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The smell of us – crowdsourcing human body odor evaluation

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ABSTRACT

Human body odor is produced when sweat-secreted compounds are metabolized by bacteria present on the skin. The resulting volatile mixture is often negatively perceived, motivating the use of personal cosmetic deodorants. Yet body odor may also be positively perceived in some contexts, and is proposed to play a role in sexual attraction, kin identification and social bonding. Because only human smellers can report the hedonic qualities of body odor, their perceptions are a valuable complement to modern GC-MS-based quantitative chemical measurements. Here we present a crowdsourcing framework that engages volunteer smellers to characterize human sweat samples. Our approach seeks to reward both the sweat donor and the smeller with a web-based graphical interface that is informative, interesting, and fun. 300 samples from 87 individual donors were scored by 93 smellers for intensity, pleasantness, and a variety of odor descriptors. Body odor intensity and pleasantness were determined to vary with age, gender, and self-reported deodorant use. Counterintuitively, deodorant use showed no effect on the perceived intensity of body odor, and was associated with a decrease in the perceived pleasantness. From these data, we determine the precision and dynamic range of the volunteer nose as a body odor evaluation instrument. Given the high variability of smeller perceptions, a large-scale crowdsourcing effort may be needed to produce a comprehensive description of body odor perceptions. We discuss the role of learning, creativity and fun in motivating volunteer sweat donors and smellers for such an effort.

1. INTRODUCTION

1.1 The production and perception of body odor

Underarm sweat is rich in secretions from the apocrine glands and cell debris shed from the striatum corneum. Bacteria resident on the skin metabolize this medium to produce a blend of scented compounds commonly identified as body odor. Hundreds of distinct volatile molecules are released from sweat(Dormont, Bessière, & Cohuet, 2013b), with major contributors to body odor including short- and medium-chain fatty acids, aldehydes, steroid derivatives and thiol compounds(Fredrich, Barzantny, Brune, & Tauch, 2013).

The chemical composition of body odor varies among individuals and over time, representing a personal odor signature(Curran, Ramirez, Schoon, & Furton, 2007). Factors influencing sweat chemistry include gender(Penn et al., 2007), age(Yamazaki, Hoshino, & Kusuhara, 2010), genetics(Kuhn & Natsch, 2009; Martin et al., 2010), disease(Olsson et al., 2014), diet(Havlicek & Lenochova, 2006), physical activity(Callewaert et al., 2014a), and the bacterial species composition of the skin microbiome(Leyden, McGinley, Hölzle, Labows, & Kligman, 1981).

Body odor is popularly understood to be unpleasant and undesirable(McBurney, Levine, & Cavanaugh, 1976). This perception motivates the use of commercial antiperspirants and deodorants, which reduce body odor by suppressing sweat production or killing odor-causing bacteria(Urban et al., 2016). A large part of body odor research is focused on technical improvements to these products, motivated by a multi-billion dollar global market(Gilbert & Firestein, 2002).

However, body odor is not always negatively perceived. Subjects will often rate intense body odors as pleasant or even sexy(Havlicek, Roberts, & Flegr, 2005; Singh & Bronstad, 2001). These more subtle aromas have roles to play in romantic and sexual attraction(Herz & Inzlicht, 2002) and social empathy(Camps, Stouten, Tuteleers, & Son, 2014). This is perhaps unsurprising, given the well documented importance of chemosignaling in the social behavior of mammals and other primates(Drea, 2015). The existence of *bona fide* human pheromones, compounds that control behavior through innate and evolved signaling pathways, is unproven and controversial(Wyatt, 2015). Nevertheless, a range of emotional and psychological responses are evoked by the smell of sweat(Lundström & Olsson, 2010). These responses may be linked to specific odorants or odor qualities, as has been shown for other scents(Haze, Sakai, & Gozu, 2002).

Other chemical signals are carried in sweat, including some with clinical or psychological importance. Breath odor carries markers for early preclinical cancer that can be identified by trained dogs(Jezierski, Walczak, Ligor, Rudnicka, & Buszewski, 2015). A variety of infectious diseases are marked by characteristic odors including the "stale beer" smell of tuberculosis and the "butcher's shop" odor of Yellow Fever(Shirasu & Touhara, 2011). The aromas of body odor are proposed to correlate with a sweat donor's personality(Sorokowska, 2013), and to indicate moods including happiness and fear(Chen & Haviland-Jones, 2000). In most cases, these odor signals were noticed by human smellers and reported informally long before being systematically investigated for molecular markers.

1.2 Human smellers as scientific instruments

Only human smellers can describe attraction (or aversion) to a particular odor or the subjective impressions that it evokes. This makes the human sense of smell a natural complement to more quantitative and objective mass-spectrometry-based chemical analysis(Dormont, Bessiere, McKey, & Cohuet, 2013a). Despite common misconceptions, human olfaction is highly sensitive(Laska, Seibt, & Weber, 2000; Shepherd, 2004) and shows detection thresholds below 1 ppm for many simple odorants, comparable to those of canines or rodents(Laska et al., 2000). The higher cognitive functions are fully integrated with the olfactory cortex(Menini, 2004), allowing human smellers to recognize patterns in complex smells composed of many volatiles in varying proportions against a background of unrelated odors(Thomas-Danguin et al., 2014).

Yet the scientific application of the human sense of smell faces unique and important challenges(Chastrette, 1998). Volatile molecules are difficult to control, and will variably diffuse during the process of presenting them to a smeller(Lundström, Gordon, Alden, Boesveldt, & Albrecht, 2010). Alterations in odorant concentrations or changes to the temporal profile of delivery may have a strong effect on the quality of an odor. For example, a thiol compound might be perceived as fruity at low concentration and sulfurous at high concentration(Demole, Enggist, & Ohloff, 1982).

Finally, and perhaps most importantly, human odor preferences are irredeemably subjective. Individual smellers will differ in their genetics(Keller, Zhuang, Chi, Vosshall, & Matsunami, 2007), level of training(Cain, 1979), previous experience with an odor(Poncelet et al., 2010), and demographic profile(Keller, Hempstead, Gomez, Gilbert, & Vosshall, 2012). To an unknown extent, odor perception is the product of cultural forces beyond the scope of chemistry or physiology(Agapakis & Tolaas, 2012).

1.2 Crowdsourcing the sense of smell

Crowdsourcing approaches may help to overcome the inherent variance of odor perception by aggregating the opinions of many independent smellers. Groups of human agents, coordinated over the internet, can be effectively directed to solve large scale problems(Brabham, Ribisl, Kirchner, & Bernhardt, 2014). These strategies especially benefit from access to higher cognitive functions and unique human aptitudes including those for image analysis(Candido Dos Reis et al., 2015) and pattern recognition(Williams et al., 2014). Even where individual opinions show high variance, the central tendency of many human-derived estimates can be highly informative(Galton, 1907).

In this work, we develop a crowdsourcing application for evaluating human body odors. Our platform design draws on recent research into the motivations that drive public participation in crowd-sourced volunteer work(Nov, Arazy, & Anderson, 2014). The approach was found to reproduce results from conventional laboratory-based studies, including the finding that men have a more intense odor than women on average. Using similar methodology, we discover an unexpected negative correlation between self-reported deodorant use and odor pleasantness. We further identify several strong associations among smell descriptors of different classes that smellers apply to body odor. For example, the image descriptor of "passion fruit" was frequently co-assigned with the emotion descriptor of "happiness," suggesting a connection between these terms in the context body odor perception.

Finally, we assess the accuracy, precision and dynamic range of the volunteer nose as an instrument for analyzing body odor. These results highlight the variable nature of body odor perception, and underscore the need for a scalable investigative tool.

2. METHODS

2.1 A crowdsourcing framework for body odor evaluation

All sweat samples and smell data were crowd-sourced from untrained volunteers using a web-based platform (Fig. 1A). The application was designed to engage participants with an intuitive interface that required no experimenter guidance. The evaluation process produced a graphical "odor badge" summarizing scores for intensity and pleasantness as well as smeller-selected odor descriptors (Fig. 1B). Following their evaluations, smellers were able to compare their input to others collected for the same samples. Sweat donors were able to return to the exhibit and see the odor badges generated for their sample. The odor badges served to reward volunteers by appealing to their natural curiosity about their own body odor and that of others. The digital experience is depicted in supplementary Fig. S1.

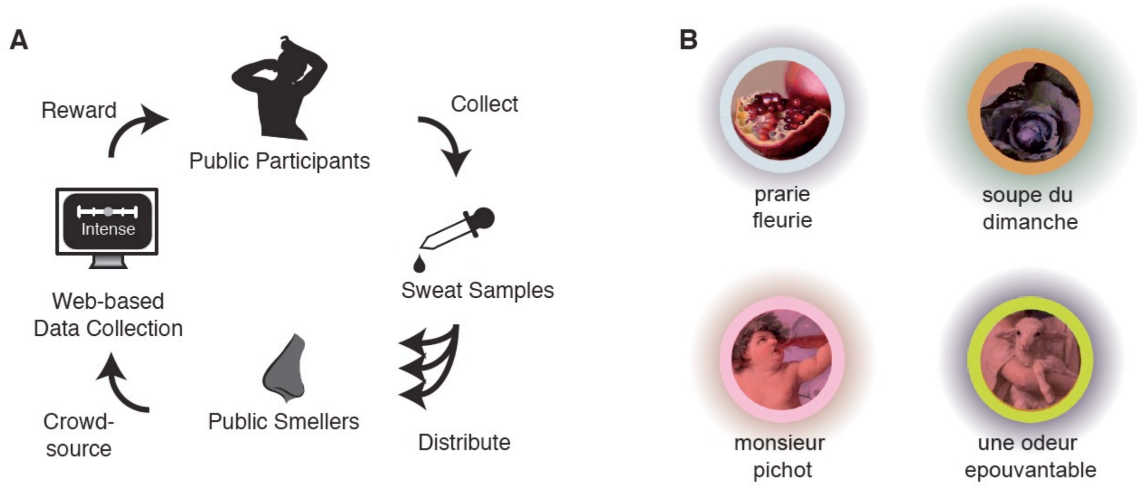

Fig. 1. A crowd-sourced workflow for collecting and evaluating body odor. A Samples are collected from volunteer donors, then divided among volunteer smellers. The web-based data collection platform is simple enough to be used without training. B Graphical "odor badges" are produced to reward the curiosity of volunteers and to promote conversation and sharing. The outer halo is proportional to the intensity score and is colored to represent the choice of emotional descriptor. The color of the inner circle represents the class descriptor and the central graphic depicts the image descriptor. The central image is shaded from red to green to indicate the pleasantness score and the odor name is entered freeform by the smeller.

2.2 Sweat sample collection

Volunteers attended public events at *La Cité des Sciences et de l'Industrie*, Europe's largest science museum, on September 20th, 26th and October 4th, 2014. The event was advertised as a chance for citizen scientists to learn about their own body odor and, in exchange, to evaluate the body odor of strangers.

Samples were collected with adhesive cotton pads worn under the clothing and against the axillary vault. The collection continued for a period of 30 minutes of light physical activity while subjects viewed a presentation and exhibit on the science of body odor. Following collection, the pads from both right and left armpits were separated from adhesive and combined as a single sample. Samples were stored in odorless glass vials with cork stoppers.

Sweat donors were asked to complete a brief personal and lifestyle questionnaire. Questions included donor age, gender, and current use of a deodorant product. Donors were also asked to rate their own body odor intensity and pleasantness. Responses were optional and completion rates ranged from 65-90%. Donor data collection employed the same web-based application later used for collecting odor evaluations and served as a user tutorial for the interface. Each donor was assigned a unique numerical code, guaranteeing anonymity and allowing double-blind odor evaluations.

2.3 Odor evaluation

Human smellers were recruited from the same population of donors present at the same public event. Volunteers were randomly assigned a panel of five odors to evaluate. Coffee beans were provided as an olfactory palate cleanser to reduce odor fatigue between samples. Smellers were not trained and were given no external guidance in their work beyond what was provided in the evaluation platform.

Odor intensity and pleasantness were assigned using a web-browser-based slider bar initially set to the center. The slider was presented with no numerical scale, but the position was tracked internally on a scale from 0% to 100%.

Descriptors associated with the odor were selected for each of three categories: emotion, class and image. Image descriptors were collected from the body odor literature(Havlicek & Lenochova, 2006; Troccaz et al., 2008; Troccaz, Starkenmann, Niclass, van de Waal, & Clark, 2004) and included, for example, Fish, Gasoline and Onion. Six class descriptors were chosen to group image descriptors: Animal, Chemical, Spicy, Fruity, Fatty and Vegetal. Emotional descriptors were selected from a range of emotional categories including Liking, Joy, Anger, Sadness and Fear(Parrott, 2001). Each of the three descriptor selection tasks were performed independently and descriptors presented in random order.

3. RESULTS

We collected a total of 300 odor evaluations from 87 donors and 92 smellers. 46% of sweat donors identified as female, 12% were smokers and 35% reported wearing no deodorant product. Donor ages ranged from 9 to 65, with the 70% of volunteers between the ages of 15 and 35. The smeller population demographics were similar.

We first explored the effect of gender on body odor intensity and pleasantness (Fig. 2). Male sweat donors were found to have significantly more intense body odor than females (p-val: 0.015). This is consistent with previous findings(Troccaz et al., 2008; Wilke, Martin, Terstegen, & Biel, 2007) and validates our approach against laboratory-controlled results. Interestingly, we found no significant differences in odor pleasantness by donor gender.

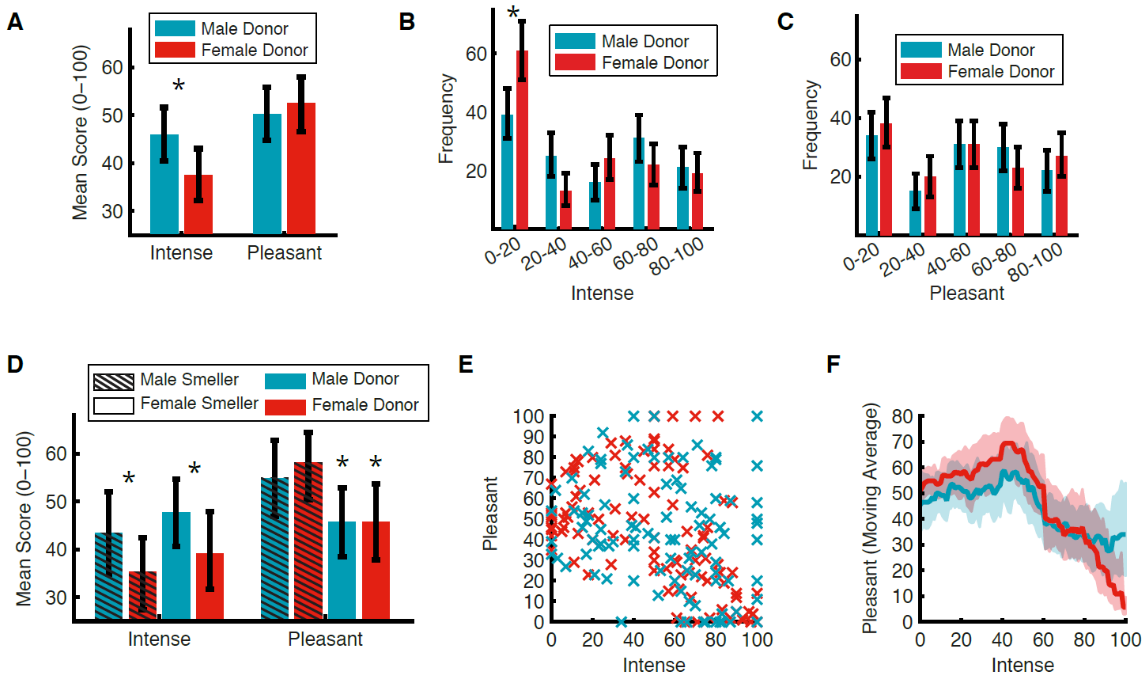

Fig. 2. Variations in body odor evaluation by gender. Asterisks indicate significance at $p < 0.05$ by bootstrap resampling. **A** Male sweat was found to be more intense on average than female sweat. Donor gender had no effect on sweat odor pleasantness. **B** Female sweat samples were more likely to belong to the lowest quintile of odor intensity. **C** Pleasantness scores showed similar distributions by sweat donor gender. **D** Male and female smellers both awarded higher intensity scores to male sweat odor on average. Male smellers awarded higher pleasantness scores to all samples on average, regardless of the donor gender. **E** The distribution of intensity and pleasantness scores for sweat from male donors (yellow Xs) and female donors (green Xs). Intensity and pleasantness were negatively correlated (Spearman's $\rho = -0.36$, *p-val*: $2 \cdot 10^{-10}$). **F** A moving average of pleasantness scores taken for samples with the indicated intensity score and a range of +/- 10 points. Samples from male donors (yellow lines) and female donors (green lines) showed a negative correlation between intensity and pleasantness primarily at intensity scores above 50. Shaded areas indicate 95% confidence intervals, determined by bootstrap resampling.

Smeller gender also influenced body odor evaluation (Fig. 2B). On average, male smellers awarded higher pleasantness scores than female smellers (p-val: $8 \cdot 10^{-3}$). This was true regardless of the gender of the sweat donor. We found no significant difference in the intensity scores assigned by female and male smellers.

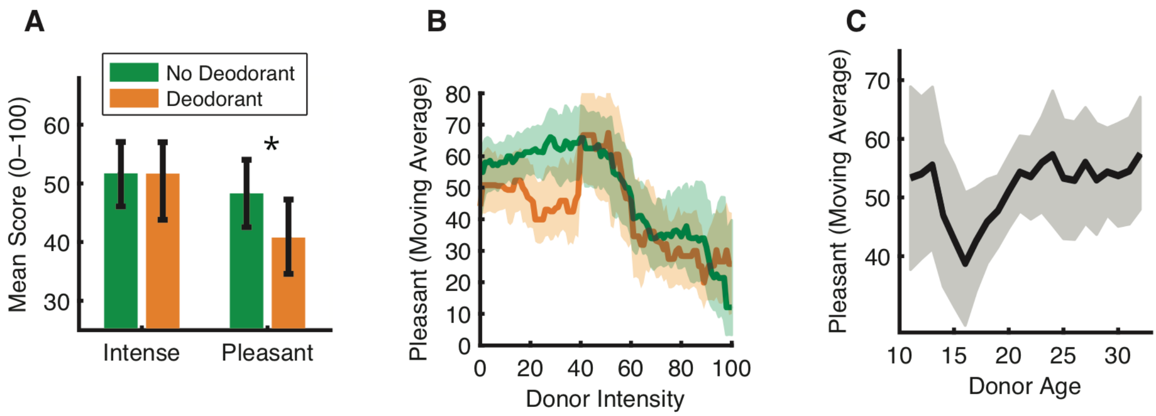

Fig. 3. Effects of deodorant use and age on body odor intensity and pleasantness. **A** 40% of sweat donors reported wearing no deodorant. Deodorant use was associated with no effect on body odor intensity and a decrease in odor pleasantness. Asterisks indicate significance at $p < 0.05$ by bootstrap resampling. **B** A moving average of pleasantness scores taken for samples with the indicated intensity score and a range of +/- 10 points. Samples from deodorant users (red lines) and non-users (blue lines) showed a negative correlation between intensity and pleasantness primarily at intensity scores above 50. Deodorant users were assigned lower pleasantness scores primarily in the range of lower odor intensities, decreasing the average pleasantness scores of that group. Shaded areas indicate 95% confidence intervals, determined by bootstrap resampling. **C** A moving average of odor pleasantness scores for samples from donors of the indicated age and a range of +/- 2 years. Pleasantness scores reached a local minimum for donors near age 16. Shaded areas indicate 95% confidence intervals, determined by bootstrap resampling.

The distribution of intensity and pleasantness scores was similar for male and female donors, with one exception (Fig. 2CD): Samples from female donors were more likely to be assigned intensity scores in the 0-20% range (p-val: $2{\cdot}10^{-3}$). This low-odor cohort was responsible for most of the overall mean difference between male and female odor intensities.

Odor intensity and pleasantness were negatively correlated (Fig. 2E). with Spearman's $\rho = -0.36$ (p-val: $2{\cdot}10^{-10}$). This relationship was most apparent at higher intensity levels. For low-intensity samples, pleasantness scores tended to intermediate values. Mean pleasantness reached a maximum at intensity scores near 50%, then declined sharply thereafter. This pattern was more pronounced among female-derived sweat samples (Fig. 2F).

We next investigated the effects of deodorant use and on odor intensity and pleasantness (Fig. 3). Deodorant use had no effect on odor intensity, but significantly decreased odor pleasantness (p-val: 0.04). This difference could be attributed primarily to samples of low intensity, which were scored to have lower pleasantness among deodorant users (Fig. 3B).

Donor age also affected odor perceptions (Fig. 3C). Samples from teenage donors were found to be less pleasant, with the lowest average pleasantness assigned to donors at age 16. Donors of other age groups were assigned stable baseline pleasantness scores and no correlation of pleasantness with age was observed past age 20. Odor intensity showed no consistent trend with age (data not shown).

Odor descriptors were selected by smellers for three different descriptor groups: class (6 descriptors), image (19 descriptors) and emotion (12 descriptors). Although the assignments were performed independently and non-sequentially, smellers were likely to co-assign image descriptors with a related class descriptor (Fig 1A). For example, 83% of the samples assigned the class descriptor "animal" were also given animal-like image descriptors: "fish," "wet dog," "goat," "boar taint," or "chicken broth." This association demonstrates that smellers assign descriptors coherently across descriptor sets.

Surprisingly, we also found that certain emotion descriptors were frequently co-assigned with specific images (Fig 2BC). For example, 42% of smellers selecting "passion fruit" as an image descriptor also chose "happiness" as an emotion descriptor. Similar associations were found between "grape" and "tenderness" and between "wet dog" and "irritation".

Descriptor assignments varied by gender and by deodorant use (Fig. 5). Male-derived sweat was more likely to be assigned the class descriptor of "chemical" and the image descriptors of "alcohol," "vinegar," and "cumin." (Fig. 5ABC). Female-derived samples were more likely to be assigned the class descriptor of "fruity" and the image descriptors of "passion fruit" and "grape." No significant differences were observed in the emotional descriptors assigned to male or female sweat.

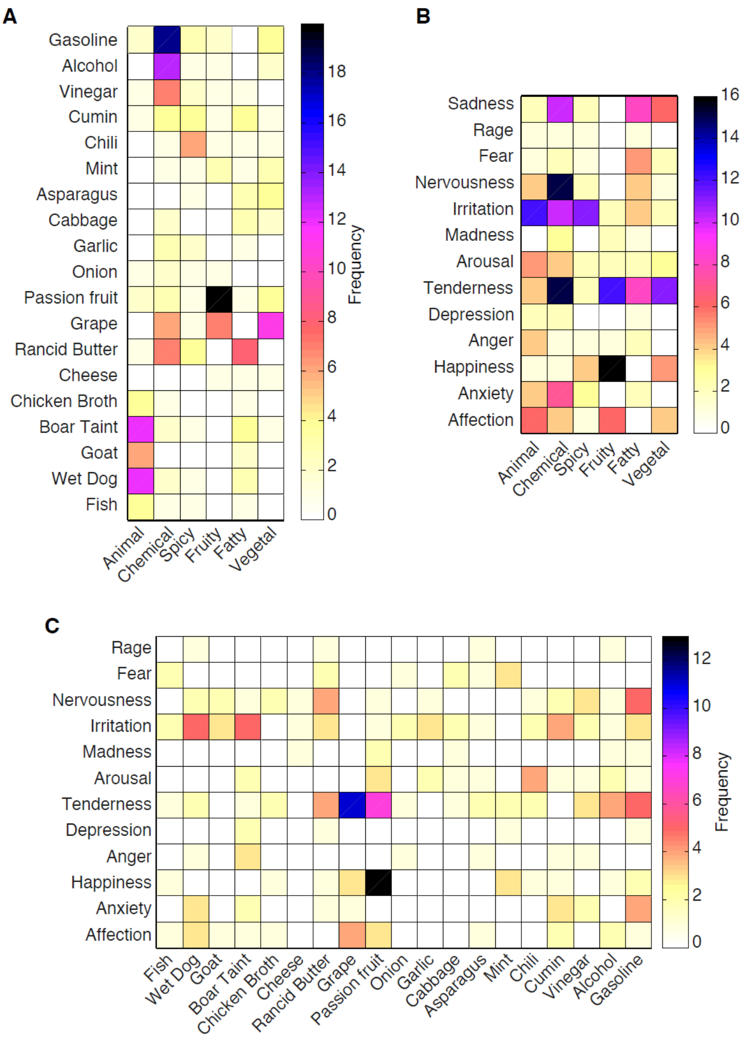

Fig. 4. Co-assignment patterns for three types of smell descriptors. Smellers were asked to select descriptors associating the odor with a specific smell class, image and emotion. The heat map depicts the number of smellers co-assigning the descriptors. **A** Image and class descriptors are assigned coherently. Smellers were likely to co-assign chemical-like image descriptors and the "chemical" class descriptor. Similarly coherent selections were made for the "Animal," "Fruity" and "Fatty" class descriptors. **B** Fruity body odors were likely to be associated with the emotions of happiness or tenderness, while animal odors were associated with primarily irritation. Other odor classes were similarly associated with only a distinct subset of emotions. **C** Body odors assigned the image descriptor "passion fruit" were likely to also evoke happiness, while the image of "grape" was associated with tenderness. In general, only a small number of image-emotion descriptor pairs were frequently coassigned.

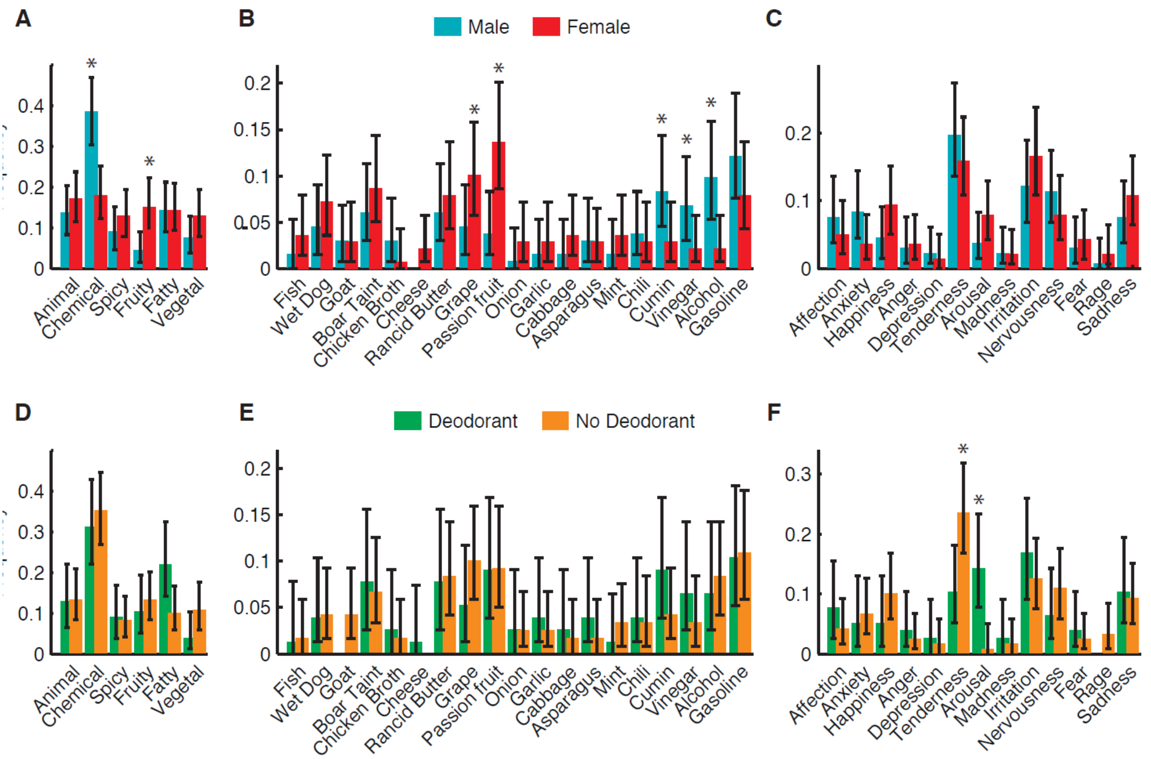

Fig. 5. Descriptor assignment frequencies by gender and deodorant use. Asterisks indicate significance at $p < 0.05$ by bootstrap resampling. **ABC** Male-derived sweat odors were more likely to be described as "chemical," "alcohol," "vinegar" and "cumin." Female-derived sweat odors were more likely to be described as "fruity," "grape," and "passion fruit." No significant differences in emotional descriptors were found by donor gender. **DEF** Sweat from deodorant users was more likely to evoke the emotion of "arousal" while sweat from non-users was more likely to evoke "tenderness." No other descriptor differences were associated with deodorant use.

In contrast, only emotional descriptors were found to significantly vary with deodorant use (Fig. 5DEF). Sweat samples from donors reporting deodorant use were more frequently associated with "arousal," whereas sweat from donors without deodorant was more likely to evoke "tenderness."

Mean intensity and pleasantness scores were found to vary with descriptor assignments. As expected, positive emotions like "happiness" and "arousal" were associated with higher average pleasantness (~70%), while negative emotions like "nervousness" and "irritation" had the lowest average pleasantness scores (~30%). The complete ranking of mean intensity and pleasantness scores for all descriptors is available as a supplementary figure (Fig. S2).

Finally, we quantified the statistical variance of our data set to estimate the precision of the untrained human nose as a scientific instrument (Fig. 6). Smeller-assigned intensity and pleasantness scores were well fit by a uniform distribution (p-val > 0.1; Chi-square goodness-of-fit test) with the exception of extreme values 0 and 100, which were both more frequently assigned. Neither the intensity nor the pleasantness score sets were well-fit by a normal distribution (p-val < 10^{-100}, Kolmogorov-Smirnov test).

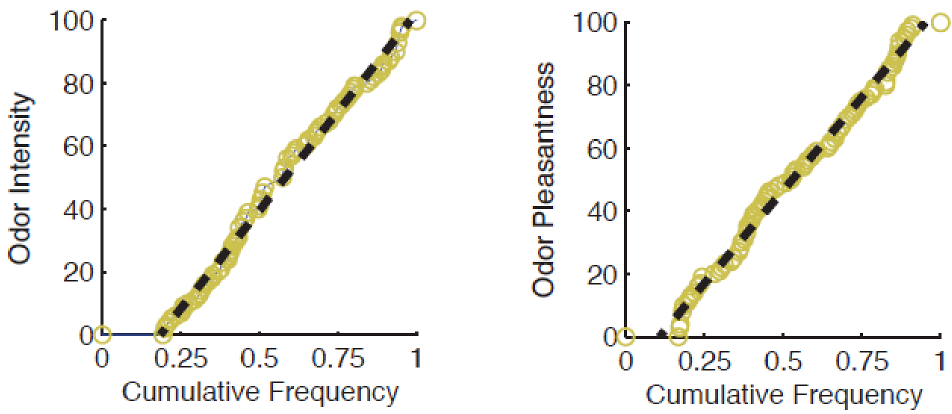

Fig. 6. Body odor intensity and pleasantness scores are uniformly distributed. Shown are the cumulative distribution functions for odor intensity and pleasantness, collected from all smellers and all donors (yellow circles). Both data sets were well fit by a uniform distribution (p-val > 0.1; Chi-square goodness-of-fit test). In contrast, the data was not well fit by a normal distribution (p-val < 10^{-100}, Kolmogorov-Smirnov test). The fit distributions are shown as dotted lines. Discontinuities at 0 and 100 indicate that those scores were disproportionately likely to be assigned.

In total, we collected 87 sweat samples that were assessed by two or more smellers. Smeller scores overall had standard deviation of 34 for intensity and 43 for pleasantness. Independent smells of the same sample produced a range of distributions with standard deviations of 26 (Intensity) and 26 (Pleasantness) on average.

Independent smell scores of the same sample for intensity were positively correlated (Spearman's rho: 0.15, p-val: $3 \cdot 10^{-6}$) as were scores for pleasantness (Spearman's rho: 0.12, p-val: $2 \cdot 10^{-4}$). In contrast, donor's self-reported assessments of the intensity and pleasantness of their own odor showed no correlation with smeller-assigned scores.

4. DISCUSSION

4.1 Motivation and learning opportunities for citizen smellers

Body odor is an everyday phenomenon with popular associations to social status, hygiene and sex. It is therefore the subject of public curiosity that naturally attracts participants to volunteer research efforts. In this work, we have attempted to reward our volunteers' curiosity by providing learning opportunities at every stage of the research process.

As they entered the exhibit and again during the sweat collection process, volunteers were offered a short presentation on the scientific background of body odor. The desire for learning and self-improvement has been shown to motivate participation in many crowdsourcing projects (Nov & Ye, 2009).

On web-based platforms, users must teach themselves the data collection process without experimenter guidance. Therefore our interface was constructed to be amusing, engaging and intrinsically rewarding. An intrinsically rewarding participation process is believed to elicit higher quality user-derived data (Schroer & Hertel, 2009), a relationship that motivates efforts to create fun and game-like research interfaces (Curtis, 2015).

Volunteer smellers were given access to their own smell data in real time. Although individuals may be able to recognize their own body odor (Lord & Kasprzak, 1989), they are not able to accurately assess how they smell to others (Bornstein, Stocker, Seemann, Bürgin, & Lussi, 2008). The opportunity to see their own anonymized smell evaluations served as both a motivating reward and a learning opportunity. For example, it was soon evident to sweat donors that their own odor could be perceived differently by different smellers.

Finally, smellers were also able to access plots of aggregate smell data, grouped by factors with hypothesized influence. Volunteers could observe results from this work in real time, for example those described in Fig. 2 and 3. In citizen science efforts, it is often the desire to participate in the basic research and discovery process that provides the primary motivation (Raddick et al., 2013).

4.2 Factors affecting body odor perception

Crowd-sourced research has the potential to scale to very large data sets, but sacrifices access to expensive instrumentation and direct experimenter control. It is therefore unclear to what extent this method can produce high quality scientific data. As a proof-of-principle, this work was able to reproduce key findings from laboratory controlled settings. Specifically we have confirmed that male sweat odor is more intense. This can be attributed to the higher density of apocrine glands in the male axilla(P. A. J. Kolarsick, Kolarsick, & Goodwin, 2011).

We also observed that female smellers award lower pleasantness scores than males on average. Women typically outperform men in odor perception and recognition tasks(Doty, 1986; Koelega, 1994). Women also show a greater interest in olfaction across cultures(Seo et al., 2011) and have a higher neuron density in the olfactory bulb(Oliveira-Pinto et al., 2014), which may contribute to a greater odor sensitivity. Gender-based differences have been shown in the perceived pleasantness of many odorants(Keller et al., 2012) including other body odors(Doty, Ford, Preti, & Huggins, 1975), but it is unknown to what extent these differences are biological or cultural.

Surprisingly, deodorant use was found to have no effect on body odor intensity and a negative impact on pleasantness. This is in marked contrast to the advertised purpose of deodorant products: to reduce and improve personal odor. Our study did not ask donors to differentiate between antiperspirant and deodorant products. We also did not ask smellers to distinguish between sweat-derived odor and other fragrances often present in cosmetic deodorants. Therefore smellers may be assigning lower pleasantness to these artificial scent compounds.

Alternately, cosmetic deodorants may directly reduce body odor pleasantness for some users. Our data indicates that body odor pleasantness reaches a maximum at moderate intensity (Fig. 2F) and that deodorant use reduces the pleasantness of primarily low-intensity odors (Fig. 3B). This is consistent with a model in which body odors are found pleasant at low intensity but unpleasant at high intensity. Many odorant molecules are appealing at low doses yet unpleasant at high concentrations(Demole et al., 1982; Moskowitz, Dravnieks, & Klarman, 1976), and the principle is well understood in the perfume industry(Calkin & Jellinek, 1994).

A third possibility is that deodorant use may change skin chemistry or the composition of the microbiome in ways that alter the qualities of body odor or reduce pleasantness. For example, microbiological studies have suggested that antiperspirant use can preferentially favor the growth of bacteria associated with malodor(Callewaert, Hutapea, Van de Wiele, & Boon, 2014b). The consequence may be an odor that is both less intense and less pleasant.

Descriptor terms are selected by human smellers to summarize the cognitively rich experience of olfaction. Descriptor selections often show high variance between smellers, yet tend to cluster around stable odor profiles (Dravnieks, 1982). In this work, we observe a similar behavior for descriptor selections of three separate types: class, image, and emotion. All available descriptors were chosen with some frequency (minimum 2%). A wide range of descriptors was applied, with little agreement between independent smellers for the same body odor.

Despite this wide diversity in descriptor use, consistent patterns were detectable in the co-application of descriptors of different types. For example, we observed a strong association of fruity class smells "passion fruit" and "grape" with the positive emotions of "happiness" and "tenderness." Other cross-type descriptor associations were observed (Fig. 4). Fragrances are known to evoke emotional responses, and fruity smells in particular have been associated with positive affect(Haze et al., 2002; Hinton & Henley, 1993; Kadohisa, 2013; Nakano, Kikuchi, Matsui, Hatayama, & al, 1992)However, in previous work smellers were presented fruit-derived odorants directly, rather than detecting a fruity note in a complex mixture like body odor.

4.3 The structure of crowdsourced smell data

In aggregate, our intensity and pleasantness data sets were not normally distributed. Rather we observed a uniform distribution of smeller scores, with the exception of extreme values that were more likely to be selected. In contrast, other large-scale odor analysis projects have observed normal or bell-shaped distributions of pleasantness scores(Keller et al., 2012). This difference may be caused by the slider tool used to collect user inputs. Smellers were able to select intensity and pleasantness scores from a continuous line, rather than from a discrete set of categories (Fig. S2).

Alternately, diversity may be an inherent property of body odor perception. The uniform distribution is the distribution of maximum entropy, used to describe variables that are unconstrained except by their extrema. The chemical complexity of sweat and the subjectivity of smeller perception may combine to produce a diverse collection of individual perceptions with no central tendency at a population level.

Our results suggest that the emotional response to a body odor is strongly linked to the descriptive image it evokes. Although olfaction represents a high dimensional perception space, it has been argued that odor is a "sensory emotion" and that positive or negative emotional responses delineate a primary axis of perception (Yeshurun & Sobel, 2010). On this model, emotional associations to specific odor descriptions may be consistent, even as the range of descriptions is highly variable among smellers. If emotion and image associations to a specific body odor are not independent, a larger study may have the power to cluster smeller perceptions by related descriptors, reducing the high dimensionality of body odor perception space into a set of well-defined odor objects.

We were able to obtain correlated estimates for the intensity and pleasantness of a given body odor sample from independent, untrained smellers, although with significant variance. This, along with the violation of normality, suggests that large numbers of smellers may be required to estimate the mean intensity and pleasantness of a given sample with high confidence.

This work points towards the possibility of a large-scale, crowd-sourced study of body odor by establishing that sample collection and odor evaluation can be distributed and performed by volunteers without experimenter guidance. Further, this work underscores the need for such a study by demonstrating that body odor perception is a high variance, highly personal phenomenon that cannot be well resolved from small data sets. Future research may further resolve the relationship between the composition of sweat and the experience of smellers by resolving the principle dimensions on which body odor is perceived.

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6. SUPPLEMENTARY FIGURES

Supplementary Fig. S1 A web-based platform for collecting odor perceptions from volunteer smellers. Smellers are randomly assigned numerically coded sweat samples. Odor intensity and pleasantness scores are input by manipulating a vertical sliding scale. Odor descriptors are chosen from an ordered list. During the process, a graphical odor badge is produced. The badge is made available online to both donors and smellers to reward curiosity and motivate public participation.

Supplementary Fig. S2 Mean intensity and pleasantness scores assigned to each descriptor. Error bars indicate 95% confidence intervals, determined by bootstrap resampling. **AB** Animal descriptors including "goat" and "boar taint" were assocated with the most intense odors, while vegetal odors like "cabbage" and "mint" were assigned lower intensity scores on average. **C** Aggressive emotions like "rage" were associated with high intensity samples, while "tenderness" was among the emotional descriptors scored lowest in intensity. **DE** Fruity and vegetal smells like "passion fruit" and "mint" earned higher pleasantness scores, while animal and spicy smells like "garlic" and "goat" were unpleasant. **F** Positive emotions like "happiness," "tenderness," and "arousal" were associated with the highest pleasantness scores on average.

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