Market Smells: Odor 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 olfactory psychophysics data are from low odor labs using pure odors delivered directly to the nostrils. While useful, these experiments tell us little about human olfaction in natural environments, most commonly the built environment. We asked volunteers at London-area markets to smell four odors in order to determine if environmental signals (e.g., fish stalls, cooking foods) interfered with identifying odors under one's nose. We found that less than one odor per person was correctly identified. Further, we found that lemon had the highest market identification rate but was not as well identified in the lab. Do some odors have greater significance when smelled in the wild? While this study was limited (e.g., lack of repeated

measures, small samples), we feel it uncovers the value of incorporating ecology into research that seeks to understand the functional use of human olfaction.

Introduction

While much is known about the human ability to smell in low-odor lab environments, 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. Odor purity 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, Münch, Haase, Skoulakis, Turin, & Galizia, 2017) and another has claimed that background odors constitute a serious confounding effect on sensitivity testing (Oleszkiewicz, Rambacher, Whitcroft, & Hummel). 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 the modern natural environment that most humans find themselves in—the built environment?

We were interested in a rough quantification of how impactful a sensory rich environment (busy food markets vending fruit and vegetables alongside meat and fish as well as cooked foods) is on odor identification. We were also interested in whether individuals tested in a more polluted area would have poorer performance. While we recognize that design-based issues such as sample size and lack of repeat testing limit the power of the results, we feel the question (and our

findings) warrant further investigation. In addition, the results constitute the first step towards understanding the human ecology of olfaction.

Why study smelling in natural settings? There are a small number of papers focused on odor detection in different ecological settings which have resulted in some interesting findings—mainly that non-industrial populations may have a better sense of smell (Sorokowska, Sorokowski, & Hummel, 2014; Sorokowska, Sorokowski, Hummel, & Huanca, 2013; Sorokowski, Sorokowska, & Witzel, 2014) . Research on olfactory language has suggested a similar relationship (Burenhult & Majid, 2011; de Valk, Wnuk, Huisman, & Majid, 2017; Majid, 2015; Majid & Burenhult, 2014; Majid & Kruspe, 2018; Majid & Levinson, 2011; Majid & Senft, 2011; San Roque, Kendrick, Norcliffe, Brown, Defina, Dingemanse, Dirksmeyer, Enfield, Floyd, Hammond, Rossi, Tufvesson, Van Putten, & Majid, 2015; Wnuk & Majid, 2014). Finally, there is a robust body of research in sensory ecology focused on anthropogenic disruptions to sensory-guided animal behavior (for example, see Boivin, Zeder, Fuller, Crowther, Larson, Erlandson, Denham, & Petraglia, 2016; Jürgens & Bischoff, 2017; Kunc, Lyons, Sigwart, McLaughlin, & Houghton, 2014; Morris-Drake, Kern, & Radford, 2016)—but much less known about the effects on humans (Hoover, 2018a, 2018b).

Why study smelling in built environments? There is an established relationship between modern living and olfaction—chiefly, pollution damages olfactory soft and impedes olfactory acuity (for a review, see Ajmani, Suh, & Pinto, 2016). While the detrimental effects of modern lifestyles are well-studied in vision (for a recent paper, see He, Xiang, Zeng, Mai, Chen, Zhang, Smith, Rose, & Morgan, 2015; for a recent review, see Holden, Fricke, Wilson, Jong, Naidoo, Sankaridurg, Wong, Naduvilath, & Resnikoff, 2016) and audition (Agrawal, Platz, & Niparko, 2008; Gopinath, Rochtchina, Wang, Schneider, Leeder, & Mitchell, 2009), research on the sense of

smell is limited. 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 (Hoover, 2018a, 2018b; Lewis, 2016a, 2016b).

In this study, were interested in two key ideas. The first is whether smelling in the wild (natural or built settings) is very different from smelling in the lab. This is an important point to address because it opens up a new area for validation of smell assays in the wild that better characterize the breadth of the human olfactory performance across different settings. The second is whether pollution is playing a role in diminishing olfactory performance and this is tested by comparing data from two markets: one suburban with lower pollution and one urban with higher pollution. Olfactory ability is a critical component of health and well-being due to the many linkages between olfactory dysfunction and mental health (for recent reviews, see Rochet, El-Hage, Richa, Kazour, & Atanasova, 2018; Taalman, Wallace, & Milev, 2017), appetite regulation (Boesveldt & de Graaf, 2017; Obrebowski, Obrebowska-Karsznia, & Gawlinski, 2000; Ulusoy, Dinc, Dalgic, Topak, Dizdar, & Is, 2016; van Langeveld, Teo, de Vries, Feskens, de Graaf, & Mars, 2018), and sociability (Alves-Oliveira, Carvalho, Ferreira, Alho, Nobre, Olsson, & Soares, 2017; Bendas, Hummel, & Croy, 2018; Croy, Bojanowski, & Hummel, 2013; Lübke & Pause, 2015; Smiljana Mutic, Brünner, Rodriguez-Raecke, Wiesmann, & Freiherr, 2017; S. Mutic, Parma, Brunner, & Freiherr, 2015; Oettl & Kelsch, 2017; Oettl, Ravi, Schneider, Scheller, Schneider, Mitre, da Silva Gouveia, Froemke, Chao, Young, Meyer-Lindenberg, Grinevich, Shusterman, & Kelsch, 2016; Prehn-Kristensen, Wiesner, Bergmann, Wolff, Jansen, Mehdorn,

Ferstl, & Pause, 2009; White & Cunningham, 2017; Zou, Yang, Wang, Lui, Chen, Cheung, & Chan, 2016). A tertiary goal is to examine data also for sex differences, given that there are known sex-based differences in olfactory ability (Dalton, Doolittle, & Breslin, 2002; Richard L. Doty, Applebaum, Zusho, & Settle, 1985; R. L. Doty & Cameron, 2009; Oliveira-Pinto, Santos, Coutinho, Oliveira, Santos, Alho, Leite, Farfel, Suemoto, Grinberg, Pasqualucci, Jacob-Filho, & Lent, 2014). Thus, our general aim is to provide preliminary data on the ecology of human olfaction in the built environment with three questions:

1. Do subjects perform significantly worse in the wild compared to the lab?
2. Do individuals tested in a more polluted environment perform worse than those in the less polluted environment?
3. Do females perform better than males?

Materials

Two London-area markets (St. Alban's and Borough) were visited between October and November 2017. The Borough Market is London's oldest food market serving the area of Southwark in South London since at least 1276 ("Borough Market," 2018). Borough Market is a semi-enclosed pedestrian zone with market stalls very close together and narrow pedestrian lanes located at Southwark and Borough High Streets. 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 and the open space of St. Alban's Market diffuses odors more rapidly.

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 (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. As a visual aid to between-market pollution variation, the mass (per cubic meter) of small particulate matter ($PM_{2.5}$, air particles with a diameter less than 2.5µm) is displayed on the map (using the current 2015 DEFRA dataset, https://uk-air.defra.gov.uk/data/gis-mapping). $PM_{2.5}$ was selected because it is most implicated in olfactory dysfunction (see Ajmani et al., 2016) and typically derives from human sources (e.g., traffic emissions). 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.

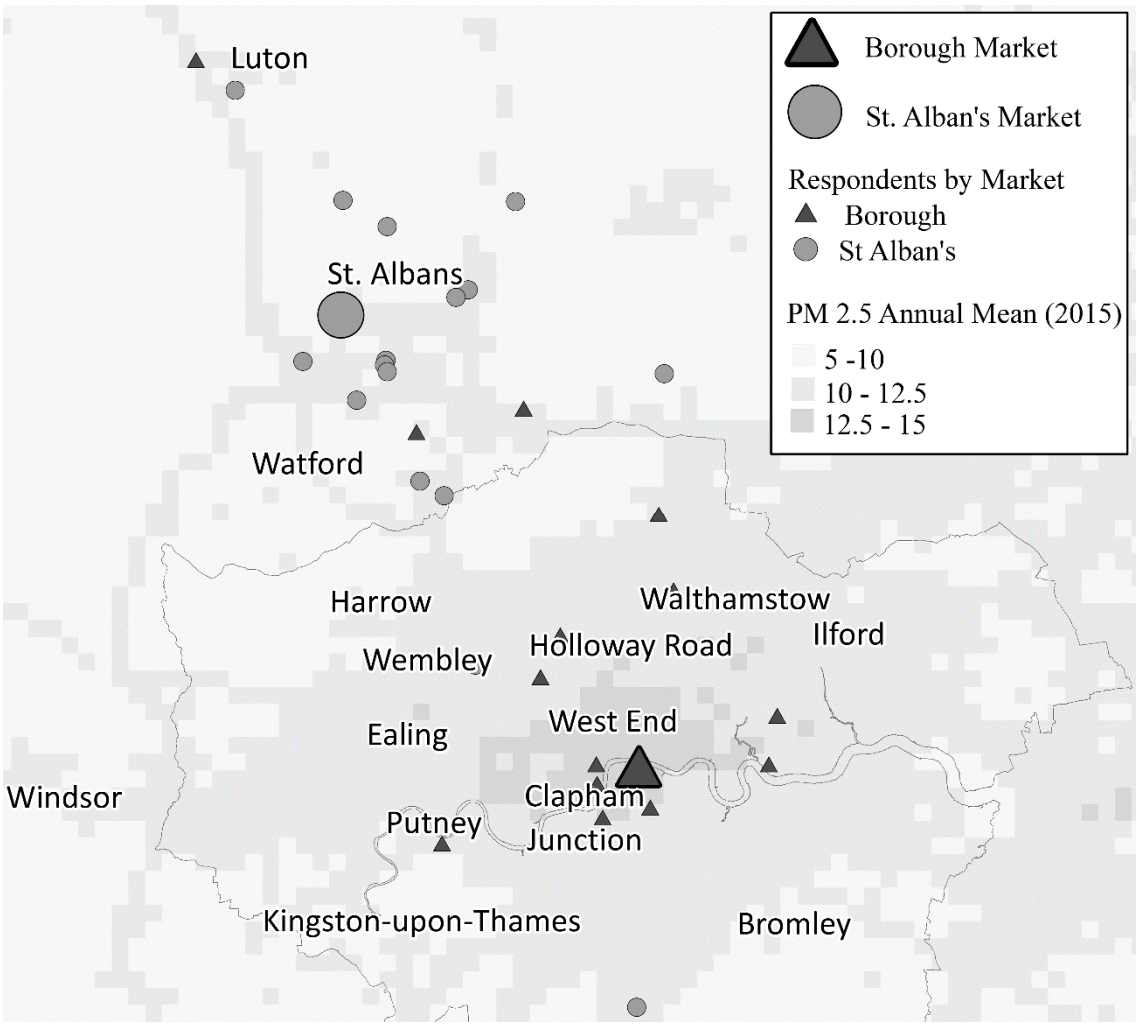

Fig. 1: Map of volunteer post codes, market locations, $PM_{2.5}$ data

The two markets share the characteristic of complex odorscapes but differ in terms of pollution levels and structural variables that influence odor diffusion. The structure of Borough Market aids odor concentration but that area experiences more pollution. The structure of St. Alban's Market aids odor diffusion but that area experiences less pollution. Each provides a different setting in which to test human ability to smell odors in the built environment.

Methods

Thirty-nine adult volunteers (over the age of 18) were recruited: 19 at Borough Market and 20 at St. Albans Market. For raw data, see Supplementary Table 1. Volunteer odor identification ability was assessed via the Sniffin' Sticks test (Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997), which has been validated in UK populations (Neumann, Tsioulos, Merkonidis, Salam, Clark, & Philpott, 2012). To ensure fresh materials, we purchased the smell training Sniffin' Sticks quartet specifically for this study three weeks prior to its commencement and stored them at the University of Roehampton at a temperature within the recommended range. The quartet contained lemon, eucalyptus, eugenol (clove), and phenylethanol (rose). We chose the smell training kit because those odors were validated to be familiar to the UK the time and required minimal time to administer—a small set of odors has been clinically shown to provide an initial baseline diagnosis of normosmia versus hyposmia if the odors are easily identifiable in the population (Mueller & Renner, 2006).

After removing the pen cap, the field worker (JR) placed the pen tip 2cm in front of the volunteer's nostrils then slowly moved the pen across the nostrils three times. Volunteers were given an interval of ~30 seconds between odors. We asked volunteers if they detected an odor and, if so, to describe it. Because there is increased accuracy in identification performance when provided verbal information (Hummel, Kobal, Gudziol, & Mackay-Sim, 2007; Negoias, Troeger, Rombaux, Halewyck, & Hummel, 2010), we felt the forced-choice test might fail to capture a true difference in identification ability. Further, forced-choice methods engage volunteers in the process of elimination, which may overcome individual variation in odor experience but may, more importantly, mask true olfactory ability by introducing guesswork (Kern, Wroblewski, Schumm, Pinto, & McClintock, 2014). While these issues are resolved in the full 16-odor identification kit, the small number of odors tested would be more susceptible. The free

description method using a short odor identification test has been validated previously in a field setting (Kern et al., 2014).

Descriptive answers were coded (correct, near miss, far miss) with near misses defined as ‘substances similar to and possibly confusable with test substances’ (Cain, 1979). Inter-observer (JCB, KCH) code agreement was analyzed by Cohen’s kappa (κ). A one-sample t-test was used to test the hypothesis that smelling in the wild is significantly different from smelling in the lab, using the scaled average odor identification score for UK normosmics, 3.4 (Neumann et al., 2012), as a test value. By scaled, we mean 25% of the correct identification score (maximum possible total of 16) to match the number of odors used in this study (n=4). For this test, we used two variables to compare to the test statistic: correct identification and pooled correct and near miss identification (due to the low number of correct answers across the sample). The Mann-Whitney U tested for significant between-market differences and between-sex differences. A post-hoc power analysis (due to small samples sizes) was conducted in G*Power {Faul, 2007 #4974}.

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 et al., 2012) and have caused no documented harm or ill effects. The collection of personal identifying information was limited to written informed consent and those data were limited to volunteer name (signed and printed). Data collection sheets were labelled with a unique numeric ID. The unique numeric ID was not noted on the informed consent which means no personally identifying information was linked to test data. The data collection sheet included basic demographic information (sex, age, ethnicity, postcode) and odor identification test data.

Results

Demographics. The sample (Supplementary 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).

Inter-observer agreement. Cohen's kappa suggested high inter-observer (JCB, KCH) agreement on coding descriptive terms (Table 1). In the final coded dataset, eucalyptus near misses included tea tree oil and all references to cough or decongestant treatments due to the use of eucalyptus as an active ingredient in many of these. Eugenol near misses included cinnamon and nutmeg due to their common association in baking and one response for cough sweets because clove is used in flavoring some cough medicine. Lemon near misses were lime and orange. There were no near misses for phenylethanol; the only specific flowers named in our study were lily and lavender, which are not similar substances.

Table 1: Inter-observer reliability test results for descriptor codes

	κ	Asymp SE	Approx T	Approx Sig
Eucalyptus	**0.39**	**0.12**	**4.14**	**0.00**
Eugenol	**0.54**	**0.10**	**6.24**	**0.00**
Lemon	**0.80**	**0.08**	**9.57**	**0.00**
Phenylethanol	**0.61**	**0.09**	**7.35**	**0.00**

Question 1. 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 identify odors as individuals in a lab environment. Do subjects perform significantly worse in the wild compared to the lab? When counting only correct identifications, the average of correct identification is less than one per person. When counting correct and near miss correct identifications, the average is one per person (Table 2, Figure 2). A post-hoc achieved power analysis using a medium effect size (0.50) suggests adequate power (0.92).

Figure 2: Sunburst chart of descriptor terms from volunteers

Question 2. We were also interested in whether individuals tested in a more polluted area would have diminished olfactory performance. Do individuals tested in a more polluted environment perform worse than those in the less polluted environment? The Mann Whitney U test for between-market difference suggested no significant differences (Table 3). A post-hoc achieved power analysis for means difference using (0.50) suggests low power (0.33). We expected a medium effect size due to prior studies showing the impact of pollution diminishing olfactory function up to 20% {Guarneros, 2015 #3934;Hudson, 2006 #2351}.

Table 2: T-test for between-market difference in Total Correct odor identification and Total Correct + Near Miss odor identification

Test Value=3.4	n	Mean	SD	SEM	t	df	Sig.	Mean Diff	95% CI Diff	
									Lower	Upper
Total Correct	39	0.36	0.54	0.09	-35.34	38	0.00	-3.04	-3.22	-2.87
Total Correct + Near Miss	39	1.00	0.79	0.13	-18.86	38	0.00	-2.40	-2.66	-2.14

Question 3. Do females perform better than males? The Mann Whitney U test for between-sex difference suggested no significant differences (Table 4). A post-hoc achieved power analysis using a medium effect size (0.50) suggests low power (0.46). We expected a medium effect given prior studies demonstrating a clear difference in male and female olfactory ability (see Introduction for full discussion).

Table 3: Mann Whitney test results for between-sex differences

	By Market	p*	By Sex	p*
n	39		39	
Eucalyptus	127.00	0.08	202.5	0.707
Eugenol	184.50	0.88	247	0.106

Lemon	**165.50**	**0.50**	**234**	**0.213**
Phenylethanol	**180.50**	**0.79**	**128**	**0.088**

***Exact 2-tailed**

Discussion

The most common incorrect odor identifications in the UK validation study that overlap with this study were clove (26%) and lemon (30%)—rose was only misidentified by 23% of the patients and menthol was listed only as a distractor (Neumann et al., 2012). In our study, lemon was the most identifiable odor but was still only correctly identified by 22% of the total sample that could smell an odor (n=36). Cloves and rose were correctly identified, respectively by only 8% and 10% of the total sample that could smell an odor (n=37 and n=31, respectively)—20% of the volunteers could not detect the rose odor which is striking compared to the lower rates for the other odors (5-8% unable to smell an odor). Not one volunteer correctly identified eucalyptus.

The free description responses exclusively pointed to some environmental interference at Borough Market from food that created the illusion the sticks were filled with a fried food smell. Individuals who described an odor as fried food or frying did not do so for all odors presented which is interesting—the total time for the test was less than three minutes and a frying smell present for one odor would be there for all odors. In other words, subjects were not consistently reporting fried food for all odors which suggests some may have been attributing the smell to the stick. That location specific food aroma prevented volunteers from smelling the odor presented to them and may be masking true differences between markets. Common associations for eucalyptus were cough and cold medicines while common associations for eugenol were Christmas spices or related spices. Lemon solicited descriptions of cleaning fluids and wood/forest/trees.

The comparison between total odors identified in our study and the scaled mean total odors identified in the UK Sniffin' Sticks validation study (Neumann et al., 2012) suggested that our volunteer ability to identify odors is significantly lower than expected. Despite small sample size, the achieved power is high. There is a significant difference in olfactory ability in market settings compared to data from laboratory settings for the larger UK population. Without having comparative lab-based data for the market volunteers, we cannot draw broad conclusions but the dramatic difference in results is not statistically likely to be attributed to a sample of poor smellers. Further, the tools were purchased three weeks prior to the study and stored in the recommended conditions. Rather, the results suggest that background odors mask olfactory ability and demonstrate how different the sense of smell may be functioning in the environment. For instance, the fact that some odors are very familiar and easily identifiable in a low odor environment does not indicate that those odors are ones to which we are specifically tuned. In this small study, lemon appeared to the odor that most strongly overcame the impact of frying smells across volunteers that reported the interfering smell—give that each of those volunteers had only 30 seconds between odors and that each were tested at different times, the strength of the lemon signal compared to the other odor signals cannot be explained by differences in test conditions or differences in environment between odor exposure. Perhaps lemon is an odor that signals Vitamin C—something that humans (and some related primates and rodents) cannot synthesize, unlike the majority of mammals (Montel-Hagen, Kinet, Manel, Mongellaz, Prohaska, Battini, Delaunay, Sitbon, & Taylor, 2008). What that supposition is beyond the scope of the paper, the idea that some odors might have evolutionary significant (likely related to food), is raised here. What odors are providing strong environmental signals that evoke an evolutionarily (or even culturally) patterned response?

Given that olfactory performance is worse in natural (here, built) environments, we further explored whether pollution levels further differentiated olfactory ability. There were no significant differences between markets but we have noted that market conditions may have mitigated the impact of pollution and we also note the small sample size failed to achieve adequate power to detect a difference. Borough Market, while more polluted has an architecture that serves to concentrate odors due to the closeness of the stalls and the relatively enclosed market space. St. Alban's, by way of comparison, has lower rates of pollution but the open-style market space enables odors to diffuse more rapidly. While there is no statistical difference in odor identification between markets, the explanation may be more complicated than pollution not having a confounding effect on olfactory ability.

Given that there are known sex-based differences in olfactory ability (Dalton et al., 2002; Richard L. Doty et al., 1985; R. L. Doty et al., 2009; Oliveira-Pinto et al., 2014), we expected females might perform better than males but our analysis showed no significant differences. The small sample size did not allow sufficient power for a one-tailed means comparison and might have failed to capture a significant result. Another possibility worth additional data collection is that perhaps the greater acuity of females in lab settings is not transferrable to natural (here, built) environments, which raises interesting questions about the evolutionary and biological significance of better olfactory ability in females as having some meaningful function relative to child-bearing (for a recent review, see Lübke et al., 2015).

In conclusion, this initial exploratory study on smelling in the wild found that individual ability to identify four common odors (eucalyptus, eugenol clove, lemon, phenylethanol) in impaired in the built environment, specifically sensory rich food markets. We used a field-validated approach that allowed free description of odor identification (Kern et al., 2014). There are a few key

results that open avenues of further research. First, odor identification is significantly impeded in market settings compared to lab settings. Second, odors more readily identified in the lab are not equivalently identified in the field. Converse to the UK validation study, lemon was the most identifiable odor (20% of the time) and the variation arising from environmental odor tuning compared to lab odor identification is one worth exploring further. A related finding is what background interference overcomes specific odors, such as the Borough Market olfactory illusion that the stick contained a fried food odor. Third, sex-based differences were not significant nor were pollution. These two areas are worth further consideration in larger samples across a wider range of environments as the tests are statistically underpowered due to small sample sizes. We aim to pursue these new questions in a follow-up study that will include repeated measures in three smellscapes (market, polluted street, reduced-odor environments) that will test odor identification of the top 5 recognized odors in the UK using the short-screening method (Mueller et al., 2006) and free description (Kern et al., 2014).

Our study shows that our sense of smell is heavily disrupted in daily living by the odorscape of 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). More importantly, there may be some odors that rise above the noise, perhaps due to evolutionary tuning or perhaps due to cultural significance. The ecological salience of olfactory ability has thus far been completely ignored. We need to better characterize olfaction ability across ecological settings in order to understand and contextualize the evolution of human olfaction and the implications of olfaction function in natural and built environments. The social implications of this research are that the local environment increases vulnerability of olfactory disruption in already vulnerable populations. While we recognize that the significance of our results are limited by small sample

size and research design (particularly the absence of repeated measures), the study is a valuable first step in exploring the human ecology of olfaction and has uncovered some interesting research pathways.

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

Agrawal, Y., Platz, E. A., & Niparko, J. K. (2008). Prevalence of hearing loss and differences by demographic characteristics among US adults: data from the National Health and Nutrition Examination Survey, 1999-2004. *Archives of Internal Medicine, 168*(14), 1522-1530. doi:10.1001/archinte.168.14.1522

Ajmani, G. S., Suh, H. H., & Pinto, J. M. (2016). Effects of ambient air pollution exposure on olfaction: a review. *Environmental Health Perspectives, 124*(11), 1683-1693. doi:10.1289/EHP136

Alves-Oliveira, P., Carvalho, J., Ferreira, J., Alho, L., Nobre, P., Olsson, M. J., & Soares, S. C. (2017). Influence of body odors and gender on perceived genital arousal. *Archives of Sexual Behavior*. doi:10.1007/s10508-017-1091-5

Bendas, J., Hummel, T., & Croy, I. (2018). Olfactory Function Relates to Sexual Experience in Adults. *Archives of Sexual Behavior*. doi:10.1007/s10508-018-1203-x

Boesveldt, S., & de Graaf, K. (2017). The differential role of smell and taste for eating behavior. *Perception, 46*(3-4), 307-319. doi:10.1177/0301006616685576

Boivin, N. L., Zeder, M. A., Fuller, D. Q., Crowther, A., Larson, G., Erlandson, J. M., . . . Petraglia, M. D. (2016). Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distributions. *Proceedings of the National Academy of Sciences of the United States of America, 113*(23), 6388-6396. doi:10.1073/pnas.1525200113

Borough Market. (2018).

Burenhult, N., & Majid, A. (2011). Olfaction in Aslian ideology and language. *Sens Soc, 6*, 19-29.

Cain, W. (1979). To know with the nose: keys to odor identification. *203*(4379), 467-470. doi:10.1126/science.760202

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. *Biological Psychology, 92*(2), 292-294. doi:10.1016/j.biopsycho.2012.11.008

Dalton, P., Doolittle, N., & Breslin, P. A. S. (2002). Gender-specific induction of enhanced sensitivity to odors. *Nature Neuroscience, 5*(3), 199-200. doi:http://www.nature.com/neuro/journal/v5/n3/suppinfo/nn803_S1.html

de Valk, J. M., Wnuk, E., Huisman, J. L. A., & Majid, A. (2017). Odor–color associations differ with verbal descriptors for odors: a comparison of three linguistically diverse groups. *Psychon Bull Rev*, *24*(4), 1171-1179. doi:10.3758/s13423-016-1179-2

Doty, R. L., Applebaum, S., Zusho, H., & Settle, R. G. (1985). Sex differences in odor identification ability: A cross-cultural analysis. *Neuropsychologia*, *23*(5), 667-672. doi:http://dx.doi.org/10.1016/0028-3932(85)90067-3

Doty, R. L., & Cameron, E. L. (2009). Sex differences and reproductive hormone influences on human odor perception. *Physiology and Behavior*, *97*(2), 213-228. doi:10.1016/j.physbeh.2009.02.032

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

Gopinath, B., Rochtchina, E., Wang, J., Schneider, J., Leeder, S. R., & Mitchell, P. (2009). Prevalence of age-related hearing loss in older adults: Blue mountains study. *Archives of Internal Medicine*, *169*(4), 415-418. doi:10.1001/archinternmed.2008.597

He, M., Xiang, F., Zeng, Y., Mai, J., Chen, Q., Zhang, J., . . . Morgan, I. G. (2015). Effect of time spent outdoors at school on the development of myopia among children in China: a randomized clinical trial. *Journal of the American Medical Association*, *314*(11), 1142-1148. doi:10.1001/jama.2015.10803

Holden, B. A., Fricke, T. R., Wilson, D. A., Jong, M., Naidoo, K. S., Sankaridurg, P., . . . Resnikoff, S. (2016). Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology*, *123*(5), 1036-1042. doi:http://dx.doi.org/10.1016/j.ophtha.2016.01.006

Hoover, K. C. (2018a). Anthropogenic disruptions: is modern living killing the human senses? In: Social Science Research Network.

Hoover, K. C. (2018b). Sensory Disruption in Modern Living and the Emergence of Sensory Inequities. *91*.

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), 237-243. doi:10.1007/s00405-006-0173-0

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

Jürgens, A., & Bischoff, M. (2017). Changing odour landscapes: the effect of anthropogenic volatile pollutants on plant-pollinator olfactory communication. *Functional Ecology, 31*, 56-64. doi:10.1111/1365-2435.12774

Kern, D. W., Wroblewski, K. E., Schumm, L. P., Pinto, J. M., & McClintock, M. K. (2014). Field Survey Measures of Olfaction:The Olfactory Function Field Exam (OFFE). *26*(4), 421-434. doi:10.1177/1525822x14547499

Kunc, H. P., Lyons, G. N., Sigwart, J. D., McLaughlin, K. E., & Houghton, J. D. (2014). Anthropogenic noise affects behavior across sensory modalities. *Am. Nat., 184*(4), E93-100. doi:10.1086/677545

Lewis, S. K. (2016a). Climate Justice: Blacks and Climate Change. *Black Scholar, 46*(3), 1-3. doi:10.1080/00064246.2016.1188350

Lewis, S. K. (2016b). An Interview with Dr. Robert D. Bullard. *Black Scholar, 46*(3), 4-11. doi:10.1080/00064246.2016.1188351

Lübke, K. T., & Pause, B. M. (2015). Always follow your nose: The functional significance of social chemosignals in human reproduction and survival. *Hormones and Behavior, 68*(0), 134-144. doi:http://dx.doi.org/10.1016/j.yhbeh.2014.10.001

Majid, A. (2015). Cultural factors shape olfactory language. *Trends in Cognitive Sciences, 19*. doi:10.1016/j.tics.2015.06.009

Majid, A., & Burenhult, N. (2014). Odors are expressible in language, as long as you speak the right language. *Cognition, 130*(2), 266-270. doi:http://dx.doi.org/10.1016/j.cognition.2013.11.004

Majid, A., & Kruspe, N. (2018). Hunter-gatherer olfaction is special. *28*(3), 409-413.e402. doi:10.1016/j.cub.2017.12.014

Majid, A., & Levinson, S. C. (2011). The senses in language and culture. *Sens Soc, 6*(1), 5-18. doi:10.2752/174589311X12893982233551

Majid, A., & Senft, G. (2011). Categories across language and cognition. In E. Giering, R. Sheer, M. Tinbergen, & A. Verbunt (Eds.), *Categories across Language and Cognition*. Nijmegen, Netherlands: Max Planck Institute for Psycholinguistics.

Montel-Hagen, A., Kinet, S., Manel, N., Mongellaz, C., Prohaska, R., Battini, J.-L., . . . Taylor, N. (2008). Erythrocyte Glut1 Triggers Dehydroascorbic Acid Uptake in Mammals Unable to Synthesize Vitamin C. *132*(6), 1039-1048. doi:10.1016/j.cell.2008.01.042

Morris-Drake, A., Kern, J. M., & Radford, A. N. (2016). Cross-modal impacts of anthropogenic noise on information use. *Current Biology, 26*(20), R911-R912. doi:10.1016/j.cub.2016.08.064

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. *American Journal of Rhinology, 20*(1), 113-116.

Mutic, S., Brünner, Y. F., Rodriguez-Raecke, R., Wiesmann, M., & Freiherr, J. (2017). Chemosensory danger detection in the human brain: Body odor communicating aggression modulates limbic system activation. *Neuropsychologia, 99*, 187-198. doi:http://dx.doi.org/10.1016/j.neuropsychologia.2017.02.018

Mutic, S., Parma, V., Brunner, Y. F., & Freiherr, J. (2015). You smell dangerous: Communicating fight responses through human chemosignals of aggression. *Chemical Senses, 41*(1), 35-43. doi:10.1093/chemse/bjv058

Negoias, S., Troeger, C., Rombaux, P., Halewyck, S., & Hummel, T. (2010). Number of descriptors in cued odor identification tests. *136*(3), 296-300. doi:10.1001/archoto.2009.231

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. *Clinical Otolaryngology, 37*(1), 23-27. doi:10.1111/j.1749-4486.2012.02431.x

Obrebowski, A., Obrebowska-Karsznia, Z., & Gawlinski, M. (2000). Smell and taste in children with simple obesity. *International Journal of Pediatric Otorhinolaryngology, 55*(3), 191-196.

Oettl, L. L., & Kelsch, W. (2017). Oxytocin and olfaction. *Current Topics in Behavioral Neurosciences*. doi:10.1007/7854_2017_8

Oettl, L. L., Ravi, N., Schneider, M., Scheller, M. F., Schneider, P., Mitre, M., . . . Kelsch, W. (2016). Oxytocin enhances social recognition by modulating cortical control of early olfactory processing. *Neuron, 90*(3), 609-621. doi:10.1016/j.neuron.2016.03.033

Oleszkiewicz, A., Rambacher, L., Whitcroft, K. L., & Hummel, T. (2018). The confounding effect of background odors on olfactory sensitivity testing. *306*, 88-91. doi:https://doi.org/10.1016/j.jneumeth.2018.05.012

Oliveira-Pinto, A. V., Santos, R. M., Coutinho, R. A., Oliveira, L. M., Santos, G. B., Alho, A. T. L., . . . Lent, R. (2014). Sexual dimorphism in the human olfactory bulb: females have more neurons and glial cells than males. *PloS One, 9*(11), e111733. doi:10.1371/journal.pone.0111733

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

Prehn-Kristensen, A., Wiesner, C., Bergmann, T. O., Wolff, S., Jansen, O., Mehdorn, H. M., . . . Pause, B. M. (2009). Induction of Empathy by the Smell of Anxiety. *PloS One, 4*(6), e5987. doi:10.1371/journal.pone.0005987

Rochet, M., El-Hage, W., Richa, S., Kazour, F., & Atanasova, B. (2018). Depression, Olfaction, and Quality of Life: A Mutual Relationship. *Brain Sci, 8*(5). doi:10.3390/brainsci8050080

San Roque, L., Kendrick, K. H., Norcliffe, E., Brown, P., Defina, R., Dingemanse, M., . . . Majid, A. (2015). Vision verbs dominate in conversation across cultures, but the ranking of non-visual verbs varies. *Cogn. Linguist., 26*, 31-60. doi:10.1515/cog-2014-0089

Sorokowska, A., Sorokowski, P., & Hummel, T. (2014). Cross-cultural administration of an odor discrimination test. *Chemosens. Percept., 7*(2), 85-90. doi:10.1007/s12078-014-9169-0

Sorokowska, A., Sorokowski, P., Hummel, T., & Huanca, T. (2013). Olfaction and environment: Tsimane' of Bolivian rainforest have lower threshold of odor detection than industrialized German people. *PloS One, 8*(7), e69203. doi:10.1371/journal.pone.0069203

Sorokowski, P., Sorokowska, A., & Witzel, C. (2014). Sex differences in color preferences transcend extreme differences in culture and ecology. *Psychon Bull Rev, 21*(5), 1195-1201. doi:10.3758/s13423-014-0591-8

Taalman, H., Wallace, C., & Milev, R. (2017). Olfactory functioning and depression: a systematic review. *Front Psychiatry, 8*(190). doi:10.3389/fpsyt.2017.00190

Ulusoy, S., Dinc, M. E., Dalgic, A., Topak, M., Dizdar, D., & Is, A. (2016). Are people who have a better smell sense, more affected from satiation? *Brazilian Journal of Otorhinolaryngology, 16*. doi:10.1016/j.bjorl.2016.08.011

van Langeveld, A. W. B., Teo, P. S., de Vries, J. H. M., Feskens, E. J. M., de Graaf, C., & Mars, M. (2018). Dietary taste patterns by sex and weight status in the Netherlands. *119*(10), 1195-1206. doi:10.1017/S0007114518000715

White, T. L., & Cunningham, C. (2017). Sexual preference and the self-reported role of olfaction in mate selection. *Chemosens Percept, 10*(1-2), 31-41. doi:10.1007/s12078-017-9223-9

Wnuk, E., & Majid, A. (2014). Revisiting the limits of language: The odor lexicon of Maniq. *Cognition, 131*(1), 125-138. doi:http://dx.doi.org/10.1016/j.cognition.2013.12.008

Zou, L. Q., Yang, Z. Y., Wang, Y., Lui, S. S., Chen, A. T., Cheung, E. F., & Chan, R. C. (2016). What does the nose know? Olfactory function predicts social network size in human. *Scientific Reports, 6*, 25026. doi:10.1038/srep25026