters were our preferred after volatilizing higher liquid viscosities and emitting longer bursts in shorter times. Additionally, we updated the transformer, we currently use a 10:0.45 transformer (0.045, Ratio 20:1) instead of a 5.4:0.5 transformer (0.09, Ratio 10:1); thus, the prototype is more efficient than in previous work, taking 24 mAh when the BLE is connected and 250 mAh when a burst is released (instead of 60 and 500 mAh). Such intensity is due to the high voltage needed to run the piezoelectrics at a high frequency of 108 kHz. Finally, compared to previously used batteries (350 mAh), we use a smaller battery, almost half the weight and height (150 mAh).

3.3.2. Capsule Holder

The capsule holder consists of a glass bottle (which can be easily unscrewed and refilled), a cotton holder, and a cotton filter that transports small quantities of liquid through its fibers to the piezoelectric (as shown in **Figure 6**). The cotton filter is supported from the bottom to apply enough pressure for the piezoelectric to release scent (3). Minimal changes in the pressure of the piezoelectric can prevent the scent from being released. Different designs were carefully studied and tested until the best performance was achieved (e.g., the bottle holder has cutouts for the liquid to be absorbed from the side and bottom). All components were custom made, we tested different stick filter hardness, lengths and diameters (some of the results shown in **Table 1**). It was found that diameters of <5 or 29 mm long had leaks (e.g., 4 and 28 mm). Lengths larger than 29 mm excessively pressured the piezoelectric and would not release scent and sometimes break the disc. Thus, the final settings used for the study were those with the longest-lasting time and no leaks that were achieved using a rigid stick filter with a diameter of 5 and 29 mm long.

3.3.3. Front Case

See **Figure 6** (2): The front case has two magnets with reversed polarities to the electronics back case (1). A rotate and snap mechanism was designed to make the refill and replacement of fragrance simple, quick, and clean. Users can choose between replacing the capsule with a new one (including a new cotton filter), or refilling the bottle.

TABLE 1 | Test conditions for 10 ms bursts every 60 s.

Substance	Cotton	ml/burst	Lasting time
H2O	Rigid	≈ 0.0023	≈ 15 h
H2O	Soft	≈ 0.0031	≈ 11 h
80% H2O + 20% Sleep blend oil	**Rigid**	≈ 0.0006	≈ 54 h
80% H2O + 20% Sleep blend oil	Soft	≈ 0.0014	≈ 27 h
90% H2O + 10% odorless oil	**Rigid**	≈ 0.0007	≈ 46 h

The table depicts the average burst sizes for various substances and cotton filter densities and their calculated lasting hours (using a 2 ml bottle).

3.3.4. Piezo Holder

See **Figure 6** (3): The piezoelectric disks are placed on top of the cotton filter. Separate piezoelectrics cavities were designed to reduce cross-contamination between the capsules.

3.3.5. Sleep Holder

The prototype holder was designed to clip to a bedboard or nightstand (as showcased in **Figure 4**). The inspiration came in the form of a gooseneck night light that was modified to hold and charge the prototype. The gooseneck provides flexibility to adjust the distance between the prototype and the user's nose, regardless of their bedroom layout. The holder is 3D printed and holds the prototype in place (even upside down) with a plugged-in micro USB and a snap clip that holds the center bottle on the front case. The snap clip was tested and iterated upon so the prototype can be easily inserted and removed without breaking.

3.3.6. Case Materials and Design for Manufacturing

The casing was initially 3D printed using a Form 2 with multiple types of Photopolymer resin as well as with Stratasys. Unfortunately, essential oils and alcohol-based fragrances are corrosive and eroded the cotton holder and caused the case to change color, bow, deteriorate, and fail after a couple of months of using the prototype. With the need for a durable material and to accommodate the expected number of devices for future user studies, an injection mold case was fabricated. We manufactured ∼100 PCB boards and 100 injection molded cases. The materials used were HDPE and PP (commonly used in the food industry) with different colors (white, black, and transparent). The black color was chosen for the final design based on the users' feedback to avoid the LED light shining through the case at night.

3.4. Technical Tests

The prototype was tested for multiple nights in a row, with various substances, ranging from essential oils, hydrosols, to water with different carrier oils. The results shown in **Table 1** are the chemical compounds used for the pilot and final study (in bold). The variables involved in how long the scent can last in the prototype are: $f(n, c, X, Tb, Fb, B)$, where n = number of containers, c = container capacity in ml, Tb = burst duration in ms, Fb = how often scent is released (e.g., every 60 s) and B = burst size in ml/ms. B is a system-dependent parameter that depends on the size of the piezoelectric microholes (larger holes will create bigger burst, therefore larger quantities of the liquid will be emitted), the viscosity of the liquid in cps (centipoise units), type of cotton filter (softer cotton creating a bigger burst), and the pressure between cotton and the piezoelectric. The battery power will also influence these results, as well as natural variability in injection molding, which affects the way the holder and cotton presses against the piezoelectric.

3.4.1. Cotton Filter, Piezoelectric, and Viscosity

It was found that the olfactory user experience varies depending on the cotton filter and the piezoelectric. High density filters have slower absorption and volatility than low density filters [soft cottons release more scent, harder (more rigid) cottons emit less quantity]. The same holds for a piezoelectric with larger microholes (more odor), while a piezoelectric with smaller microholes will release less. It was also observed that with a high viscosity liquid (e.g., CBD oil), the atomization performance worsens after a few bursts; therefore, it is recommended for future researchers to dilute the fragrance based on the centipoise units (cps) of the liquid's viscosity.

3.4.2. Dilution

Previous researchers (Diego et al., 1998), conducted their studies using essential oil diluted at 10%. Based on their insights, similar ratios of fragrance were tested. Water was chosen as a diluting substance because a carrier oil like coconut oil was too viscous to be atomized and resulted in smaller bursts that did not reach the participant's nose. The ideal ratio for the essential oil selected ("Good Sleep Blend" by Solutions, 2021), was 20% essential oil and 80% water. A variety of essential oils diluted in water at different ratios were tested at a distance of $\sim$ 20 cm away from the participant's nose using the "sleep holder." Several odorless carrier blends of different viscosities were tested to use a similar viscosity for the control group than for the experimental group (using the sleep blend). The blends consisted of different ratios of Benzyl Benzoate ($\approx$9 cps) and Isopar H. ($\approx$1.5 cps) to achieve blends with viscosities of 2, 3, 4 cps, etc. The prototype was tested with several of these carrier oils at ratios of 20% oil and 80% water, but unfortunately, they clogged relatively fast (after $<$30 min of usage). With further testing, the ideal ratio of 10 and 90% water with a 2 cps viscosity was found.

4. MATERIALS AND METHODS

4.1. Evaluating the Use of Ezzence

To evaluate the usability and feasibility of the Ezzence device for home-based sleep studies, we conducted a user study with 40 participants. We opted out for only assessing the usability and feasibility of Ezzence without the EEG sensor to avoid confounders that could have biased the study (e.g., decreased sleep quality due to the head-mounted sensor instead of the Ezzence device).

The study was conducted using a between-subjects experimental design. To avoid observer-expectancy effect and unconscious influences on participant behavior, half of the participants were randomly assigned to the control condition (prototype with release of water) and the rest to the scent condition (lavender blend). Non-smoking, healthy participants were recruited by an e-mail that was sent to the department (21 female, 19 male, with a mean age of 28.7; the oldest person was 56 years old and the youngest 19). No one suffered from respiratory problems or odor allergies. A written, informed consent form was obtained from all participants before participation, and the university ethics committee approved the experiment.

4.2. Daytime Olfactory Test

Participants were given the consent form, filled out a survey about their demographics, the dimensions, and ventilation of their bedroom as well as their habits related to the use of scent while sleeping. After that, they performed an olfactory test and were told how to set up the prototype. The total duration of the olfactory test was $\sim$30 min, and its primary goal was to:

1. Determine if users perceived a 10 ms burst of scent.
2. Evaluate how strong and pleasant they perceived it to be.
3. Identify if there were participants that had anosmia or difficulties smelling, so they could be removed from the study.
4. Test the usability and efficiency of the rotation mechanism designed to replace and refill the scent containers.

During this daytime test, participants wore the prototype as a necklace shown in **Figure 7** and inhaled diluted essential lavender mix oil at a signal given by the experimenter (only then a 10 ms burst was released). They were asked to report if they could smell something, for how long, how strong, and how pleasant it was. After this, five control (80% water, 20% odorless carrier oil) and five diluted essential lavender mix oil were randomly triggered every 30 s (with pauses in between). The rationale for the 30 s was based on previous work on habituation and desensitization (Sinding et al., 2017). Finally, we tested the usability of the refilling mechanism. Participants were not required to refill the bottles in our sleep study because it was only one night. However, we wanted to test the usability and ease of refill for potential future use cases where participants might need to take the device home for several weeks. Thus, we conducted a practice test in which we measured the time spent by participants filling the scent container and their subjective feedback.

4.3. Preparation for the Sleep Study

Participants were told that the study's goal was to deploy the device in their homes to test its usability. They were not given any instructions about how it might positively/negatively affect their sleep and mood the following morning. They did not know if they were assigned to the scent or the control condition. They were instructed to sleep at least 7 h and not consume alcohol or caffeine after 3 p.m. (as suggested in the literature). They were asked to keep their pets outside of their bedroom and make sure that, if they shared the bed with someone, that person did not have odor allergies or respiratory problems. They were given instructions to use the device and the smartphone app. They learned how to set up an automatic scent release of 10 ms every 60 s that would be triggered 20 min after falling asleep. They were given instructions to assemble the holder and adjust the flexible neck (so that the prototype faced toward their nose, approximately

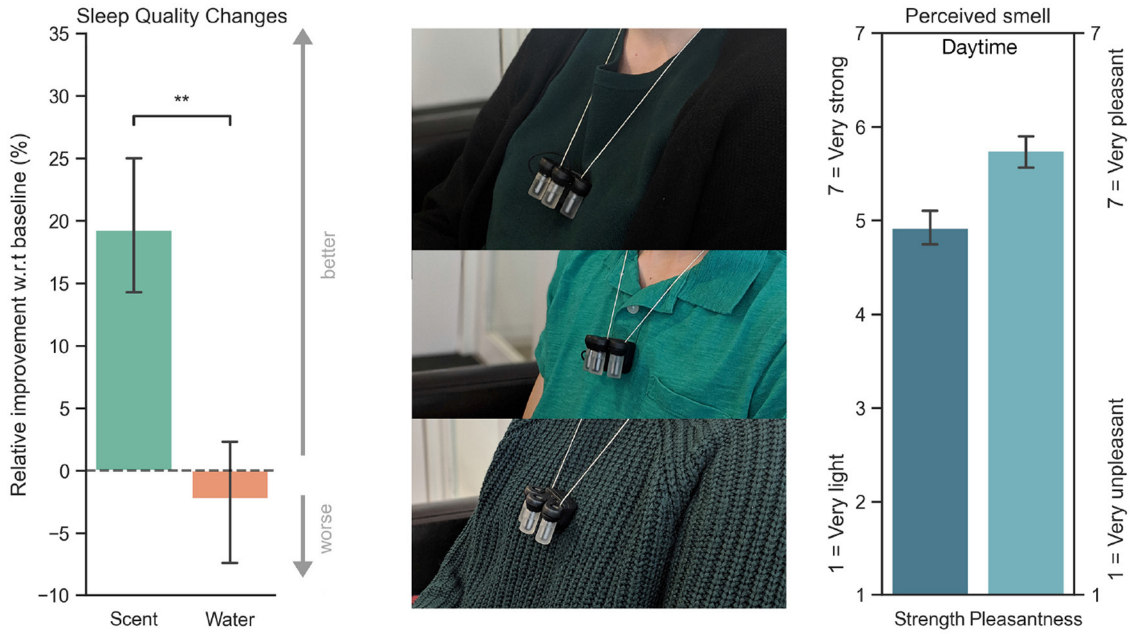

FIGURE 7 | Participants wearing the prototype during the daytime olfactory test. As seen in the right image, participants rated how strong (1 = Very light, 7 = Very strong) the fragrance was, as well as how pleasant (1 = Very unpleasant, 7 = Very pleasant). On the left, self-reported relative improvement with respect to their sleep quality on a baseline night. There was a significant improvement when comparing scent with control (water). $^{**}P < 0.01$.

two hands away from their face ∼ 20–40 cm). They took the device, the holder, and a document (with all the detailed steps) to their homes and slept with the device for one night. In the morning, they filled out two surveys: one about their sleep quality and the functioning of the prototype (right after waking up) and another about their overall experience with and usability of the device. Some days after the study was finished (without prior notice), participants were asked to report their sleep quality for a typical night.

4.4. Odorants and Delivery

The scent selected was a commercially available essential oil blend "Good Sleep Blend" by Solutions (2021) that contains Lavender, Clary Sage, and Copaiba oil, and has a viscosity of 3.9 cps. 20% of the sleep blend oil was diluted in 80% of distilled water. The fragrance was chosen based on its high ratings on pleasantness and lavender's natural sedative effect (Diego et al., 1998; Motomura et al., 2001; Goel et al., 2005; Lehrner et al., 2005; Field et al., 2008; Yazdkhasti and Pirak, 2016). Distilled water with 10% odorless carrier oil was used for the control group. All odors were delivered at low, non-trigeminal concentrations by the device that was worn on the chest during the olfactory test and in the holder near their nose in their bedroom at night (as shown in **Figure 4**). The devices were cleaned and replenished after each use. All sleep experiments were conducted in people's homes, without the experimenter's intervention or presence. Scent or water was released 20 min after they reported lying down to sleep (20 min after they triggered the sleep timer on the smartphone UI to "on," see **Figure 5**). Scent or water was triggered at a frequency of 10 ms of burst every 60 s. The main reason behind this frequency was to reduce the length of the burst and minimize the number of molecules released in the air to avoid habituation (also known as olfactory fatigue, or "nose blindness," see the work by Chaudhury et al., 2010 for more information on this topic). This frequency was also used to ensure that it might overlap with some K-complexes and sleep spindles (McCormick et al., 1997; with the hopes to increase deep sleep/slow-wave activity). The bottles contained 2 ml of liquid (enough to last for an overnight of sleep without refilling).

4.5. Data Exclusion and Technical Problems

Data from 10 participants was excluded from the analysis. Of these, three participants did not finish the study. Two of them because of work deadlines/other personal issues, the other because the participant had a diminished sense of smell because of a cold. The seven other removed participants (one male, six female) reported that the prototype worked but that they did not see a "burst/scent" in the morning due to the following reasons: one participant set up 10 ms of scent every 6 s instead of every 60 s, therefore running out of fragrance earlier than expected. Another participant reported plugging the prototype into an outlet that did not work and realized it in the morning; therefore, the prototype stopped working 5–6 h after the first burst (using the internal battery instead of external power). Similarly, another participant reported not turning the switch on. The fourth participant reported "bumping into it" and suspected that she probably unplugged it. Another participant set up the wrong frequency as when the prototype was returned, there was no liquid left. Finally, the last participant reported that the prototype might have fallen, or he might not have charged it properly.

4.6. Statistical Analysis

To test if the differences between the scent and the control group's means were statistically significant, we first examined if the assumptions to perform a two-sample t-test were met: normal distribution of data, homogeneity of variance, and independence of the observations. Each participant belonged to only one group (either scent or control group measured with interval scale values). Thus, there was no relationship between the observations in each group. For sleep quality changes (**Figure 7**), both the control and scent conditions had fairly symmetrical data [slightly positively skewed for the scent condition (0.4) compared to control (−0.1)], both distributions had a short-tailed distribution (Kurtosis of −1.7 and −0.8). To test if the variance of the outcome variable was equal in each group, we applied the Levene test ($p = 0.199$). The variance criterion held true ($p > a$), where "a" is the probability threshold set to 0.05. As $p > 0.05$, the data sets conform to the variance criterion. In addition, we computed the Shapiro–Wilk test for each group [$p = 0.229$ (control condition), $p = 0.01$] for the scent condition. The results showed that only the Control group had p-values greater than the significance level 0.05, indicating that the data distribution is not significantly different from the normal distribution. In summary, based on the results from the Shapiro–Wilk test, we can only assume normality for the control group. Thus, we ran both parametric and non-parametric tests to validate our results because the scent group was only moderately skewed. In addition, the parametric t-test has been shown to be robust against non-normality, and some argue that there is nearly no need to use Wilcoxon (Mann–Whitney) non-parametric test (Rasch D. et al., 2007). Nevertheless, for completeness, we ran both tests. We demonstrated that both tests show a statistically significant difference between the means of the two groups (scent vs. control): Mann–Whitney-Wilcoxon ($p = 0.009$) and independent t-test ($p = 0.003$), both one-tail. Similarly, we also ran both tests for the perceived mood, rest, deep sleep, awareness, etc., and found that they resulted in very similar p-values, with both significant results for sleep onset ($p = 0.010$ for Mann–Whitney and $p = 0.008$ for the t-test), mood ($p = 0.043$ and $p = 0.038$, respectively), and scent awareness ($p = 0.001$ and $p = 0.005$). Neither of the tests showed a significant difference between the scent and control conditions for the perceived rest, deep sleep, and positive dreams. The **Supplementary Material** provides more details on the analysis, the Python code, and data, including the original quotes from participants with their feedback.

5. RESULTS

All the prototypes successfully worked as expected, except for seven participants that reported not turning on the prototype, unplugging the device, or setting the wrong frequency. Nobody dropped out of the study. All participants from whom the data was analyzed reported seeing a burst of scent/water coming out in the morning. They did not have any problems or sounds due to malfunctioning, although two participants returned the holder broken, both because of transportation/packing or falls. One participant tried to unscrew an internal part of the holder; the other cracked the 3d printed neck (both when trying to pack it and return it to the laboratory).

5.1. Daytime Olfactory Results

Participants' responses regarding how long they smelled the 10ms burst during the olfactory test were the following: 33.3% noticed the smell for only 1 s, 13.3% for 3 s, 26.6% for 3 s or more, and 26.6% for 2 s. In terms of how strong (1 = Very light, 7 = Very strong) the M = 5.03; SEM = 0.21. The results for how pleasant (1 = Very unpleasant, 7 = Very pleasant) were M = 5.8; SEM = 0.19. Participants successfully differentiated between placebo or scent with an average of 8.81 correct responses out of 10, SEM = 0.16. All participants could refill the bottles; the average time spent refilling one of the capsules was ≈28 s, SEM = 1.03.

5.2. Night Time Awareness and Awakenings

Overall, participants were unaware of the device and remained mostly neutral to unaware of the scent while sleeping, as seen in **Figure 8**. There was no significant difference between the scent and water groups in the case of prototype awareness and sound awareness (disturbing noises from the apparatus). However, there was a significant difference in the scent awareness in the case of control vs. scent. The results suggest that participants remained neutral to slightly unaware of the scent and unaware in the case of water. Ninety-three percent of participants in the control condition and 78% in the scent condition did not report awakenings due to the device. Therefore, even though most participants did not wake up, there was some level of olfactory awareness that they were able to report. It is unclear why this might be the case, but one hypothesis is that they could smell the fragrance in a state of drowsiness or hypnagogia in the early transition into sleep/stage 1, as shown by previous work by Carskadon and Herz (2004). Most sleep studies track physiological information, such as EEG, to recognize arousals. However, they usually do not ask questions about the level of awareness or subjective olfactory experience after sleeping. This suggests that although most people do not wake up and remain asleep, some participants seem to be semi-conscious of the scent.

5.3. Perceived Sleep and Mood

On average, all participants that used the prototype with scent vs. those in the control condition, increased their perceived sleep quality, depth of sleep, perceived rest at night and increased the content of positive dreams as well as their mood the following morning, and decreased their time to fall asleep. Depicted in **Figure 7**, the results of an independent t-test show that participants reported a significant improvement in their sleep quality changes when compared to their typical sleep when using the device with scent in comparison to the control condition [$t_{(27)} = 2.9$, $p = 0.003$ (one-tail)]. As shown in **Figure 9**, there was no significant difference in the case of perceived rest ($p = 0.22$), deep sleep ($p = 0.30$), and the recall of positive dreams (p

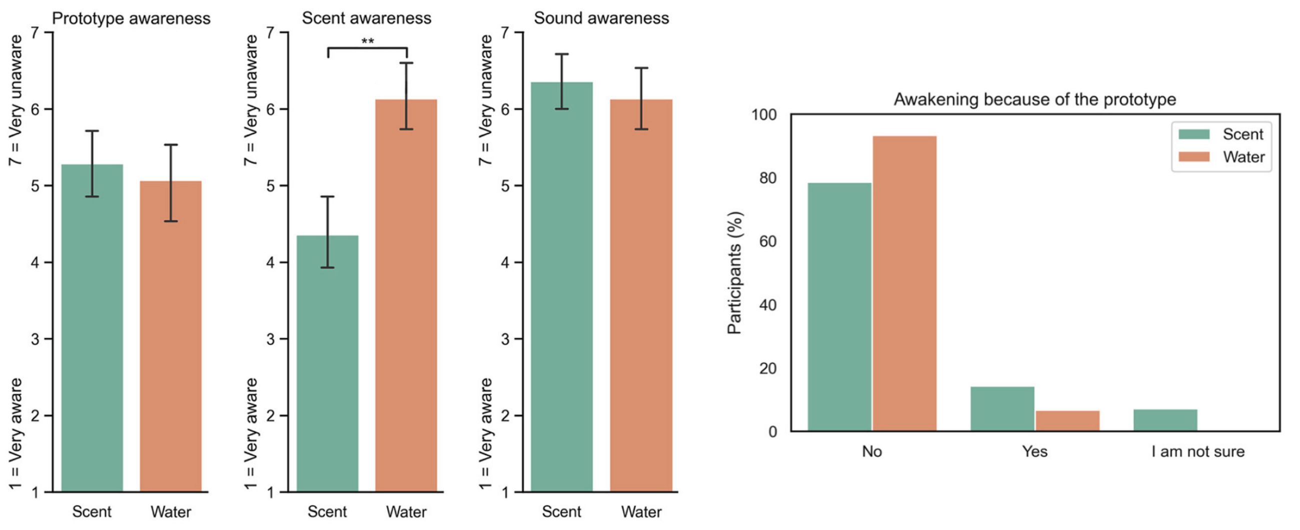

FIGURE 8 | Answers to the questions "How aware were you of the prototype?"; 7 = Very unaware, 1 = Very aware, a neutral response is a 4. "How aware were you of the scent?" and "Did you wake up because of the prototype?" Ninety-three percent of participants that were in the control condition and 78% in the scent condition reported not waking up because of the prototype. **$P < 0.01$.

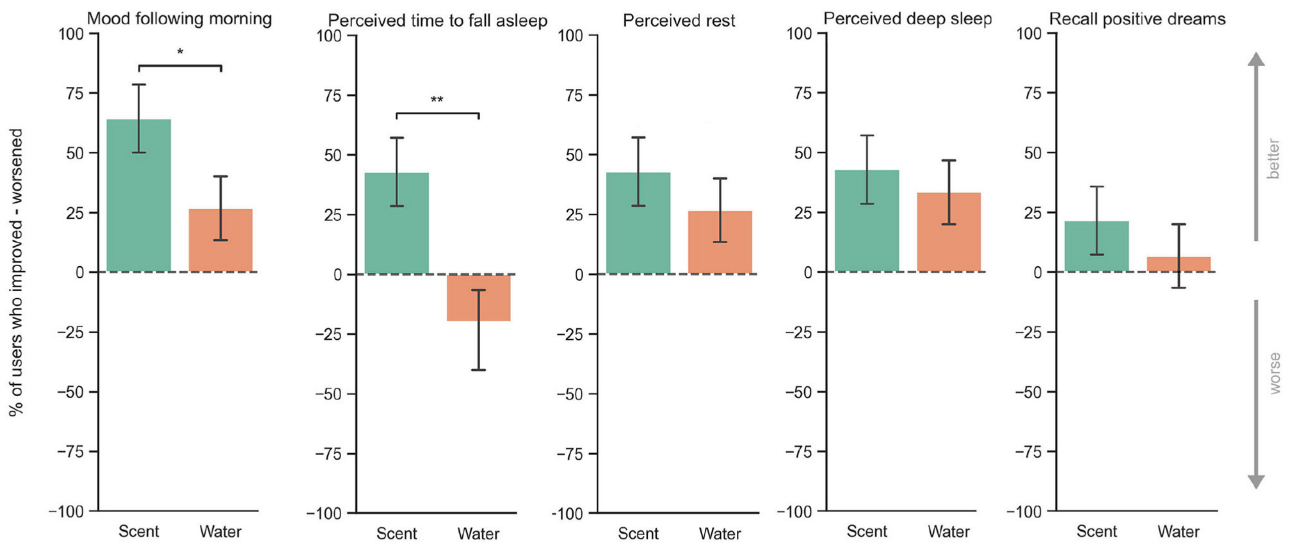

FIGURE 9 | In turquoise, experimental condition using the prototype with a lavender-based essential oil. In orange, prototype with water. The bars depict the percentage of participants who reported improvement minus those participants who reported worsening their sleep. Participants that were in the scent condition had on average more improvement than those in the control condition (water). *$P < 0.05$, **$P < 0.01$.

= 0.25) but there was a statistically significant number of users that reported better mood the following morning in comparison to control ($p = 0.038$), and they were also significantly faster to fall asleep ($p = 0.008$). Sixty-eight percent of Confidence Intervals (±1 STD) and one-tail p-values are reported.

5.4. Usability and Qualitative Feedback

Participants rated very positively the overall satisfaction using the prototype, ease of use of the app, setup of the prototype, and holder. People seemed excited about the potential applications related to sleep and scent. The majority of people were especially interested in applications that improve their sleep quality (see **Figure 10**). Seventy-three percent of the participants in the scent condition reported being interested in owning such a device and 46% in control. Ninety percent of the total participants reported that they would use it "daily" or "weekly." Some randomly picked comments include:

Scent condition: *"The scent made me relaxed when falling asleep, and made the room smell fresher in the morning," "It was a good experience. However, I managed to knock it down when*

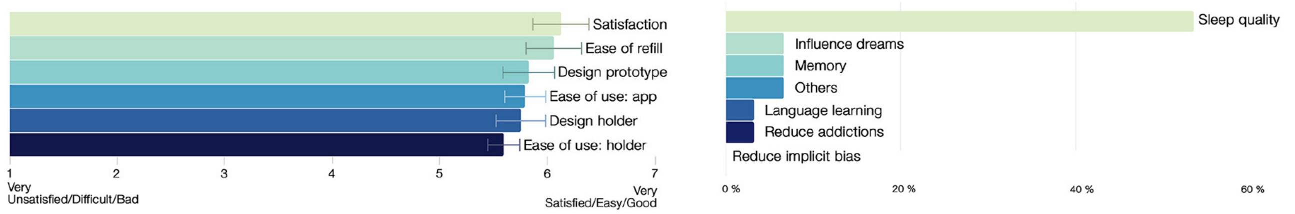

FIGURE 10 | (Left) Usability results for the prototype where 7 is "very positive" and a neutral response is a 4. Satisfaction using the prototype. **(Right)** Answers from all the participants to the question "What would you prefer to use the prototype for?"

waking up. But definitely slept better.", "At first, I fell asleep slowly due to expectation. I woke up several times during the night, but I fell back to sleep more easily and fewer dreams than usual. I felt a bit more strong some times.", "It was easy to set up and the room smells good now. I couldn't tell much of a difference but certainly a very pleasant experience."

Control (water): *"Not much difference from other nights, but I was probably a little too self conscious because of the position of the device. I usually wake up a couple times during the night and when this happened I would immediately look up to see if it was in place.", "The prototype was very easy to install and use.", "Worked well. Only challenge if you could call it that was the proximity of the arm of the prototype which I knocked a few times while sleeping with my arm when rolling over. Not a major issue, however."*

Some comments about their overall experience were: *"I usually have negative, confrontational or violent dreams. Especially if I am too hot. I left my room heater on all night by accident and was sweaty during the night. However, I had either neutral or positive dreams. Also, the scent was very familiar. So when I was confused in the middle of the night whether I was asleep or awake, I smelled the scent and felt comfortable thinking, "Oh I recognize this smell. I must be awake." Looking back though, I'm not sure if I was smelling the scent in my dreams or in an awake state. At the moment though, it was comforting to think that I know for certain that I am awake because I recognize the smell."*

Participants found the fragrance pleasant and somewhat strong (as shown in **Figure 7**). A third of participants noticed the 10 ms burst of scent for only 1 s, 13% for 3 s, 26% for 3 s or more, and 26% for 2 s. For the daytime practice test, participants were fast at refilling the device (with an average time required of ≈28 s) and they found it easy to refill (as shown in **Figure 10**). Please refer to the auxiliary material for additional information and descriptive statistics.

5.4.1. Burst Duration and Frequency

Forty-six percent of participants would keep the same intensity/frequency settings, 33% would trigger scent less often, 13% more often, and 6% did not mind. Surprisingly, for the control condition (water), 26% of the participants reported "trigger scent less often," and 13% to trigger "more often."

5.4.2. A Modular Device vs. Multiple Devices

Participants were also asked to choose between a modular device that can be worn during the day and night (current prototype) or if they would prefer two different devices (one while sleeping, and a different one for the day). Seventy percent of people choose to use only one prototype for its convenience.

6. DISCUSSION

Conducting sleep studies remotely and in the wild is challenging. We have shifted the way we test participants due to the COVID-19 pandemic, which also reflected the types of user interfaces we design. There has been an increased interest in studying the coronavirus's sensory impact, especially now that many people are losing their sense of smell. The scientific community has lately been trying to conduct more studies that involve the sense of smell. Still, the technologies used for treatment and therapy are limited, and there is a lack of mobile scent-delivery systems to operate outside of research laboratories.

In our study, participants slept in their homes and most of them were able to use the device successfully. Therefore, this naturalistic setting minimizes the First Night Effect (FNE, Toussaint et al., 1995) and brings new opportunities to potentially use the data of the first experimental night.

It is essential to discuss the challenge of the degree of blindness in olfactory studies. Participants were told that the prototype might trigger a burst of scent in the morning, irrespectively of their assigned condition. Hence, this way even if they could smell the fragrance when waking up in the morning, it would be harder to guess if they were in the control or scent condition. In this study, some participants reported being in an odorless condition, even though they were in the experimental one, suggesting that this approach was useful.

6.1. Hygiene and Cross-Contamination

It is also worth considering that, in comparison to audio or visual interfaces, olfactory interfaces require more hygiene and care. Fragrances can be easily cross-contaminated when using a new type of scent in an old capsule. Some scented liquid can remain at the bottom of the piezoelectric, where it was pressed by the cotton filter, which can cause cross-contamination if not cleaned before a new scent is inserted. Small droplets of fragrance might accumulate on the surface of the prototype, especially when the cotton used is soft. Therefore, it is recommended that if the prototype is used for a long duration, the angle between the burst direction and the surface of the device should exceed 90° (e.g., in a horizontal position or upside down like in the study presented).

It is also advised to clean the case from time to time. In this study, the piezoelectrics and the top of the capsules were cleaned by rubbing a cotton swab with alcohol and by releasing a couple of bursts of scent with pure alcohol (to clean the microholes of the piezoelectric). The cotton filter was replaced after every use.

6.2. Limitations

Further research needs to be conducted, including an objective measurement of physiological or brainwave data from the participants and a sample size larger than 40 users. The rationale behind not using biometric sensors in the current study was to avoid external variables that could have interfered with the olfactory interface ratings. There was a chance that adding sensors to the body or in the bed could negatively affect sleep due to discomfort of wearing a headband. Additionally, the primary interest of this study was on the usability and subjective experience using the olfactory device alone instead of validating the automatic sleep stage algorithm compared to Polysomnography. In future studies—and now that the olfactory device alone has been studied—the device can be compared to a traditional olfactometer and in a sleep laboratory. One last limitation worthy of mentioning is the complexities and artifacts that the EEG signal possesses while recording, especially in a mobile setting or unsupervised at home. Therefore, to avoid noise artifacts (especially those generated from the eye movements), we recommend choosing the Tp10 electrode for classification instead of the frontal electrodes (Af8, Af7).

6.3. Ethical Implications

Sleep interfaces that track our physiological signals, such as heart rate or brain waves, sleep patterns, and even potentially dream content, should be regulated to protect the individual's privacy and always to prioritize the users' wellbeing. In this research, some of these challenges were addressed by developing on-device machine learning that can run on the user's phone and using BLE instead of sending the data via WiFi to a server; hence the data is locally stored on the user's phone. The EEG device can monitor spontaneous activity from the brain to infer their sleep stages that are only displayed in their smartphone, and the user always has the control over the olfactory feedback provided at night by presetting the intensity and frequency on the app. However, there are still many challenges that need to be addressed and recognized when creating or using sleep UIs. It is not enough simply to note the existence of privacy challenges, and ethical codes for researchers, the potential misuses of these technologies should be spelled out to minimize the unexpected, adverse outcomes and maximize their positive impact. Sleep UIs can provide unique positive outcomes that otherwise might not be possible with regular UIs used during wakefulness. For example, researchers like Hu et al. (2015) and Arzi et al. (2014) are investigating and have shown promising results to address unconscious behaviors such as cognitive biases, phobias, or addictions.

6.4. Future Directions

A future research direction is to conduct a feasibility study in sleep laboratories and a clinical setting. We have already started running preliminary tests in a sleep laboratory with a high-density EEG (see **Supplementary Material** for details on the preliminary results). The results suggest that there is potential to conduct further studies combined with wearable EEGs and automatic sleep scoring (like the one presented in this article) as an alternative to high-density EEGs and manual sleep scoring and scent release. These systems could also be combined with wristbands to deliver heart rate and electrodermal activity on sleep-related events to the scent-delivery prototype. The hope is that the research presented in this article is a step toward making sleep experiments more accessible to everyone, including those that might not have the resources to build or access sleep laboratory equipment and to foster new ways to collaborate across disciplines. There are numerous applications to design Olfactory Interfaces based on proxemics and how active the interaction for Sleep UIs is. For example, scent can be released in a mobile and discrete manner during the day in indoor and outdoor environments. The same odor can be reactivated during specific sleep stages at night, strengthening the efficacy of such interventions. Some examples include using scent for targeted memory reactivation during sleep, reducing certain types of addictions (such as smoking behavior), scent-induced lucid dreaming as well as targeted memory reactivation for wellbeing applications (such as using scent during a meditative experience and releasing it while sleeping to reactivate that emotional state). There are many other futuristic, science fiction-inspired, and intriguing applications, such as storytelling through dreams and dream communication. However, the most beneficial and realistic applications for the design of technologies for the home environment in the next decade will be wellbeing-related. Improve sleep quality, reduce insomnia, nightmares, or maladaptive memories, and ease sleep apnea, snoring, jaw clenching, and counteract sleep disorders caused by stress and anxiety. Additionally, it would be interesting to investigate how the framework for Olfactory Proxemics defined in this article might apply to co-located users who need a remote synchronization of scent over distance. For example, remote communication, social media, telecommunication, remote VR applications, and co-located sleepers.

7. CONCLUSIONS

This article describes the development, study, and framework for Olfactory Interfaces and sleep. We describe these explorations in the context of their use in developing a modular, closed-loop sleep olfactory interface and a preliminary sleep experiment with 40 participants. The study results indicate that participants were satisfied with the prototype, the holder, and the smartphone application. They found the app easy to use, the device easy to refill, and the holder easy to set up. Compared to participants in the control condition (using Ezzence with water), those in the scent condition significantly improved their subjective sleep quality with respect to their regular sleep. More than three-quarters of the participants in the scent condition (using Ezzence with lavender, clary sage, and copaiba oil) did not report awakenings caused by the device. Furthermore, a significant number of participants using Ezzence with scent reported better mood the following morning than on their regular basis and reported falling asleep faster. Besides the study and development of this device, this article presents a framework on Sleep UIs' (user interfaces for sleep environments) and "Olfactory Proxemics" (scent interactions based on the distance between the origin of the scent-delivery device and the user).

This research aimed to shed light on using scent to improve wellbeing in-home sleep environments. We hope that the detailed reporting of the considerations when developing these interfaces and wearable scent-delivery systems will prove helpful to researchers from many fields, engineers, designers, and scientists alike.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Committee on the Use of Humans as Experimental Subjects (COUHES) at the Massachusetts Institute of Technology (MIT). The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

JA and PM designed the experiment. JA and MD developed Ezzence and carried out the experiments for all participants. JA analyzed the data and wrote the article. PM provided feedback about the data and article. MD provided help with figures and the mechanical design part of the article. All authors reviewed the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.791768/full#supplementary-material

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