Market Smells: Olfactory Detection and Identification in the Built Environment

Kara C. Hoover, Department of Anthropology, University of Alaska, Fairbanks, USA. email: kchoover@alaska.edu

Jessie Roberts, Centre for Research in Evolutionary, Social and Inter-Disciplinary Anthropology, University of Roehampton, London SW15 4JD U.K.

J. Colette Berbesque, Centre for Research in Evolutionary, Social and Inter-Disciplinary Anthropology, University of Roehampton, London SW15 4JD U.K. email: colette.Berbesque@roehampton.ac.uk

Correspondence to be sent to: Kara C. Hoover, Department of Anthropology, University of Alaska, Fairbanks, USA. email: kchoover@alaska.edu

ABSTRACT

The majority of studies on human olfaction are conducted under pristine lab conditions with pure odors delivered to the nostrils. While useful for extending our knowledge of human odor detection and perception as well as integration with the other senses, these experiments tell us little about how humans smell in natural environments—increasingly, the natural environment is the built environment. We must expand our focus of inquiry in order to understand how the human sense of smell operates to discern input from a welter of environmental sensory signals. This is critical because our sense of smell is increasingly challenged by the anthropogenic effects of modern life (which are also impacting animal populations and human populations leading non-urbanized or post-industrial lifestyles). To gather data on human ability to detect identify odors in the built environment, we asked volunteers at we asked volunteers at two different London-area food markets (one urban, one suburban) to smell four odors that were previously validated for UK populations. We were mainly interested in knowing how strong environmental signals (e.g., fish stalls, cooking foods) interfere with the ability to detect and identify odors 'under one's nose'. The results indicate that the sensory rich environment of the markets disrupted odor detection and identification ability when compared to lab-based results for UK populations. Further, we found that odors from cooking food were particularly and significantly disruptive. The larger implications of the study are that we must consider the human ecology of olfaction in addition to lab-based studies if we are to understand the functional use of our sense of smell. The applied implication of the study is that olfactory environments vary and that variation results in different lived experiences of the sensory environment.

Keywords: smelling the wild, human olfactory ecology, olfactory disruption, sensory disruption, odor detection, odor identification

INTRODUCTION

While much is known about the human ability to smell in pristine lab conditions, little is known about how humans smell in natural and built environments. In the lab, precisely measured odor dilutions are presented to subjects directly into the nostril, sometimes with all other senses blocked. The control over purity of odors in the lab is such an issue that one study has claimed even the tiniest impurity (non-GC-pure compounds) may lead to a difference in assessing olfactory receptor selectivity (Paoli and others 2017). Reducing all variables in a controlled setting allows investigation of very particular questions related to odor detection and perception. But what do these controlled experiments tell us about how the sense of smell operates in the natural environment, let alone what is the natural environment for modern humans today, the built environment? We were interested in assessing whether individuals in sensory rich areas (busy food markets vending fruit and vegetables alongside meat and fish as well as cooked foods) would have a similar ability to detect and identify odors as individuals in a lab environment. While our study has limitations (sample size, no repeat testing), it contributes intriguing preliminary results and constitutes the first step towards understanding the human ecology of olfaction.

Why study smelling in natural settings? There is a robust body of research in sensory ecology focused on anthropogenic disruptions to sensory-guided animal behavior—for example (Boivin and others 2016; Jürgens and Bischoff 2017; Kunc and others 2014; Morris-Drake and others 2016). There is much less known about the effects on humans (Hoover 2018a; 2018b). While the detrimental effects of modern lifestyles are well-studied in vision (He and others 2015; Holden and others 2016; Ip and others 2008a; Ip and others 2008b; Lin and others 2004; Robaei and others 2005; Rose and others 2008a; Rose and others 2008b) and audition (Agrawal and others 2008; Gopinath and others 2009), the sense of smell tends to be disregarded. Yet rates of smell loss may be as high as 20% globally—higher in practice because pollution diminishes olfactory capacity. According to the NIH, 2% of the US population suffers from some olfactory impairment due to genes, trauma, or infection (a rate equivalent to blindness). To make matters worse, the experience of pollution is differentially distributed with the most vulnerable populations (globally and locally) bearing a greater burden (Lewis 2016a; 2016b). Putting these two pieces of information together results in the conclusion that vulnerable populations are at greater risk of olfactory dysfunction (Hoover 2018a; 2018b).

Olfactory dysfunction results in chronic depression (Hummel and others 2017; Philpott and Boak 2014), influences food-guided behaviors that result in metabolic disorders (Boesveldt and de Graaf 2017; Obrebowski and others 2000; Ulusoy and others 2016), and is linked to decreased sociability, isolation, and weaker support systems (Croy and others 2013; Endevelt-Shapira and others 2017; Gaby and Zayas 2017; Li and others 2007; Mutic and others 2015; Prehn-Kristensen and others 2009; Zou and others 2016). The primary etiology of mild-to-moderate olfactory disfunction is pollution, particularly $PM_{2.5}$ (Ajmani and others 2016a; Ajmani and others 2016b; Ajmani and others 2017; Guarneros and others 2015; Guarneros and others 2009)—the effect is large with polluted urban areas suffering dysfunction at five-fold rate compared to rural areas (Hudson and others 2006). As most of the world is urbanized—the UN reports more than 54% of the world's population is concentrated in urban centers (Americas, 81%; Europe, 73; Africa, 40%; Asia 48%) with projected increases to 66% by 2050—the potential impact on our sense of smell is clear. Traffic appears to the major cause for concern (Ajmani and others 2016b) with up to eight times greater exposure to pollution when taking urban public transport compared to a car (Rivas and others 2017).

MATERIALS AND METHODS

Olfactory functioning is assessed through a lengthy process that involves odor threshold testing, discriminatory ability, and identification. The Sniffin' Sticks test (Hummel and others 1997) has been cross-culturally validated (Neumann and others 2012; Oniz and others 2013; Shu and others 2007; Yuan and others 2010) and one of the most common assessment tools used. Odors are delivered via pen-like devices which are used to test the lowest concentration of odor required for individual detection (threshold), distinction between different odors (discrimination), and ability to either name an odor or associate it with a like odors (identification) (Hummel and others 1997). Typical total scores for normosmic (functional senses of smell) individuals will be equal to or greater than 30.5 with individual tests scores as follows: greater than 6 (men) or 6.5 (women) for threshold, equal to or greater than 11 for discrimination, and equal to or greater than 12 for identification (Hummel and others 2007). Sniffin' Sticks test have been validated for UK populations (Neumann and others 2012), meaning that all odorants and verbal descriptors typically provided during the odorants during the identification part of testing have been confirmed to be culturally familiar to the subjects. Validation ensures that an unfamiliar odor or descriptor does not produce a false negative or positive. The UK validation study (Neumann and others 2012) did not vary hugely from the normative data (Hummel and others 2007) and resulted in the following average scores for normosmic individuals: 34.5 for total score, 8.3 for threshold, 12.5 for discrimination, and 13.6 for identification.

We were primarily interested in whether volunteers were able to identify or associate odors correctly in an environment with many conflicting background smells. Because volunteers were recruited from market shoppers, we limited the time asked of them for this pilot study by using the abbreviated four-odor identification test rather than the full 16 odor identification test. Odors we used overlap with the short screening test which has demonstrated accuracy in confirming normosmia and mild hyposmia (what we expect to be the case in a natural setting relative to lab-findings) (Mueller and Renner 2006). We made one modification to the protocol; rather than use the four verbal prompts for each odor in forced-choice manner, we let the volunteers name (or attempt to name) the odor themselves. Because there is a increased accuracy in identification performance when provided verbal information (Hummel and others 2007; Negoias and others 2010), we felt the forced-choice test might fail to capture a true difference in detection and identification ability.

Two London-area markets (St. Alban's and Borough) were visited during a period lasting from October to November 2017 due to difficulty in recruiting volunteers for the study. The Borough Market is London's oldest food market serving the area of Southwark in South London since at least 1276 but possibly earlier (boroughmarket.co.uk). The original market adjoined the south end of London Bridge but traffic congestion was too great by 1755 and the Mayor of London and the Commonalty of the City of London, who controlled the market by decree of Edward VI, abolished it (Act of 28 Geo. II cap. 9) and moved it to the current location south of the cathedral to Southwark and Borough High Streets (Roberts 1950). Borough Market is a semi-enclosed pedestrian zone with market stalls very close together and narrow pedestrian lanes. Some stalls prepare samples of cooked food and others vend cooked and raw food.

St. Alban's market is also a long-standing market, confirmed by King John of England in 1202 and founded officially by Royal Charter in 1553. Roughly 28 miles north and slightly west of London, the city is within the north London commuter belt; the market is located in St. Alban's city center and retail district along St Peters Street. St. Alban's market is closed to street traffic with stalls spaced widely apart. In terms of the smellscapes, the partial enclosure of the Borough Market concentrates odors in the local environment as compared to the open space at St. Alban's, where odors more rapidly diffuse.

A map (Figure 1) of the area with an anchor for each market (Borough ▲; St. Alban's ●) and smaller matching points representing the postcode information provided by volunteers was created in ArcGIS 10.5.1 (see Acknowledgements) (ESRI 2017). A few volunteers were from outside the London area (Liverpool and Leister) and were excluded from the map to preserve reader-friendly scale. Pollution data for $PM_{2.5}$ are also displayed on the map (using the most recent DEFRA dataset for 2013, https://uk-air.defra.gov.uk/data/gis-mapping). The average annual $PM_{2.5}$ background concentration at Borough Market (Postcode AL3 5DJ) is 12.5-15 μg m^{-3} and the roadside concentration for Southwark Street is 15-20 μg m^{-3}. The average annual $PM_{2.5}$ background concentration at St. Alban's Market (Postcode AL3 5DJ) is 10-12.5 μg m^{-3} and the roadside concentration for St. Peters Street is the same, 10-12.5 μg m^{-3}. Not only does the Borough Market have a higher annual average of $PM_{2.5}$ but it has an even higher roadside concentration adjacent to the market. While WHO guidelines recommend an annual mean cap at <10 μg m^{-3} or daily cap at <25 μg m^{-3}, no study has established that there is a 'safe' threshold (http://www.who.int/mediacentre/factsheets/fs313/en/).

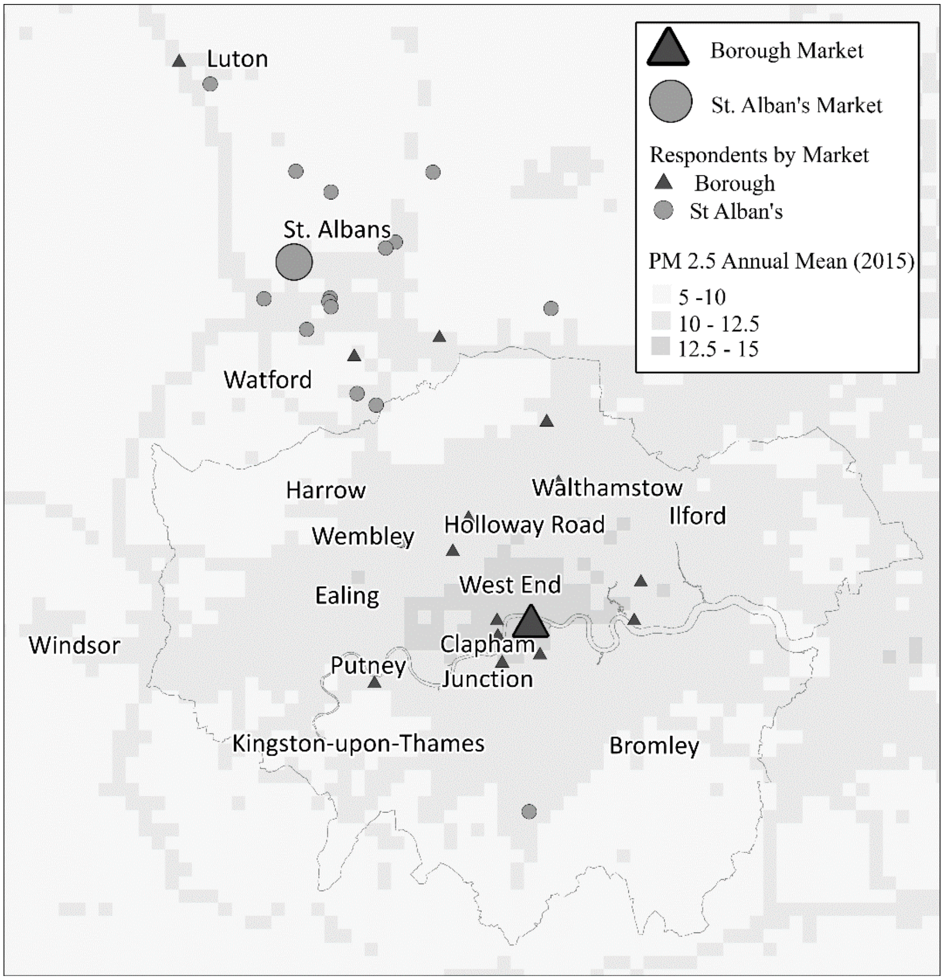


Figure 1: Map of market locations, participant postcodes, and $PM_{2.5}$ data (2015)

Thirty-nine adult volunteers (over the age of 18) were recruited: 19 at Borough Market and 20 at St. Albans Market. Data were collected on paper questionnaires that identified each volunteer by a unique number only. Raw data are reported in Supplementary Table 1. Volunteers were asked to smell four compounds: lemon, eucalyptus (mint), eugenol (clove), and phenylethanol (rose). The method of odor delivery was via the scented felt-tip pens by Burghart (Sniffin' Sticks), which were waved under the nose of the volunteer slowly three times. We anticipated that most individuals would correctly identify two odors based on the UK-based validation study of the Sniffin' Sticks test; most commonly identified odorants included peppermint (100%) and rose (~96%) Neumann, 2012 #3183}. Subjects in the validation study had trouble identifying lemon and clove—~26% had trouble with clove and ~30% had trouble with lemon (orange had a success rate in that study of ~94%) (Neumann and others 2012). Because the validation study was conducted in a lab environment using the forced-choice method, we assumed identification problems found in the lab would be magnified in the built environment.

Due to the small sample size, self-reported ethnic categories were reduced to Asian, Black, Other, White. Olfactory psychophysics data collected were coded in two variables: Detect describes whether or not the volunteer detects the odor and ID describes whether or not the volunteer correctly identified the odor (see Table 1:a-d for terms considered correct by odor). Total Detect and Total ID describe the composite score across odors per individual for each of these variables. Descriptive data were then recoded into categories (Table 1) and analyzed only for demographic variation and between-market differences. A final variable *interference* captures what we suspect may have been local interference with the smell testing (a hoped-for outcome from allowing volunteers to provide their own identifier) and derived from a high incidence of descriptors related to the smell of frying food.

	Odor	Category	Example Terms
a	Lemon	Citrus	lemon, orange, lime, citrus, fruit
b	Eucalyptus	Mint	menthol, mint, vapour rub, Vick's
c	Eugenol	Spice	clove or any spice (cinnamon most common) but not herbs
d	Phenylethanol	Flower	rose or any type of flower but not general outdoors descriptors
e		Other	idiosyncratic associations (e.g., scented candle, henna, Christmas)
f		Frying	frying smell, fried chicken
g		No association	can smell but not name or associate to a familiar smell
h		No odor	cannot smell[1]

[1]No odor was used for those who were unable to detect any odor from the pen.

Data were analyzed in the smallest possible units for demographic trends within and between markets before we tested the between-market difference. Psychophysical nominal data (Detect, ID) and nominal descriptors were analyzed using the Likelihood Ratio (LR) Test with exact significant values (2-sided). Scale data (Total Detect, Total ID) were analyzed via univariate methods. First, we tested within-market differences by demographic subgroup (age, ethnicity, sex). Second, we tested between-market differences demographic differences. Third, we tested overall between-market differences without consideration of demographic subgroups. Fourth, we compared Total ID in our sample to the identification results reported in the UK validation study of Sniffin' Sticks (Neumann and others 2012). Finally, modified descriptor data were tested for differences between markets and within demographic groups (age, ethnicity, sex).

Ethical considerations. Field research for this project was approved by the University of Roehampton Ethics Committee, approval number LSC 17/ 213 (JCB, KCH). All odors are common to the UK (Neumann and others 2012) and have caused no documented harm or ill effects. No personally identifying data were collected from any volunteer. Forms included a unique number and no other information than the answers. Written informed consent was acquired for all participants.

RESULTS

The sample (Table 2), though small, captures a wide demographic range, even if whites were predominant at St. Alban's in particular. There were no statistically significant differences between markets for age (Likelihood Ratio: 3.087, df: 4, p=0.619), sex (Likelihood Ratio: 1.301, df: 1, p=0.341), or self-reported ethnicity (Likelihood Ratio: 4.669, df:3; p=0.321).

Table 2: Sample Demographics

		Borough		St. Alban's		Total	
		n	Freq	n	Freq	n	Freq
Age Range	16-24	7	35%	7	37%	14	36%
	25-34	5	25%	3	16%	8	21%
	35-44	4	20%	2	11%	6	15%

	45-54	3	15%	3	16%	6	15%
	55-64	0	0%	0	0%	0	0%
	65+	1	5%	4	21%	5	13%
Sex	Female	11	55%	7	37%	21	54%
	Male	9	45%	12	63%	18	46%
Ethnicity	Asian	3	15%	3	16%	6	15%
	Black	1	5%	2	11%	3	8%
	Other	6	30%	1	5%	7	18%
	White	10	50%	13	68%	23	59%

Within-market variation (Table 3, Supplementary Tables 2 and 3). We first tested whether there any significant differences between demographic categories and psychophysical data; for example, were there ethnic differences in the perception of clove at the St. Alban's market or were females more likely than males to smell lemon? This resulted in three separate tests per market with group numbers varying depending on the variable: sex (2 groups), ethnicity (4 groups), age (5 groups). At the Borough Market, there were two significant LR results (Supplementary Table 2). For odor detection, there were significant associations for age with both mint (p=0.012) and clove (p=0.05). Half the individuals (n=4) in the 35-44 age bracket (which compromises 20% of the sample) could not smell mint and one in the 65+ age bracket. For clove, none of the individuals in the 55-64 age bracket could detect clove.

At St. Alban's Market, there were three significant LR results (Supplementary Table 2). For odor identification, there were significant associations between clove and all demographic categories. For sex and clove; females correctly identified clove more frequently than males. For ethnicity and clove, whites performed the worst (30%) and blacks slightly better (50%). For age and clove, younger groups and the 65+ age bracket were less able to identify clove.

We also tested within-market variation for scaled variables (total odors detected, total odors identified) by demographic subgroup. There was one significant within-market univariate result for age and total detected at the Borough Market; (F=6.48, df=4, p=0.02); this difference between ages had a large estimated effect size (.81). One additional univariate test worth noting is the association between age and total identified at St. Alban's which was close to statistically significant (p=0.08); power for this test was very low at 8% so the likelihood there was a significant different across age groups is high. The other tests had low power to detect a significant finding (Supplementary Table 3).

Table 3: Significant Results

	Association	**LR1**	**df**	**Exact p**	**Market**
Within	Detect-Mint*Age	11.36	4	0.01	Borough
	Detect-Clove*Age	7.94	4	0.05	Borough
	ID-Clove*Sex	5.25	1	0.05	St. Alban's
	ID-Clove*Ethnicity	7.24	3	0.09	St. Alban's
	ID-Clove*Age	11.18	4	0.05	St. Alban's
Between	Interference	7.38	1	0.05	Borough

Between-market within-demographic subgroup variation (Supplemental Tables 4-7). We tested whether there were any differences within demographic variable subgroups between the markets; for example, did females at St. Alban's Market detect more odors than females at Borough Market, did the 65+ age bracket detect mint less frequently than the 34-55 age bracket, or did whites identify cloves more frequently than Asians? There were no significant between-market LR results (Supplemental Tables 4-6).

There were two significant between-market univariate results for detection (F= 9.80, df=1, p=0.05) and identification (F= 9.80, df=1, p=0.05) in the 65+ age bracket (Supplemental Table 7).

Between-market variation (Table 3, Figure 2, Supplemental Tables 8 and 9). There was one significant LR result for the interference variable (use of the descriptor 'frying' and related terms) which was used exclusively at Borough Market (Table 3, Supplemental Table 8). There were no significant between-market univariate results for either of the scaled variables (Supplemental Table 9). The 95% Confidence Interval error bar plots (Figure 2) indicate slightly better performance at St. Alban's. But data by sex (because females outperformed males in our study) suggest more variation and a wider confidence interval at St. Alban's for both detection and identification for females (Figure 3); the reverse is true for males (Figure 3).

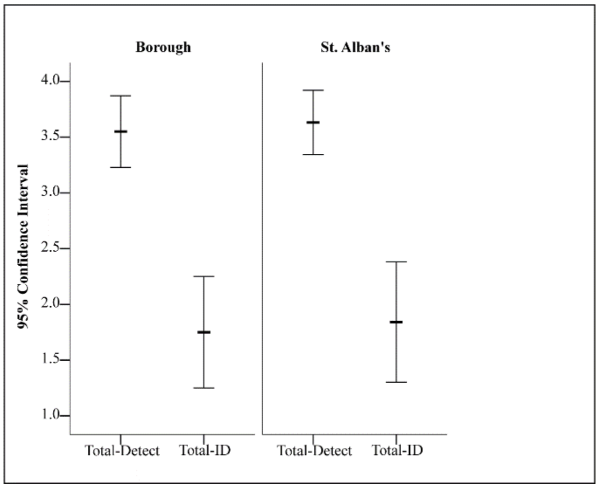


Figure 2: 95% Confidence Interval for Total Odors Detected and Identified, Market

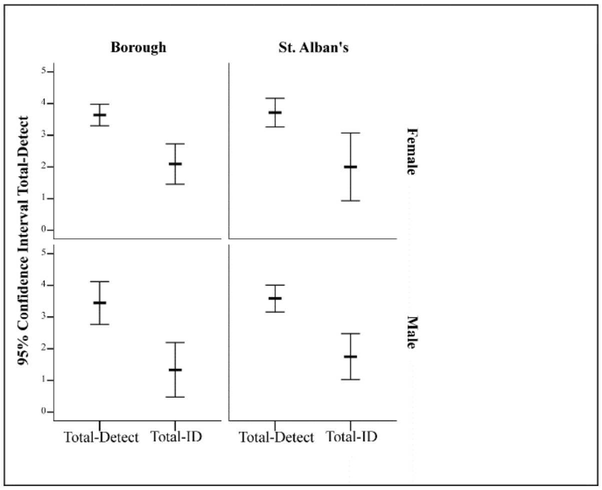


Figure 3: 95% Confidence Interval for Total Odors Detected and Identified, Sex by Market

Total ID (Table 4). For heuristic purposes, we compared the results of the total number of odors correctly identified in our study (TotalID) to a scaled mean total number of odors correctly identified in the UK validation study (Neumann and others 2012). By scaled, we refer to fact that the Sniffin' Sticks UK validation test used the full 16 odors but we only used four. The validation study reported a correct identification average of 13.6 for normosmic individuals; we scaled their result by 75% (to 3.4) in order to compare directly with our possible total of 4 correct. A one-sample t-test of comparison to the expected result of 3.4 was statistically significant for the total sample all but two subgroups: blacks and age bracket 45-55. Ability to identify odors is significantly lower at the markets than in the validation study.

Table 4: Sample Data Compared to UK Validation Study Identification mean

					95% CI						95% CI	
	n	**mean**	**SD**	**SE**	**Lower**	**Upper**	**t**	**df**	**Sig**	**Mean Diff**	**Lower**	**Upper**
Total	39	1.79	1.08	0.17	1.44	2.15	-9.28	38	**0.00**	-1.61	-1.96	-1.25
Borough	20	1.75	1.07	0.24	1.23	2.25	-6.90	19	**0.00**	-1.65	-2.15	-1.15
St. Alban's	19	1.84	1.12	0.26	1.30	2.38	-6.07	18	**0.00**	-1.56	-2.10	-1.02
Female	21	1.57	1.12	0.25	1.06	2.08	-7.47	20	**0.00**	-1.83	-2.34	-1.32
Male	18	2.06	1.00	0.24	1.56	2.55	-5.71	17	**0.00**	-1.34	-1.84	-0.85
Asian	6	1.67	1.03	0.42	0.58	2.75	-4.11	5	**0.01**	-1.73	-2.82	-0.65
Black	3	2.00	1.00	0.58	-0.48	4.48	-2.43	2	0.14	-1.40	-3.88	1.08
Other	7	2.14	0.90	0.34	1.31	2.97	-3.70	6	**0.01**	-1.26	-2.09	-0.43
White	23	1.70	1.19	0.25	1.18	2.21	-6.90	22	**0.00**	-1.70	-2.22	-1.19
18-24	14	1.93	0.92	0.25	1.40	2.46	-6.01	13	**0.00**	-1.47	-2.00	-0.94
25-34	8	1.25	0.89	0.31	0.51	1.99	-6.86	7	**0.00**	-2.15	-2.89	-1.41
35-44	6	1.50	1.05	0.43	0.40	2.60	-4.44	5	**0.01**	-1.90	-3.00	-0.80
45-55	6	2.83	0.98	0.40	1.80	3.87	-1.41	5	0.22	-0.57	-1.60	0.47
65+	5	1.40	1.34	0.60	-0.27	3.07	-3.33	4	**0.03**	-2.00	-3.67	-0.33

Descriptors. The LR results for lemon suggested no difference between markets (LR=0.593, df=3 p=1.00) (Supplementary Figure 1). The citrus descriptor group was the top association at both markets. Borough Market volunteers reported other descriptors or no association more often than St. Alban's volunteers, who reported a larger number not able to detect an odor.

The LR results for mint suggested no real difference between markets (LR=8.741, df=4, p=0.139) (Supplementary Figure 2). St. Alban's had a higher proportion of volunteers identifying mint. At both markets, the most common other descriptor was for Vick's (or rubbing vapor). St. Alban's exclusively used other terms for mint, often medicine. At Borough Market exclusively volunteers reported either an inability to detect an odor or described the odor as a *frying* smell (Supplementary Table 1).

LR results for clove suggested no difference between markets (LR=7.772, df=5, p=0.322) (Supplementary Figure 3). The number of people linking clove to a spice was higher at Borough Market; St. Alban's had more volunteers reporting other descriptors, which suggests greater difficulty in associating the smell with spice. But, Borough Market volunteers exclusively use the *frying* descriptor. St. Alban's exclusively linked clove to cleaning products (Supplemental Table 1).

The LR results for rose suggested no difference between markets (LR=7.730, df=4, p=0.173) (Supplementary Figure 4). The number of people linking rose to flowers was higher Borough Market; St. Alban's had more volunteers reporting other descriptors or not being able to associate it to a familiar odor, which suggests greater confusion in associating the smell. Borough Market volunteers exclusively use the *frying* descriptor. St. Alban's exclusively linked clove to cleaning products. A small number at St. Alban's linked rose to chemicals (Supplemental Table 1). Equally high numbers of volunteers at both markets were unable to detect an odor.

When descriptors were analyzed by sex with no market reference, there was one significant result and a few patterns emerged (Supplementary Table 10, Supplementary Figures 5-8). Females were slightly better at identifying lemon than males; in fact, there were a few males that reported not being able to detect the odor. Females were also better able to detect mint and used no association less frequently than males; but, only females reported the frying odor. There were significant between-sex differences in clove identification (LR=14.020, df=5, p=0.018); females strongly identified it as a spice, using other

associations less frequently than males; a few females reported the frying odor and a few males were not able to detect the odor. Oddly, males were much better than females at describing rose as flower; females were relatively split across categories (flower, other frying, no association, no smell) and had greater difficulty detecting it than males.
When descriptors were analyzed by ethnicity with no market reference, there was one significant result and a few patterns emerged (Supplementary Table 10, Supplementary Tables 9-12). Lemon was most easily identified by whites and slightly better identified by blacks. Whites unable to identify lemon had no other association for the odor as much as using some other odor term. Only whites and Asians were not able to detect the odor. Mint was identified readily by all ethnic groups with whites again having the most variation (using other terms or having no association more frequently). The Other category reported the frying odor instead of mint. Whites performed the worst on clove, associating it with other descriptors more frequently than spice and a larger proportion having no association. Only Asians and whites were not able to detect it. The same pattern holds for rose with whites performing significantly worse and associating it more frequently with other descriptors than with flower (LR=22.735, df=12, p=0.042); whites also had the largest proportion not detecting the odor (Asians and blacks were all able to detect it).

When descriptors were analyzed by age with no market reference, there were no significant results but a few patterns emerged (Supplementary Table 10, Supplementary Figures 13-16). Lemon was most readily identified by the younger age bracket with more variation introduced with age. Mint identified more frequently across all age brackets with more variation (and interference) in the younger age brackets. Clove was most easily identified by younger age brackets and shows the same pattern as lemon with peaks in the 18-24 and 35-44 age brackets. Rose shows the inverse with more variation in youth and a spike in correct identification in the 45-54 age bracket. With age odors, there is an increase in inability to detect with age and there is a skew towards younger age brackets in the presence of interference from frying.

DISCUSSION

The within-market LR results for Borough market suggested significant associations between detection of two odors (mint and clove) and age and the univariate analysis indicated a significant difference among age categories for odor detection—detection ability declined with age. The inability to detect mint is exclusive to the 35-44 and 65+ age brackets, but the break point is not clear because the 45-54 age brackets had a 100% identification rate. At the other end of the age spectrum, however, the 18-24 age bracket identification of mint is high who also exhibit more variation in other associations and the frying smell interference. Given the small number of individuals in each age bracket within markets, the significant findings are more likely a product of natural sensory senescence associated with age (despite a sharp break point beyond which older participants failed to detect the odor)—only repeated testing on the same individuals would establish a firm explanation for whether the effect was more likely environment or age.

The within-market results for St. Alban's Market suggested significant associations between clove identification and all demographic categories. As reflected in the Supplementary Figures (3, 7, 11), there is tremendous variation in clove identification. Between-sex differences result from females identifying clove more than males and males (those able to detect it) typically associating clove to other odors. Likewise, in all ethnicities except white, spice was the most common identification for clove; in whites, other associations are made with the odor. And, only in whites and Asians, is there a tendency to have no association (amongst those able to detect the odor). The majority of Asians in the study were Bangladeshi; while the Sniffin' Sticks have not been validated for southwest Asians, there is one published study of an odor test (I-Smell) in India that uses culturally relevant odors, including clove (Gupta and others 2013). The youngest age bracket had the most variation in clove identification and was only one of two age brackets (35-44 is the other) that had a high success rate. The same trend noted for mint is seen here: inability to detect occurs in the older age brackets. The univariate results suggest a significant age-related odor detection and identification association. Overall, however, average observed power to detect a significant finding was 25%, which drops to 20% when excluding the one high powered and significant result for age and identification. No conclusions are warranted but for the purposes of comparing markets, the lack of significant within-market variation is useful to have explored.

The between-market comparison only resulted in one significant finding. The 'frying' descriptor was used exclusively at the Borough Market and suggests a location specific food aroma that prevented volunteers from smelling the odor presented to them. Consider that mint was identified correctly 100% of the time by normosmics (and 72% of the time in individuals with olfaction dysfunction) in the UK validation study. In our study, only individuals at the Borough Market failed to identify it correctly, we might speculate that that environment has stronger odor profiles that disrupt local sense of smell. While age may be a factor because the sense of smell naturally declines with senescence (Doty and Kamath 2014), St. Alban's has a larger sample of individuals in older age brackets but a significant association between age and mint identification is not found. While the univariate results did not find a difference between markets, the confidence intervals suggest some areas for follow-up. Overall, Borough market volunteers had slightly lower accuracy in odor detection and identification; the wider confidence interval suggests a slightly less accurate estimate of the true parameter. The confidence intervals by sex suggest a difference between markets with females at Borough Market having narrower confidence intervals than males, suggesting the data for females better estimates the true parameter. Indeed, with the exception of the rose scent, females out-performed males in detection and identification, which reflects known sex-based difference in olfactory ability (Dalton and others 2002; Doty and others 1985; Doty and Cameron 2009; Oliveira-Pinto and others 2014).

We identified some trends in ethnic responses to odors. Culture shapes what odors may be readily identified by an individual. Anthropological studies on olfaction have focused primarily on indigenous populations so, while we have some data on variation in these cultures, we have few data on how ethnicity shapes olfaction (if at all) in multi-ethnic urban settings. The numerous Sniffin' Sticks cross-cultural validation studies are a useful starting place but limited to a narrow geographical range (mainly Europe with some in Asia). To date, there are no published cross-cultural validation studies of the Sniffin' Sticks assay in sub-Saharan Africa—one study has been conducted in North Africa in Egypt (Oleszkiewicz and others 2016)—or in southwest Asia, for instance.

The comparison between total odors identified in our study and the scaled mean total odors identified in the UK Sniffin' Sticks validation study (Neumann and others 2012) suggested that our volunteer ability to identify odors is significantly lower than expected. The UK validation study found lemon and clove were less successfully identified (25-35%) compared to mint and rose. While mint was easily the best recognized odor in this study (even if associated with Vick's as often as mint), it was only identified by 62% of volunteers (8% failed to detect the odor). And, rose was the hardest to detect (21% did not detect an odor) and identify (69% did not identify the odor) and the most easily disrupted by the frying odor at the Borough Market. Our results for lemon and clove fall far short of expectations as well. Clove was the second hardest to identify (36% identified the odor) and often had other associations beyond spice (e.g., Christmas, scented candle, cleaning supplies), including a rotten odor/association. Lemon was identified by 46% of volunteers (8% failed to detect an odor).

We were liberal in what was counted as a correct odor identification but we did not use the forced-choice protocol and, as a result, our findings may be regarded as heuristic. Going forward, we could interpret our results as method-derived or we could infer a real environmental effect from the market. There is circumstantial evidence in support of the latter. First, the mint and rose odors were highly identifiable in the validation study but volunteers at both markets were unable to detect either odors and a large proportion associated them with other descriptors—even the best-identified odor (mint) had a low success rate. Second, the inference from a frying smell (exclusive to Borough Market) impeded correct identification of all odors but lemon in a small portion of volunteers. Third, for most odors, other associations were often listed instead of the correct one. These association ranged from medical (e.g., smelling salts, dentist, Vick's) and cleaning smells (e.g., floor wipes) to outdoors (e.g., leaf, bark, wood, nature) and negative smells (e.g., chemical, plastic, rubber).

In conclusion, this pilot study explored individual ability to detect and identify four common odors (lemon, mint, clove, and rose) in the built environment, specifically sensory rich food markets. We used a common lab-based tool for assessing olfactory ability, the Sniffin' Sticks protocol, but modified the procedure by not allowing a forced-choice response for odor identification. The rationale was that we were most interested in the ability to identify and attempt to name familiar odors. We were liberal in our assessment of what constituted a correct identification (e.g., spice was accepted for clove). There are 2 key findings. First, odor detection and correct identification were significantly impeded at Borough Market (in comparison to St. Alban's); the welter of sensory inputs from the Borough Market appeared to disrupt the olfactory ability of volunteers, who focused instead on a stronger signal (e.g., frying food) or reported inability to detect the pen-derived odor. Second, volunteers in both markets performed significantly worse than in pristine laboratory conditions, which builds on the previous finding by indicating an overall reduced performance in sensory rich environments with competing and complex odors. We are planning a follow-up study with repeated measures (market, public space, reduced-odor environments) using both the forced-choice and the free description methods. Not only are rich odorscapes disruptive of ability to engage olfactory focus but, as previously mentioned, air pollution is a major factor (Ajmani and others 2016a; Ajmani and others 2016b; Ajmani and others 2017; Guarneros and others 2015; Guarneros and others 2009). The experience of air pollution varies by neighborhood with the most vulnerable populations experiencing the most pollution. To further complicate the issue, air pollution from volatile chemical products (VCPs) (e.g., pesticides, printer inks, adhesives, cleaning chemicals, personal care products) is increasingly a key environmental pollutant that affects both indoor and outdoor environments (McDonald and others 2018). As a result, our sense of smell is heavily disrupted (relative to lab expectations) in daily living in the built environment—smelling in the wild may be disruptive to individual ability to smell what is literally right under the nose (Hoover 2018a; 2018b). The larger implications are that we need to better characterize olfaction ability across ecological settings and the social implications are that the differential experience of local environment increases vulnerability of disruption in already vulnerable populations. This study is a valuable first step in exploring the human ecology of olfaction.

CONFLICT OF INTERESTS

There are no competing interests.

FUNDING

There was no funding for this study.

ACKNOWLEDGEMENTS

Dr. Jeremy W. Crampton (Department of Geography, University of Kentucky) for creating the study area map using DEFRA data.

REFERENCES

FIGURE LEGENDS

Fig. 1: Area map, including $PM_{2.5}$

Fig. 2: Between-markets, Confidence Interval Error Plot

Fig. 3: Between-markets, Confidence Interval Error Plot by Sex

Supplementary Fig. 1: Lemon Descriptors, by Market

Supplementary Fig. 2: Mint Descriptors, by Market

Supplementary Fig. 3: Clove Descriptors, by Market

Supplementary Fig. 4: Rose Descriptors, by Market

Supplementary Fig. 5: Lemon Descriptors, by Sex

Supplementary Fig. 6: Mint Descriptors, by Sex

Supplementary Fig. 7: Clove Descriptors, by Sex

Supplementary Fig. 8: Rose Descriptors, by Sex

Supplementary Fig. 9: Lemon Descriptors, by Ethnicity

Supplementary Fig. 10: Mint Descriptors, by Ethnicity

Supplementary Fig. 11: Clove Descriptors, by Ethnicity

Supplementary Fig. 12: Rose Descriptors, by Ethnicity

Supplementary Fig. 13: Lemon Descriptors, by Age

Supplementary Fig. 14: Mint Descriptors, by Age

Supplementary Fig. 15: Clove Descriptors, by Age

Supplementary Fig. 16: Rose Descriptors, by Age

REFERENCES

Agrawal Y, Platz EA, Niparko JK. 2008. Prevalence of hearing loss and differences by demographic characteristics among US adults: data from the National Health and Nutrition Examination Survey, 1999-2004. Arch. Intern. Med. 168(14):1522-30.

Ajmani GS, Suh HH, Pinto JM. 2016a. Effects of ambient air pollution exposure on olfaction: a review. Environ Health Perspect 124(11):1683-1693.

Ajmani GS, Suh HH, Wroblewski KE, Kern DW, Schumm LP, McClintock MK, Yanosky JD, Pinto JM. 2016b. Fine particulate matter exposure and olfactory dysfunction among urban-dwelling older US adults. Environ Res 151:797-803.

Ajmani GS, Suh HH, Wroblewski KE, Pinto JM. 2017. Smoking and olfactory dysfunction: A systematic literature review and meta-analysis. Laryngoscope 127(8):1753-1761.

Boesveldt S, de Graaf K. 2017. The differential role of smell and taste for eating behavior. Perception 46(3-4):307-319.

Boivin NL, Zeder MA, Fuller DQ, Crowther A, Larson G, Erlandson JM, Denham T, Petraglia MD. 2016. Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distributions. Proc Natl Acad Sci U S A 113(23):6388-6396.

Croy I, Bojanowski V, Hummel T. 2013. Men without a sense of smell exhibit a strongly reduced number of sexual relationships, women exhibit reduced partnership security - a reanalysis of previously published data. Biol Psychol 92(2):292-4.

Dalton P, Doolittle N, Breslin PAS. 2002. Gender-specific induction of enhanced sensitivity to odors. Nat Neurosci 5(3):199-200.

Doty RL, Applebaum S, Zusho H, Settle RG. 1985. Sex differences in odor identification ability: A cross-cultural analysis. Neuropsychologia 23(5):667-672.

Doty RL, Cameron EL. 2009. Sex differences and reproductive hormone influences on human odor perception. Physiology & behavior 97(2):213-28.

Doty RL, Kamath V. 2014. The influences of age on olfaction: a review. Front Psychol 5:20.

Endevelt-Shapira Y, Perl O, Ravia A, Amir D, Eisen A, Bezalel V, Rozenkrantz L, Mishor E, Pinchover L, Soroka T et al. . 2017. Altered responses to social chemosignals in autism spectrum disorder. Nat Neurosci.

ESRI. 2017. ArcGIS Desktop: Release 10.5.1. Redlands, CA: Environmental Systems Research Institute.

Gaby JM, Zayas V. 2017. Smelling is telling: Human olfactory cues influence social judgments in semi-realistic interactions. Chem Senses 42(5):405-418.

Gopinath B, Rochtchina E, Wang J, Schneider J, Leeder SR, Mitchell P. 2009. Prevalence of age-related hearing loss in older adults: Blue mountains study. Arch. Intern. Med. 169(4):415-418.

Guarneros M, Hudson R, Lopez-Palacios M, Drucker-Colin R. 2015. Reference values of olfactory function for Mexico City inhabitants. Arch Med Res 46(1):84-90.

Guarneros M, Hummel T, Martínez-Gómez M, Hudson R. 2009. Mexico city air pollution adversely affects olfactory function and intranasal trigeminal sensitivity. Chem. Senses 34(9):819-826.

Gupta N, Singh PP, Goyal A, Bhatia D. 2013. Assessment of Olfaction Using the "I-Smell" Test in an Indian Population: A Pilot Study. 65(1):6-11.

He M, Xiang F, Zeng Y, Mai J, Chen Q, Zhang J, Smith W, Rose K, Morgan IG. 2015. Effect of time spent outdoors at school on the development of myopia among children in China: a randomized clinical trial. J. Am. Med. Assoc. 314(11):1142-8.

Holden BA, Fricke TR, Wilson DA, Jong M, Naidoo KS, Sankaridurg P, Wong TY, Naduvilath TJ, Resnikoff S. 2016. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. Ophthalmology 123(5):1036-1042.

Hoover KC. 2018a. Sensory Disruption in Modern Living and the Emergence of Sensory Inequities. 91.

Hoover KC. 2018b. Sensory ecology and anthropogenic disruptions: is modern living killing the human senses? : Social Science Research Network.

Hudson R, Arriola A, Martínez-Gómez M, Distel H. 2006. Effect of air pollution on olfactory function in residents of Mexico City. Chem. Senses 31(1):79-85.

Hummel T, Kobal G, Gudziol H, Mackay-Sim A. 2007. Normative data for the "Sniffin' Sticks" including tests of odor identification, odor discrimination, and olfactory thresholds: an upgrade based on a group of more than 3,000 subjects. European archives of oto-rhino-laryngology : official journal of the European Federation of Oto-Rhino-Laryngological Societies (EUFOS) : affiliated with the German Society for Oto-Rhino-Laryngology - Head and Neck Surgery 264(3):237-43.

Hummel T, Sekinger B, Wolf SR, Pauli E, Kobal G. 1997. 'Sniffin' sticks': olfactory performance assessed by the combined testing of odor identification, odor discrimination and olfactory threshold. Chem. Senses 22(1):39-52.

Hummel T, Whitcroft KL, Andrews P, Altundag A, Cinghi C, Costanzo RM, Damm M, Frasnelli J, Gudziol H, Gupta N et al. . 2017. Position paper on olfactory dysfunction. Rhinology.

Ip JM, Rose KA, Morgan IG, Burlutsky G, Mitchell P. 2008a. Myopia and the urban environment: findings in a sample of 12-year-old Australian school children. Invest Ophthalmol Vis Sci 49(9):3858-63.

Ip JM, Saw SM, Rose KA, Morgan IG, Kifley A, Wang JJ, Mitchell P. 2008b. Role of near work in myopia: findings in a sample of Australian school children. Invest Ophthalmol Vis Sci 49(7):2903-10.

Jürgens A, Bischoff M. 2017. Changing odour landscapes: the effect of anthropogenic volatile pollutants on plant-pollinator olfactory communication. Funct Ecol 31:56-64.

Kunc HP, Lyons GN, Sigwart JD, McLaughlin KE, Houghton JD. 2014. Anthropogenic noise affects behavior across sensory modalities. Am. Nat. 184(4):E93-100.

Lewis SK. 2016a. Climate Justice: Blacks and Climate Change. Black Scholar 46(3):1-3.

Lewis SK. 2016b. An Interview with Dr. Robert D. Bullard. Black Scholar 46(3):4-11.

Li W, Moallem I, Paller KA, Gottfried JA. 2007. Subliminal smells can guide social preferences. Psychol Sci 18(12):1044-9.

Lin LL, Shih YF, Hsiao CK, Chen CJ. 2004. Prevalence of myopia in Taiwanese schoolchildren: 1983 to 2000. Ann. Acad. Med. Singapore 33(1):27-33.

McDonald BC, de Gouw JA, Gilman JB, Jathar SH, Akherati A, Cappa CD, Jimenez JL, Lee-Taylor J, Hayes PL, McKeen SA et al. . 2018. Volatile chemical products emerging as largest petrochemical source of urban organic emissions. 359(6377):760-764.

Morris-Drake A, Kern JM, Radford AN. 2016. Cross-modal impacts of anthropogenic noise on information use. Curr. Biol. 26(20):R911-R912.

Mueller C, Renner B. 2006. A new procedure for the short screening of olfactory function using five items from the "Sniffin' Sticks" identification test kit. Am. J. Rhinol. 20(1):113-6.

Mutic S, Parma V, Brunner YF, Freiherr J. 2015. You smell dangerous: Communicating fight responses through human chemosignals of aggression. Chem. Senses 41(1):35-43.

Negoias S, Troeger C, Rombaux P, Halewyck S, Hummel T. 2010. Number of descriptors in cued odor identification tests. 136(3):296-300.

Neumann C, Tsioulos K, Merkonidis C, Salam M, Clark A, Philpott C. 2012. Validation study of the 'Sniffin' Sticks' olfactory test in a British population: a preliminary communication. Clin. Otolaryngol. 37(1):23-27.

Obrebowski A, Obrebowska-Karsznia Z, Gawlinski M. 2000. Smell and taste in children with simple obesity. Int J Pediatr Otorhinolaryngol 55(3):191-196.

Oleszkiewicz A, Taut M, Sorokowska A, Radwan A, Kamel R, Hummel T. 2016. Development of the Arabic version of the “Sniffin’ Sticks” odor identification test. 273(5):1179-1184.

Oliveira-Pinto AV, Santos RM, Coutinho RA, Oliveira LM, Santos GB, Alho ATL, Leite REP, Farfel JM, Suemoto CK, Grinberg LT et al. . 2014. Sexual dimorphism in the human olfactory bulb: females have more neurons and glial cells than males. PLOS ONE 9(11):e111733.

Oniz A, Erdogan I, Ikiz AO, Evirgen N, Ozgoren M. 2013. The Modified Sniffin' Sticks Test in Turkish Population Based on Odor Familiarity Survey. J Neurol Sci 30(2):270-280.

Paoli M, Münch D, Haase A, Skoulakis E, Turin L, Galizia CG. 2017. Minute impurities contribute significantly to olfactory receptor ligand studies: tales from testing the vibration theory. 4(3).

Philpott CM, Boak D. 2014. The impact of olfactory disorders in the United Kingdom. Chem. Senses 39(8):711-718.

Prehn-Kristensen A, Wiesner C, Bergmann TO, Wolff S, Jansen O, Mehdorn HM, Ferstl R, Pause BM. 2009. Induction of Empathy by the Smell of Anxiety. PLOS ONE 4(6):e5987.

Rivas I, Kumar P, Hagen-Zanker A. 2017. Exposure to air pollutants during commuting in London: are there inequalities among different socio-economic groups? Environ Int 101:143-157.

Robaei D, Rose K, Ojaimi E, Kifley A, Huynh S, Mitchell P. 2005. Visual acuity and the causes of visual loss in a population-based sample of 6-year-old Australian children. Ophthalmology 112(7):1275-82.

Roberts H. 1950. 'Borough High Street'. In: Roberts H, Godfrey WH, editors. Survey of London: Volume 22, Bankside (The Parishes of St. Saviour and Christchurch Southwark). London: London County Council. p. 9-30.

Rose KA, Morgan IG, Ip J, Kifley A, Huynh S, Smith W, Mitchell P. 2008a. Outdoor activity reduces the prevalence of myopia in children. Ophthalmology 115(8):1279-85.

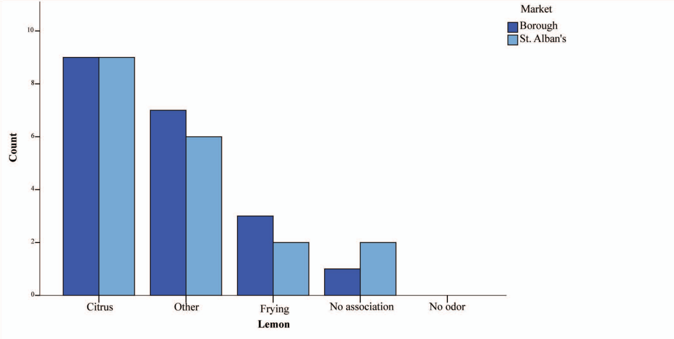
Rose KA, Morgan IG, Smith W, Burlutsky G, Mitchell P, Saw SM. 2008b. Myopia, lifestyle, and schooling in students of Chinese ethnicity in Singapore and Sydney. Arch. Ophthalmol. 126(4):527-30.

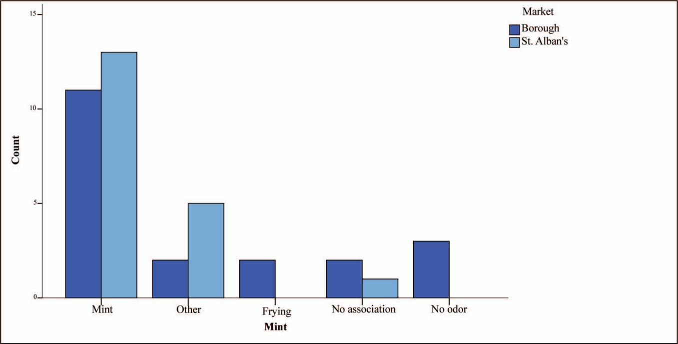
Shu C-H, Yuan B-C, Lin S-H, Lin C-Z. 2007. Cross-cultural application of the Sniffin' Sticks: odor identification test. Am J Rhinol 21(5):570-573.

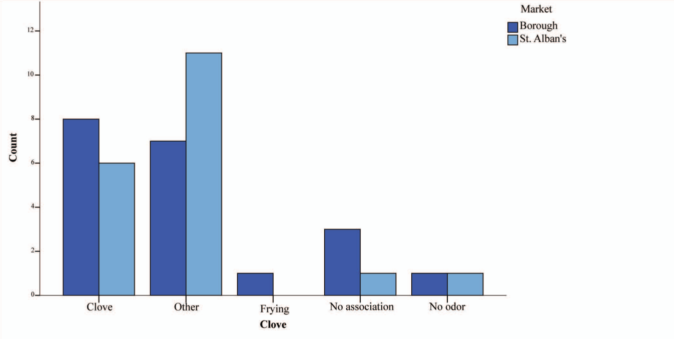
Ulusoy S, Dinc ME, Dalgic A, Topak M, Dizdar D, Is A. 2016. Are people who have a better smell sense, more affected from satiation? Braz J Otorhinolaryngol 16.

Yuan B-C, Lee P-L, Lee Y-L, Lin S-H, Shu C-H. 2010. Investigation of the Sniffin' Sticks Olfactory Test in Taiwan and Comparison With Different Continents. J Chin Med Assoc 73(9):483-486.

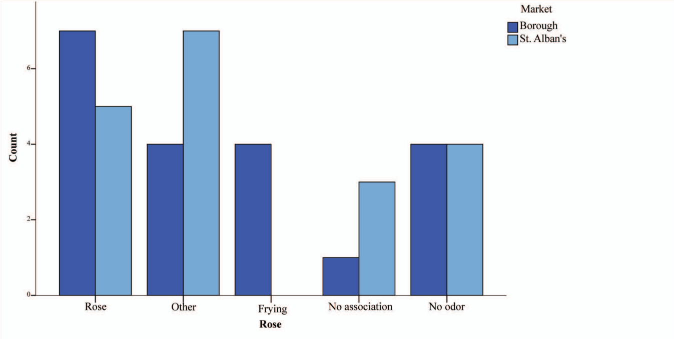
Zou LQ, Yang ZY, Wang Y, Lui SS, Chen AT, Cheung EF, Chan RC. 2016. What does the nose know? Olfactory function predicts social network size in human. Sci Rep 6:25026.

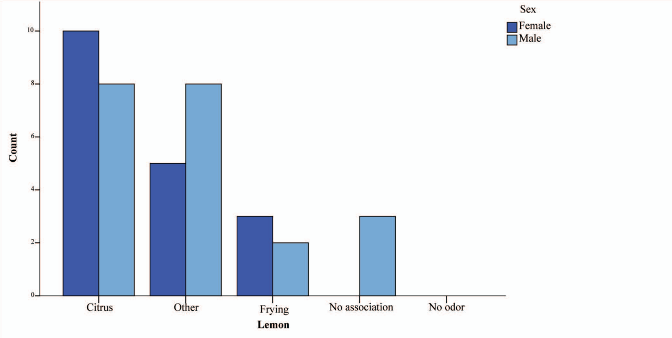

Market
Borough
St. Alban's
Count
10
8
6
4
2
0
Citrus
Other
Frying
No association
No odor
Lemon

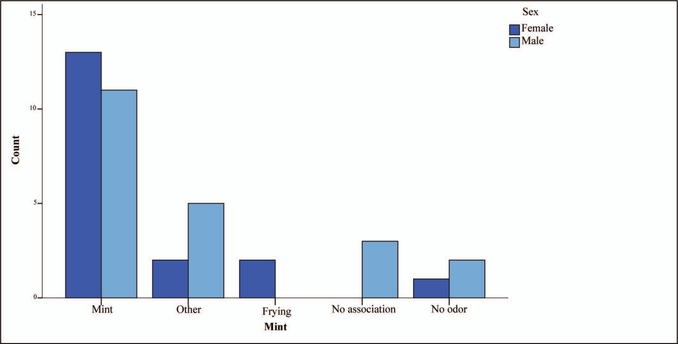

Market
Borough
St. Alban's
15
10
5
0
Count
Mint
Other
Frying
No association
No odor
Mint

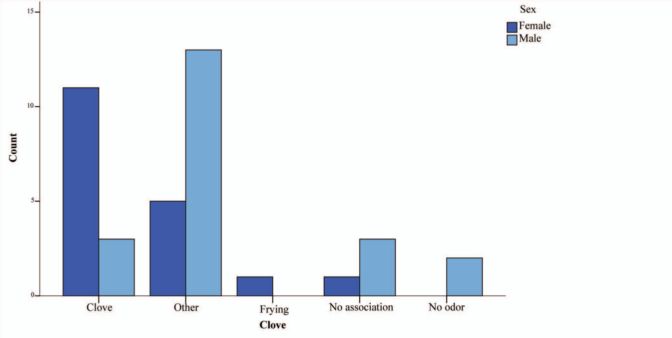


Market
Borough
St. Alban's
Count
12
10
8
6
4
2
0
Clove
Other
Frying
No association
No odor
Clove

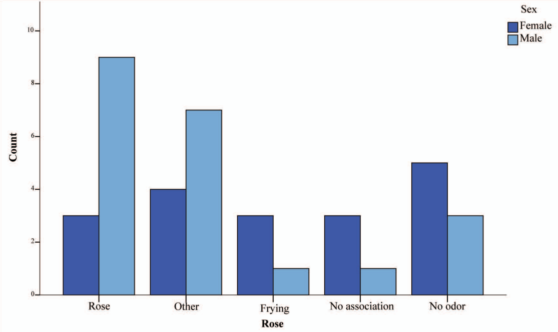

Market
Borough
St. Alban's
Count
0
2
4
6
Rose
Other
Frying
No association
No odor
Rose

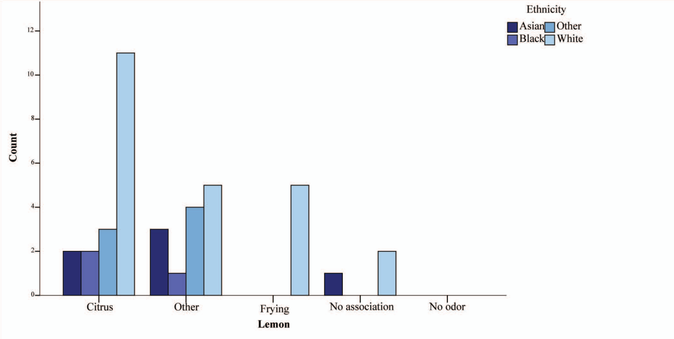

Sex
Female
Male
Count
10
8
6
4
2
0
Citrus
Other
Frying
No association
No odor
Lemon


Sex
Female
Male
Count
15
10
5
0
Mint
Other
Frying
No association
No odor
Mint

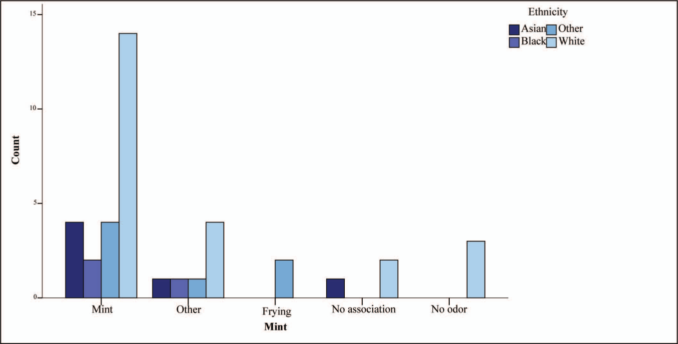


Sex
Female
Male
Count
15
10
5
0
Clove
Other
Frying
No association
No odor
Clove

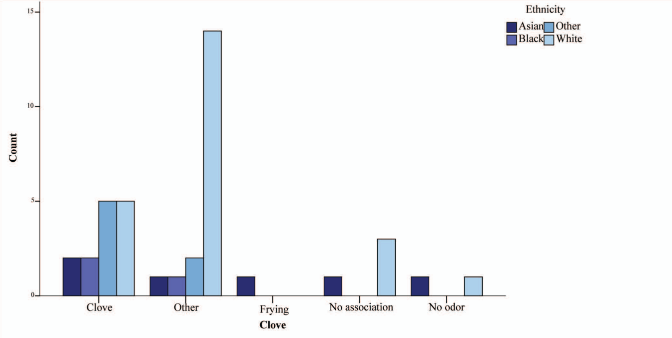

Sex
Female
Male
Count
10
8
6
4
2
0
Rose
Other
Frying
No association
No odor
Rose



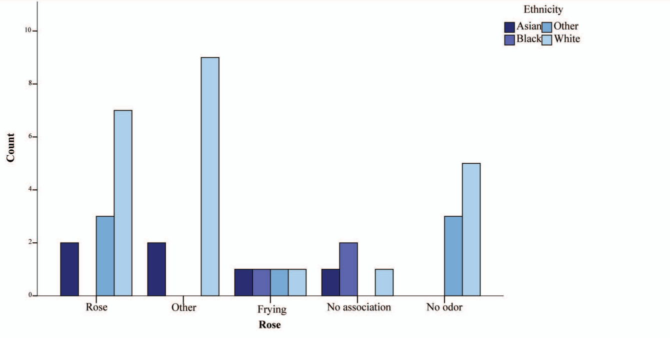
Ethnicity
Asian
Other
Black
White
Count
0
2
4
6
8
10
12
Citrus
Other
Frying
No association
No odor
Lemon



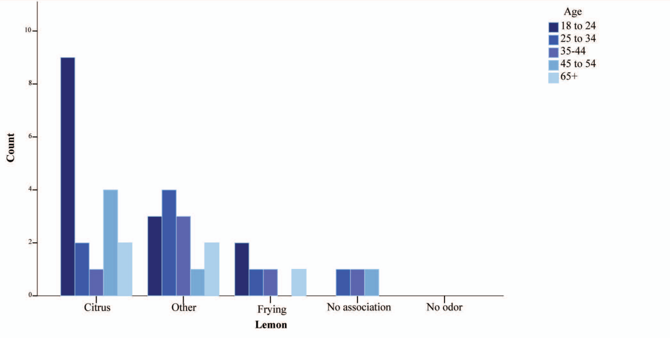
Ethnicity
Asian
Other
Black
White
Count
15
10
5
0
Mint
Other
Frying
No association
No odor
Mint

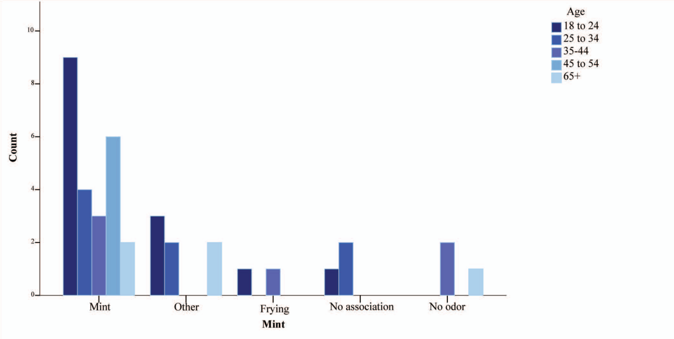


Ethnicity
Asian
Other
Black
White
Count
15
10
5
0
Clove
Other
Frying
No association
No odor
Clove

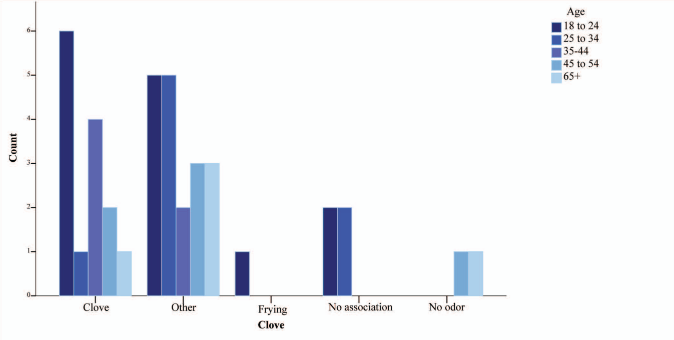


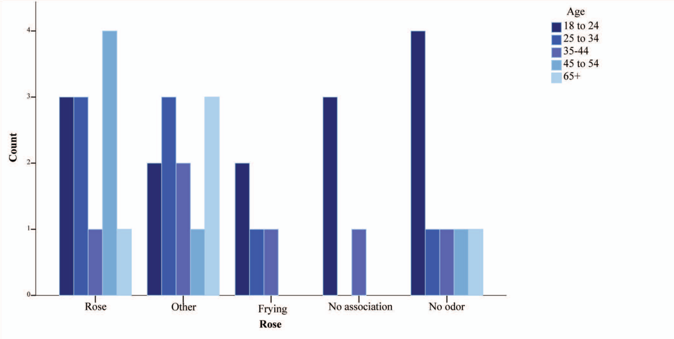
Ethnicity
Asian
Other
Black
White
Count
10
8
6
4
2
0
Rose
Other
Frying
No association
No odor
Rose


Age
18 to 24
25 to 34
35-44
45 to 54
65+
Count
10
8
6
4
2
0
Citrus
Other
Frying
No association
No odor
Lemon



Age
18 to 24
25 to 34
35-44
45 to 54
65+
Count
10
8
6
4
2
0
Mint
Other
Frying
No association
No odor
Mint


Age
18 to 24
25 to 34
35-44
45 to 54
65+
Count
0
1
2
3
4
5
6
Clove
Other
Frying
No association
No odor
Clove



Age
18 to 24
25 to 34
35-44
45 to 54
65+
Count
0
1
2
3
4
Rose
Other
Frying
No association
No odor
Rose