Towards a human ecology of olfaction in the built environment.

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ABSTRACT
We know little about human olfactory ability in natural settings—for humans, this includes urban and rural built environments. Our knowledge derives from clinics and lab experiments using samples of convenience, often students and usually WEIRD. But, humans live in odor rich environments, most are not western, and many are not industrialized or educated. The problem is that we lack field methods for studying olfactory ability outside the lab and cannot fully understand olfaction within an ecological setting. To understand the impact of varying test environments on olfactory ability, we conducted two tests: short odor identification in two locations, repeated measures short odor identification in three locations. Odor purity and background odors are not mitigated as the goal is to assess olfactory ability in quotidian life. Results indicated that environment is not a significant factor in olfactory ability and that olfactory ability is much worse in natural settings than in the lab. Further testing of the influence of variation in air quality and volatiles during non-lab testing bouts is a logical next step. More importantly, how can we reconcile measures of healthy olfaction in the lab with olfactory dysfunction in natural settings? Finally, widening representation of human populations (including indigenous groups practicing traditional subsistence) is a logical next step in understanding how much the built environment is disrupting our sense of smell. This study is a valuable first step in exploring the human ecology of olfaction.

KEYWORDS
Smelling in the wild, psychophysics, olfaction, human olfactory ecology, built environment

INTRODUCTION

We know little about how humans detect, discriminate, and identify odors in mixtures in natural settings—for humans, natural settings include the built environment, both urban and rural. The vast majority of our knowledge on human olfaction derives from psychology and cognitive science lab studies conducted in odor-controlled environments using samples of convenience—mostly WEIRD (Henrich and others, 2010) and often students (Hanel and Vione, 2016). Meanwhile, the vast majority of humans live in smelly environments with rich odor mixtures (naturally or artificially produced) and are non-western, many of whom are not industrialized or educated. The challenge in generating data that represent the human species is a lack of methods for studying olfactory ability outside the lab (Kern and others, 2014). Field-based methods will need to understand the impact of different test environments on altering olfactory ability; in other words, is there a significant difference in test results conducted in a rain forest setting versus an urban street market?

The majority of olfactory ability assessment tools rely on correct odor identification, which introduces a bias toward odor familiarity. In order for an odor to be identified, it must be familiar—or have been previously experienced. Familiarity is influenced by culture and geographic environment. Of the two assessment tools most commonly used and widely available—Sniffin' Sticks Test (Kobal, Klimek, Wolfensberger, Gudziol, Temmel, Owen, Seeber, Pauli, & Hummel, 2000) and the University of Pennsylvania Smell Identification Test (Doty, Shaman, Kimmelman, & Dann, 1984)—the Sniffin' Sticks test (SST) alone mitigates the bias by including two additional subsets—threshold detection and discrimination. A recently introduced set of tools, the SMELL-R and Smell-S (Hsieh and others, 2017), does not rely on prior olfactory experience and avoids idiosyncratic odor-specific insensitivity by using mixes of odors. While these tests show promise, they have not been widely validated for use in clinical settings, let alone the field. Currently, the best set of tools for field-testing would be the Sniffin' Sticks due to their portability, shelf-life, and reliance on three domains of olfactory function: threshold detection, discrimination, and identification (following an odor familiarity validation study on potentially naïve populations).

The Olfactory Function Field Exam is a 11-minute olfactory function test that uses two odors for threshold detection and five odors for odor identification (Kern and others, 2014). The OFFE is highly portable for field-based research (using Sniffin' Sticks) and aimed to widen data capture to increase representativeness of human olfactory function. The OFFE also aimed to capture true functional data—meaning olfactory function in the environment in which participants spent the majority of their time. Validated in the United States as part of The National Social Life, Health, and Aging Project, the OFFE was validated on a cohort of 2,304 older adults and conducted in participants homes following a short odor training session. Results were nearly identical to testing conducted in labs on a similarly aged cohort (Kern and others, 2014)—these results suggest that between-subjects environmental variation (in private homes) did not contribute significantly to summary results.

The limited research done on olfactory ability in different ecological settings suggest that non-industrial populations either have a better sense of smell (Sorokowska and others, 2014; Sorokowska and others, 2013) or an ability to represent odors abstractly (Majid and Kruspe, 2018). These findings parallel research in anthropogenic disruptions to sensory-guided animal behavior (for example, see Boivin and others, 2016; Jürgens and Bischoff, 2017; Kunc and others, 2014; Morris-Drake and others, 2016). While there are minimal data on humans (Hoover, 2018a; Hoover, 2018b), there is an established relationship between modern living and diminished olfaction—pollution damages olfactory soft tissue and reduces olfactory acuity (for a review, see Ajmani and others, 2016). Olfactory ability is a critical component of mental health (for recent reviews, see Rochet and others, 2018; Taalman and others, 2017), appetite regulation (Boesveldt and de Graaf, 2017; Obrebowski and others, 2000; Ulusoy and others, 2016; van Langeveld and others, 2018), and sociability (Alves-Oliveira and others, 2017; Bendas and others, 2018; Croy and others, 2013; Lübke and Pause, 2015; Mutic and others, 2017; Mutic and others, 2015; Oettl

and Kelsch, 2017; Oettl and others, 2016; Prehn-Kristensen and others, 2009; White and Cunningham, 2017; Zou and others, 2016).

We were interested in testing whether other types of environments might impact olfactory ability and conducted two sets of tests, short odor identification test in two locations and repeated measures short odor identification in three locations. In these studies, issues of odor purity and background odors are not mitigated as the goal is to assess olfactory ability in quotidian life. For Market Smells I (MS1), we asked if there were differences in olfactory ability between two different environments. For Market Smells II (MS2), we asked if there were intra-individual differences in olfactory ability dependent on environment. For both tests, we asked if there were sex-based differences given previously documented differences (Dalton and others, 2002; Doty and others, 1985; Doty and Cameron, 2009; Oliveira-Pinto and others, 2014).

MATERIALS AND METHODS

For Market Smells 1, we used direct solicitation for participants at two London food markets during October and November 2017. Borough Market is a semi-enclosed pedestrian zone with market stalls very close together and narrow pedestrian lanes located in Southwark, central London. Average annual $PM_{2.5}$ is 12.5-15 µg m-3 with roadsides concentration on Southwark Street at 15-20 µg m-3. St. Alban's market is a pedestrian street with stalls spaced widely apart in the St Peters Street retail area in the city center St. Alban's, located in the north London commuter belt. Average annual $PM_{2.5}$ background concentration is 10-12.5 µg m-3 with roadside concentrations on St. Peters Street the same. Thus, markets differ in pollution levels and structural variables that influence odor diffusion (partial enclosure of Borough concentrates odors in the local environment; open spaces at St. Alban's allows odors to diffuse more rapidly). Thirty-nine participants over the age of 18 were recruited, 19 at Borough Market and 20 at St. Albans Market, to identify two common odors, rose and cloves.

For Market Smells 2, we used social media (e.g., Twitter, meetup.com), blogs (smellofevolution.com), word of mouth, and direct solicitation for participants. Testing was conducted on two separate days in 2018 (28 July and 4 August). Each test day, we had two groups (10am and 2pm). Testing commenced for all groups at the entrance area to the Tate Turbine Hall, continued under Southwark Bridge pedestrian area, and finished at the Borough Market food stalls. The Tate Turbine Hall entrance is in a no traffic zone with no food vendors nearby. The Southwark Bridge pedestrian area is a heavily trafficked zone with restaurants, buskers, and normal city smells (e.g., urine, cigarettes, food). The Borough Market is a sensory rich environment with many vendors of raw and cooked foods. Nineteen participants over the age of 18 were recruited and subject to three trials of the five-odor identification test (Mueller and Renner, 2006): peppermint, orange, garlic (replaces leather due to a lower identification rate for leather in UK populations), rose, fish.

For Market Smells 3, we recruited University of Roehampton students to participate in a lab-based experiment. Testing was conducted in the same two labs at the same time of the day (1-2 pm) during the week of 12-15 February 2019). The first lab was a low-odor well-ventilated space. The second lab was a food lab that we populated with the same odors in the same concentrations diffused for one hour prior to testing). Diluted solutions were added to odorless aloe vera in open acrylic jars. Odors included trimethylamine (fish), caramel furanone (caramel at low concentration, curry at high concentrion), 2-Ethylfenchol (beer), 2-heptanone (blue cheese), and 2-furfurylthiol (coffee). Odors were chosen to mimic the market atmosphere of the two prior studies. We tested students in the clean lab first and, within 60 minutes, in the food lab next. Olfactory ability was assessed by odor identification using the Sniffin' Sticks (which were five months old) and odor threshold using n-butanol and the staircase method. Odors

for threshold testing were distributed via squeeze bottles with concentrations diluted to match those of Sniffin' Sticks.

All tests were conducted in the London area and used odors that were previously validated as familiar and easily identified in UK populations (Neumann and others, 2012). Volunteer odor identification ability was assessed via Sniffin' Sticks (Hummel and others, 1997), We were unable to use the OFFE due to the time required per participant (12 minutes). So, we used the short odor identification test, which is one component of the OFFE. The Sniffin' Sticks used for each test were purchased within the month prior to commencement of MS1 (September 2017) and MS2 (July 2018) and stored at the University of Roehampton at a temperature within the recommended range. Testing protocols were the same for both tests: a tester wearing cotton gloves presented the odor underneath the nostrils of the participant for 3 seconds and asked if the participant could smell an odor and to describe it. For the repeated measures test, we also used a forced-choice method (choose the most likely odor descriptor from a card of 20 odors) following free description. All participants were screened via questionnaire for factors that might contribute to impaired olfaction (e.g., smoking, allergies). No participant had eaten or drunk anything other than water 20 minutes prior to testing.

All data were analyzed in R (Charif and Lobry, 2007) using the R Studio GUI (Team, 2015). Descriptive answers were coded as correct, near miss, far miss, and incorrect (Cain, 1979). Inter-observer (JCB, KCH) code agreement was analyzed by Cohen's kappa (κ). Between-market differences (MS1) were tested using linear-by-linear test for ordered contingency tables. Between- and within-subjects differences (MS2) were tested using a repeated measures ANOVA with independent variable (environment), dependent variable (olfactory ability as assessed via odor identification, forced choice), and interaction terms (sex, testing time). Between- and within-subjects differences (MS3) were tested using a repeated measures ANOVA with independent variable (environment), dependent variable (olfactory ability as assessed via odor identification), and an interaction term (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. Written informed consent included asked volunteers to provide no further information beyond a 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 olfactory ability scores.

RESULTS AND DISCUSSION

For MS1, the coding of descriptive data did not differ significantly between observers (clove: $\kappa = .828$, $p = 0.000$; rose: $\kappa = .772$, $p = 0.000$). There were no significant between-market differences identified by the linear-by-linear test (using KCH codes): rose ($Z = -0.123$, p-value = 0.90), clove ($Z = 0.19$, p-value = 0.85). Descriptors for Borough Market included fried odors, a descriptor that is absent from St. Alban's, which suggests some background interference. There were no significant between-sex differences identified by the Mann Whitney U test for rose ($W = 247.5$, p-value = 0.08). A larger sample might have detected differences as 50% of males failed to identify rose but 77% of females failed. There were significant between-sex differences for clove ($W = 99$, p-value = 0.004) with males performing much worse (1 correct, 2 near misses, rest incorrect or can't smell) than females (2 correct, 6 near misses, 3 far misses). Clove is mis-identified in forced choice tests by ~26% of the UK population (Neumann and others, 2012)—84% of males and 39% of females in MS1 could not name it in free choice.

The within-subjects ANOVA found only one significant term—the effect from sex (Table 1). In other words, there were no differences in the repeated measures attributable to location or time of day tested

(am or pm) but there were significant sex-based differences. The repeated measures test reflects the previously document lab phenomenon of increased accuracy in identification performance when provided verbal information (Hummel and others, 2007; Negoias and others, 2010). 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 and others, 2014). Thus, the forced-choice component of the repeated measures MS2 might fail to capture a true difference in identification ability.

Table 1: Repeated measures ANOVA, within-subjects effects

	df	Sum Sq	Mean Sq	F	P-value
Location	2	1.22	0.61	0.46	0.63
Sex	1	12.15	12.15	9.10	0.00
Time	1	1.37	1.37	1.03	0.31
Loc:Sex	2	3.79	1.90	1.42	0.25
Loc:Time	2	0.23	0.12	0.09	0.92
Sex:Time	1	0.26	0.26	0.20	0.66
Loc:Sex:Time	2	1.08	0.54	0.41	0.67

Given that there are 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 expected females might perform better than males. In fact, females appear to be better at learning the odors (order of testing was Tate, Southwark, Borough) (Figure 1) which is an explanation for better performance in lab tests (REF). The greater acuity of females in odor learning in lab settings appears transferrable to natural (here, built) environments. Further, females are closer to having a healthy functioning sense of smell (OA Score of 4 or 5) at the last location whereas males are hyposmic in all settings (>3 odors correct). Results raise interesting ecological questions about adaptation relative to odor identification and food foraging, an activity that makes a large contribution to survival and reproduction. What is the evolutionary and biological significance of better olfactory ability or better learning ability in females?

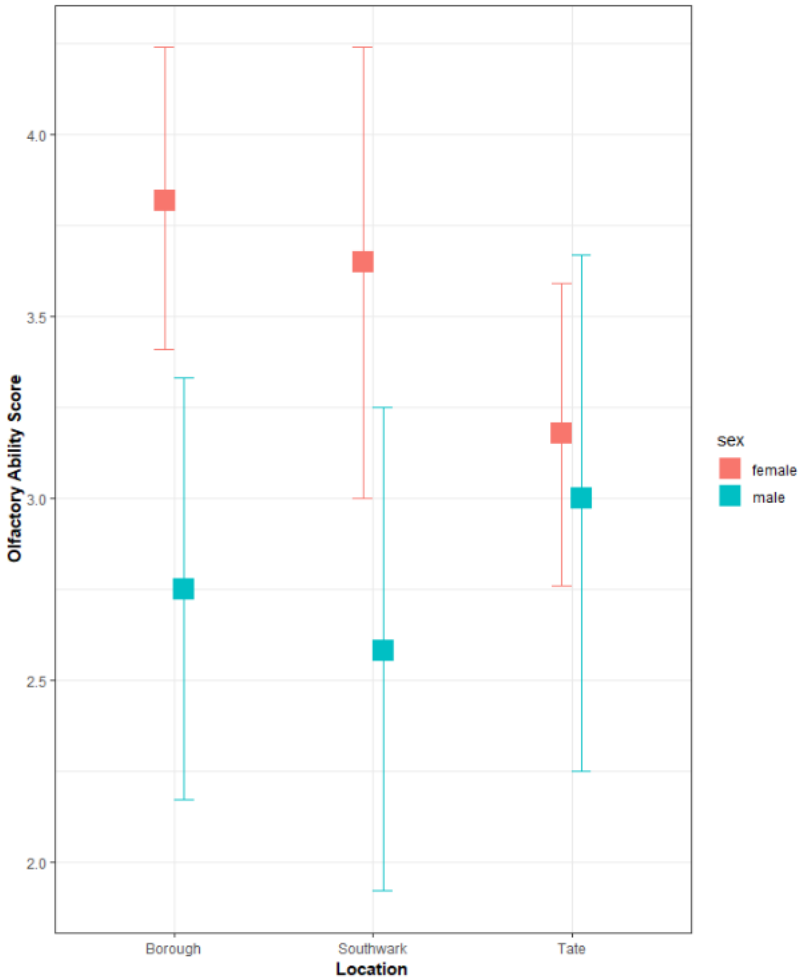

Figure 1: Interaction Plot (Sex*Location)

<MS3 results>

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