January 2008

Association of Odor Measures with Annoyance: Results of an Odor-Monitoring Field Study

Richard R. Stowell
University of Nebraska-Lincoln, rstowell2@unl.edu

Christopher G. Henry
University of Nebraska-Lincoln, chenry1@unl.edu

Richard K. Koelsch
University of Nebraska-Lincoln, rkoelsch1@unl.edu

Dennis D. Schulte
University of Nebraska-Lincoln, dschulte1@unl.edu

Association of Odor Measures with Annoyance: Results of an Odor-Monitoring Field Study

Linkages between odor measurements and consequential odor annoyance were found, which raises the prospects that objective measures may be used to predict when odors will be construed as being annoying.

Richard R. Stowell
Christopher G. Henry
Richard K. Koelsch
Dennis D. Schulte[1]

Summary

Multiple assessments of ambient odor were made by trained individuals around a swine finishing operation in eastern Nebraska. Assessor responses were analyzed to determine relationships between field odor measurements/ratings and ratings of annoyance potential, and to identify candidate measurement threshold values for causing annoyance. The likelihood of annoyance increased as odors became more offensive, intense, and concentrated, with r^2 values of 0.89, 0.81, and 0.64, respectively. Candidate thresholds were sought to delineate both "any degree of stated annoyance" and "consequential annoyance," defined as likely causing a change in behavior or activity level and instilling some memory of the odor event. Candidate thresholds for any stated annoyance and consequential annoyance, respectively, were: 1 and 2 for intensity (on a 0-5 scale); 2 and 7 dilutions to threshold for odor concentration (as measured using a mask scentometer); and -1 and -2 for Hedonic tone (on a +4 to -4 scale).

Background

Odor concerns are a primary barrier at the local level to the growth of livestock operations. Dispersion modeling may help producers evaluate the expected extent of odor impact from their operations on neighbors, and control strategies are being developed to mitigate odor emissions. Credible field odor measurement techniques are needed, though, to help demonstrate the benefits that improved site selection and odor control may offer to rural residents.

While progress is being made in measuring ambient odors using electronic devices, using humans to make field measurements of ambient odor remains the most widely accepted approach. People with a normal range/sense of smell can be trained to provide fairly consistent, calibrated responses for odor intensity and odor concentration. People can also provide subjective ratings of odor offensiveness (via Hedonic tone), odor character, and the potential for annoyance, the latter of which is necessary to evaluate cause-and-effect relationships.

More cause-and-effect information on measurable odor parameters and the potential for odor to be annoying is needed. Odor having an intensity of 2 or greater (on a 0-5 scale) has been assigned as a threshold for annoyance, but has not been verified with supporting data. Odor concentration is often used in odor regulation, with 7 dilutions to threshold (D/T) being a common regulatory threshold for states that consider ambient odor levels[2]. Odor offensiveness and annoyance are often used interchangeably, even though the meanings of each differ.

To help validate use of the Odor Footprint Tool as an odor impact/

(Continued on next page)

setback-estimation tool, the University of Nebraska–Lincoln conducted a field study of ambient odor levels in the vicinity of a livestock facility during 2005-06. The design of the field study was adapted from a study conducted to help validate use of the OFFSET setback-estimation tool developed by the University of Minnesota. As a secondary objective of this project, the field measurement data were analyzed to determine individual relationships of odor intensity, concentration, and hedonic tone with perceived annoyance potential. This report provides results of this analysis and discusses candidate thresholds for predicting annoyance.

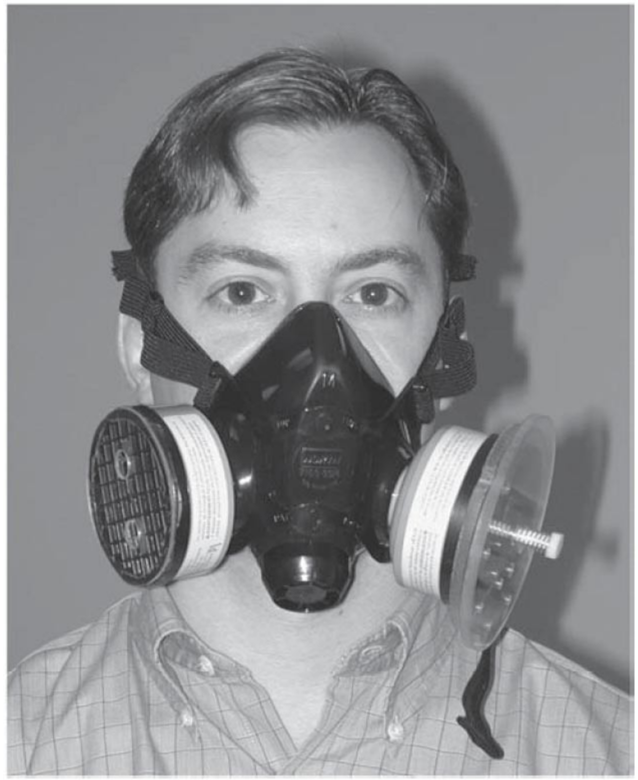

Figure 1. Mask scentometer for performing field olfactometry.

Methodology

Study participants

Graduate students from the University of Nebraska were trained in field olfactometry methods and employed to make objective assessments of odor in the vicinity of a swine finishing operation in eastern Nebraska. The students had a mix of farm and nonfarm backgrounds. During July and August of 2005, they made weekly visits to measure and rate ambient odors downwind of the primary (4,800-head) facility and at three set locations around the facility. These "mobile odor assessors" traveled as a group under the guidance of a scout and a team leader. Assessments were made by five to seven people every Tuesday for six weeks, with one assessment period occurring during the early evening (before dusk) and another taking place later in the evening (after sunset).

Measured parameters and scales

Odor intensity: Odor intensity measures the strength of an odor. Field odor intensity was measured on a 0-to-5 scale. The method used was adapted by the University of Minnesota from an ASTM Standard.

Odor concentration: Odor concentration was measured using a special mask fitted to conduct field olfactometry (Figure 1). Readings were taken by turning a dial on the mask through a series of notches that corresponded to decreasing dilution ratios. With each turn of the dial, more ambient, potentially odorous air was allowed to be drawn into the mask. When the dilution setting first reached the point at which the person wearing the mask detected the odor, the mask setting was recorded. The mask settings corresponded to dilution ratios as follows:

A = 170 D/T (dilutions-to-threshold)	D = 7 D/T
B = 31 D/T	E = 2 D/T
C = 15 D/T	Non-detect ➔ 1 D/T

For reference, 170 dilutions-to-threshold is conceptually the same as an odor concentration of 170 odor units (OU).

Hedonic tone: Hedonic tone ratings were made to assess the degree of unpleasantness or pleasantness of odor using a -4 to +4 scale.

Odor character: Assessors filled in the blank to the phrase "This odor smells like ________."

Annoyance potential: Participants rated the degree of annoyance that they would likely experience if the given state of odor existed outside their respective residences. The rating scale was designed to incorporate two response parameters that appeared to be generally associated with nuisance events: the prospective nuisance i) affects behavior and ii) invokes remembrance of the event. Odor assessors used the following scale and symbols:

Rating:	*Symbol*	*Likely behavioral response, memory effect:*
Not annoying	O	No response or effect
Slightly annoying	S	Make no changes in activities or routine; short-term recall only
Moderately annoying	M	Alter routine/activities to reduce exposure; recollection fades
Highly annoying	H	Postpone activities or stop sooner than planned; lasting effect
Extremely annoying	X	Stop activities to find relief / leave area; engrained into memory

To help establish a common basis for making these ratings, participants were to picture themselves having

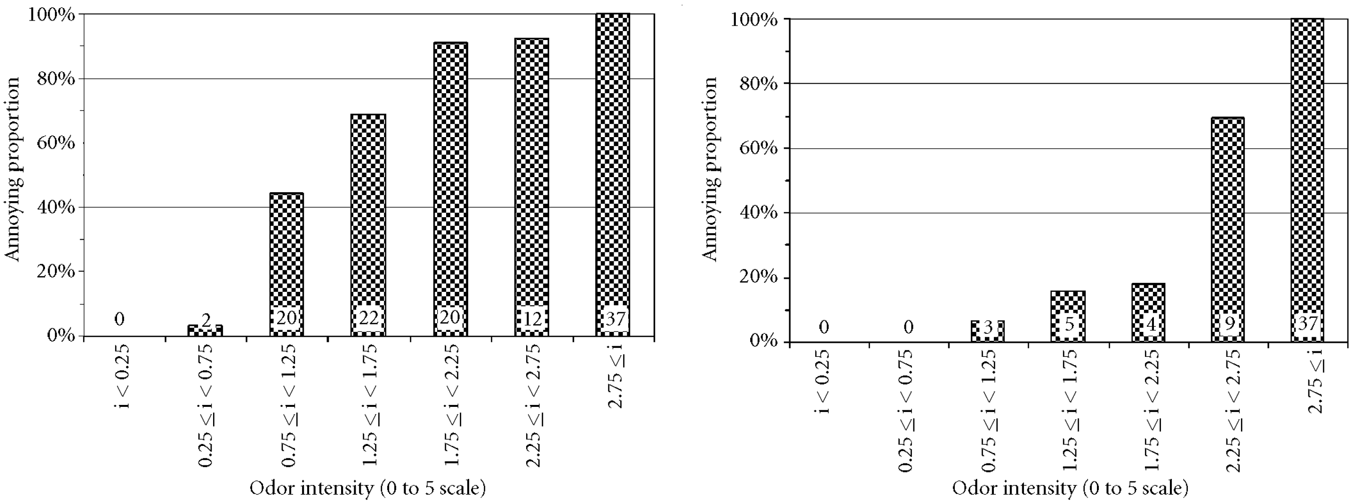

Figure 2. Likelihoods that odors assessed by mobile odor assessors were perceived as annoying (left) and consequentially annoying (right) based upon odor intensity. The number at the bottom of each bar is the number of responses indicating annoyance within the given range.

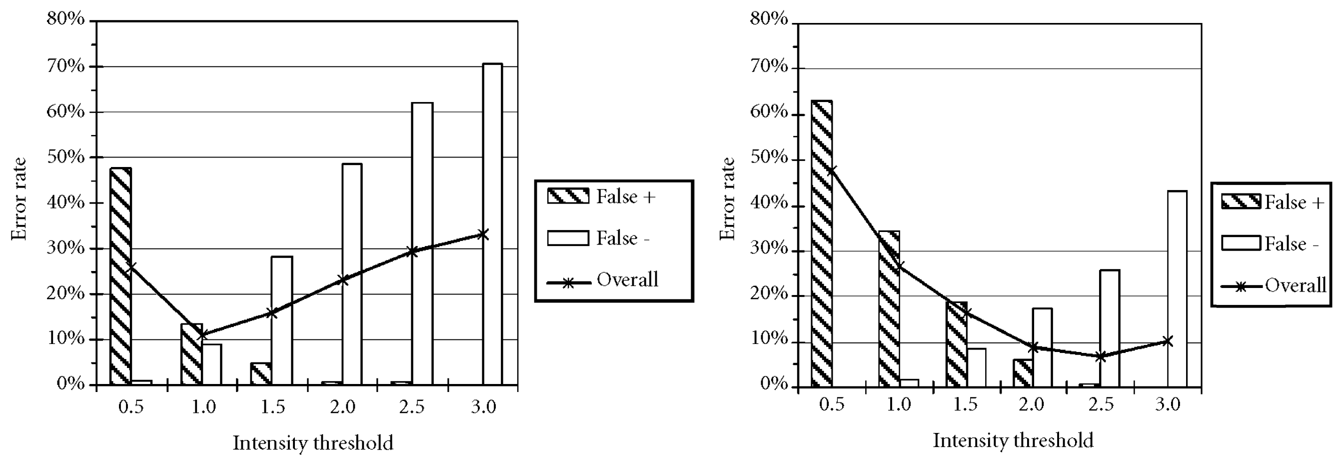

Figure 3. Error rates when using odor intensity to predict odor annoyance (left) and consequential annoyance (right), shown as functions of the threshold odor intensity.

invited friends/family over for an informal outdoor gathering. Beyond establishing the rating scale and common basis for making ratings, no attempt was made to calibrate participant responses.

Measurement data collection

When assessing detectable odor, the assessors made twelve sets of mask and intensity readings. When all 12 sets of readings were made, each assessor assigned a Hedonic tone rating, an odor descriptor, and an annoyance potential rating to represent the general state of odor during the measurement period (typically 8-10 minutes).

Data analysis

Each round of readings made by an individual assessor for a given time and location was evaluated as a single assessment. The 12 mask and intensity readings for each individual assessment were averaged and subsequently analyzed as means.

Linear regressions were performed to determine relationships between odor intensity, concentration, and Hedonic tone (independent variables) and annoyance potential (dependent variable). Thresholds were delineated as causing either any degree of annoyance (slightly annoying and greater) or consequential annoyance (moderately annoying and greater). Prospective thresholds were then evaluated based upon annoyance frequency and rates of false positives and negatives.

Results and Discussion

Odor was detected in 241 of the individual assessments (312 total) made by mobile odor assessors in 2005. Of these 241 assessments, the state of odor was considered to be at least slightly annoying in 113 (47%) of them and consequentially annoying — implying that the state of odor would likely influence assessor behavior — in 58 (24%) odor assessments.

(Continued on next page)

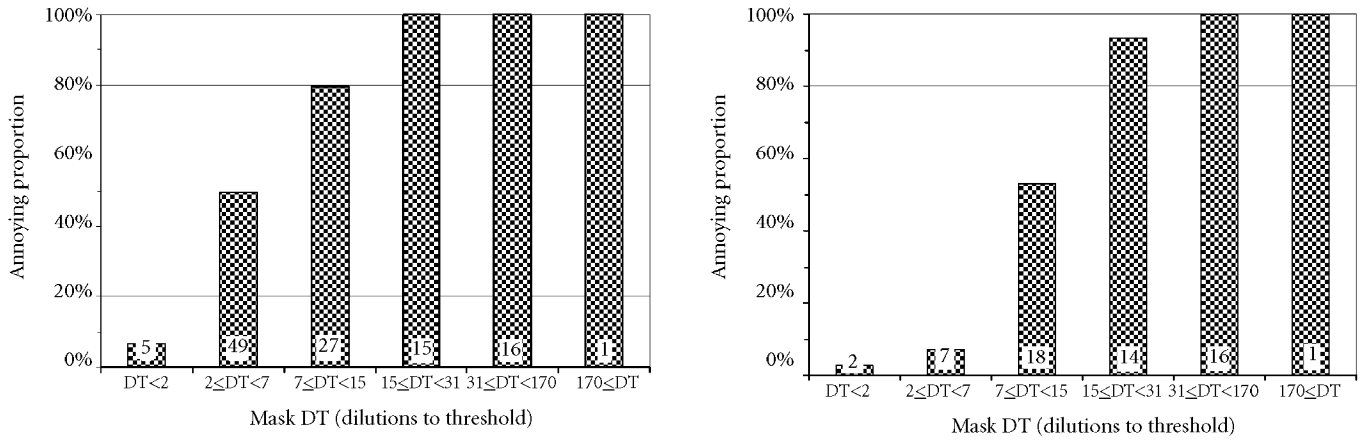

Figure 4. Likelihoods that odors assessed by mobile odor assessors were perceived as annoying (left) and consequentially annoying (right) based upon odor concentration. The number at the bottom of each bar is the number of responses indicating annoyance within the given range.

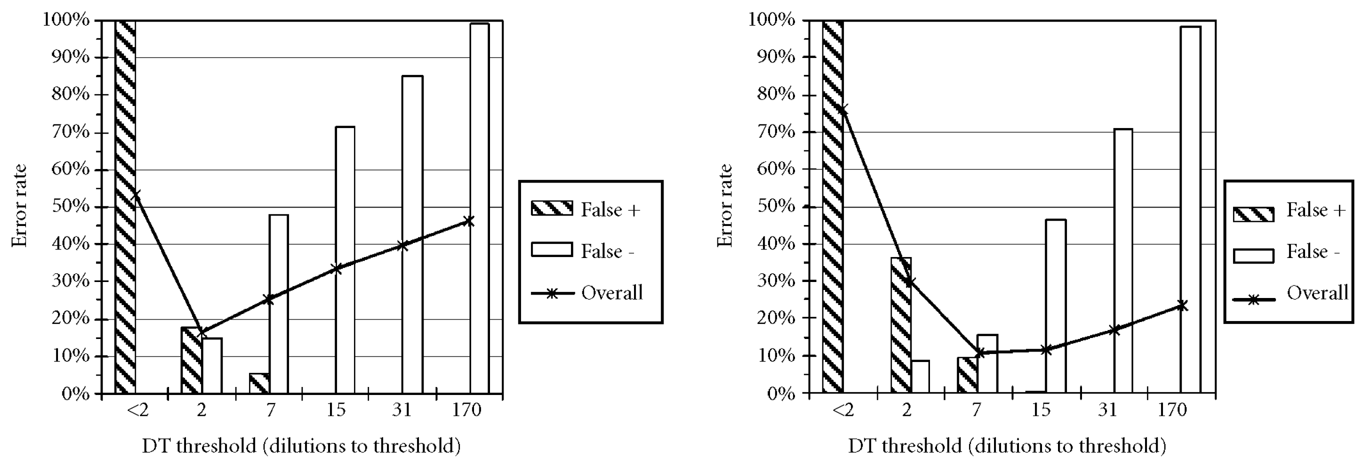

Figure 5. Error rates when using odor concentration to predict odor annoyance (left) and consequential annoyance (right), as a function of the threshold concentration (via mask scentometer).

Odor intensity

The perceived potential for odor annoyance increased with measured odor intensity and correlated reasonably well with intensity ($r^2 = 0.81$). A histogram can show where a sudden increase in the frequency of reported annoyance potential occurs. According to Figure 2, the thresholds for any annoyance and for consequential annoyance occurred for odor intensities of 1 and 2.5, respectively.

Another way to evaluate thresholds is to consider prediction error rates. Figure 3 shows the trends in prediction errors when the threshold for annoyance is set incrementally at intensities of 0.5 up to 3, for any annoyance and for consequential annoyance, respectively. A “false +” error refers to a situation where an intensity exceeded the assigned threshold, but the receptor did not rate the state of odor as being annoying, and a “false -” error refers to a situation where an intensity did not exceed the threshold value, but the receptor rated the state of odor as annoying.

The false-positive error rate for predicting any annoyance ranged from about 48% (61/128) at a 0.5 intensity threshold to below 1% for $i \geq 2$ (Figure 3, left graph). The false-negative error rate ranged from below 1% for a 0.5 threshold to over 70% (80/113) at $i = 3$. The data illustrate the challenge involved in trying to catch all objectively reported annoying odor conditions, in that a high false-positive rate would need to be endured, or visa versa. The minimum number of errors overall occurred for an intensity threshold of $i = 1.0$. The false-positive error rate for identifying consequential annoyance ranged from about 63% at a 0.5 intensity threshold to below 1% for $i \geq 2.5$ (Figure 3, right graph). The false-negative error rate ranged from 0% at an intensity threshold of 0.5 to about 43% at $i = 3$. The minimum number of errors overall occur for an intensity threshold of $i = 2.5$, but a lower threshold probably is needed to avoid not catching a sizeable percentage of objectively reported, consequentially annoying odor conditions.

Odor concentration

The perceived potential for annoyance also increased with measured odor concentration. Annoyance was moderately correlated with concentration ($r^2 = 0.64$).

When the odor concentration measured using a mask scentometer was reported to exceed 15 D/T, over 90% of the assessor responses indicated that potential for consequential odor annoyance existed (Figure 4). Given that the definition of odor annoyance would likely be defined at a lower frequency (i.e. 67%, 50% or lower), the threshold for any degree of annoyance appears to be between 2 and 15 D/T (Figure 4, left graph). Similarly, the threshold for consequential annoyance appears to be between 7 and 31 D/T (Figure 4, right graph).

The false-positive error rate ranged from 100% for odors that were not detectable at a 2:1 dilution ratio (128/128, by default) to 0% for a concentration threshold of 15 D/T (Figure 5, left graph). The false-negative error rate started at 15% and was over 99% for 170 D/T. The minimum number of errors overall occurred for a concentration threshold of 2 D/T. The false-positive error rate in identifying odor states that were likely to lead to consequential annoyance ranged from 100% for odors that were not detectable at 2:1 dilution to below 1% for an odor concentration threshold of 15 D/T (Figure 5, right graph). The false-negative error rate started at about 9% and was over 98% for 170 D/T. The minimum number of errors overall occurred for a concentration threshold of 7 D/T.

Hedonic tone

No positive/pleasant Hedonic tone ratings were provided by the assessors, so the ratings fit within the context of an offensiveness rating. A fairly strong correlation ($r^2 = 0.89$) existed between the perceived potential for odor annoyance and odor offensiveness, and a nearly 1-to-1 association existed between the two ratings (slope = 0.97). The assessors in this study clearly associated the offensiveness of odor with the potential for the odor to cause an annoying odor event. This occurred even though the two parameters were assigned differing non-numeric scales and had different bases for the ratings.

Measurement of hedonic tone is much more subjective than is measurement of odor intensity or concentration, however, and one could question the merits of comparing two ratings, which involve perceptions about odor. Unfortunately, hedonic tone ratings do not lend themselves to use in prediction of odor events using dispersion modeling either.

Odor character

The descriptive information collected by assessors was examined, but was not used in subsequent analysis, due to challenges in assigning quantitative values to descriptive terms and the limited variety of resulting responses. The terms used most often to describe the odor being assessed were "manure" / "pig manure"; "pigs" / "animals"; and less frequently, "earthy."

Summary and Conclusions

Field data were analyzed to compare assessor measurements of odor intensity, concentration, and hedonic tone (offensiveness) against assessor ratings of perceived odor annoyance potential. The following conclusions were made about the strength of associations between these measures and annoyance, and about candidate thresholds for defining annoying states of odor:

1) Positive correlations with annoyance potential exist for the 3 assessed odor measures, with the ranked order of correlations being offensiveness ($r^2 = 0.89$), intensity ($r^2 = 0.81$), and concentration ($r^2 = 0.64$).
2) Selection of threshold values for defining odor annoyance depends on whether the intent is to describe any degree of perceived odor annoyance or only consequential annoyance. Candidate thresholds for the three field measures at each of the two levels of annoyance are:

	Any Annoyance	Consequential Annoyance
Intensity (0-5 scale)	1	2
Concentration	2 D/T	7 D/T
Hedonic tone	-1	-2

Data is needed from more operations, including other types of swine facilities and production phases, to confidently establish thresholds for predicting potential for odor annoyance. Further inquiry into what constitutes annoyance and guidance on acceptable error rates is also needed.

Implications

This information provides baseline data for objectively defining states of odor that impact people. If objective measures of odor can be shown to be associated with annoying odor events, then rural residents will become more trusting of objective, science-based means of predicting when such odor events exist. Some pork producers might be a little uncomfortable with the notion that field measurements could be used to document that odors exceeded a prescribed threshold for annoyance. On the other hand, many find the current landscape, which relies primarily on complaints and arbitrary standards to define annoyance as far less desirable.

---

[1]Richard R. Stowell is an extension specialist in animal environment; Christopher G. Henry is an extension engineer; Richard K. Koelsch is an extension livestock bioenvironmental engineer; and Dennis D. Schulte is a professor in the Department of Biological Systems Engineering.

[2]Iowa DNR. 2006. Results of the Iowa DNR Animal Feeding Operations Odor Study. Iowa DNR, Ambient Air Monitoring Group, *http://www.iowadnr.com/air/afo/afo.html.*

Acknowledgements

The field study from which this data was obtained was supported by a grant from the Nebraska Pork Producers Association.