

Fragrance intensity measurement by magnitude estimation

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During the past 25 years a new form of sensory evaluation—magnitude estimation—has become very popular among research scientists in a number of different fields. The premise and forte of magnitude estimation is that people are able to assess sensory intensity by numerical means. Furthermore, the magnitude estimation method allows the participant an opportunity to use a wide range of numbers, with the property that ratios or proportions among the numerical assignments reflect ratios of sensory intensities.⁷

History of the method

Magnitude estimation was first suggested in its present form by Stevens.⁸ He reported that naive, untrained individuals could successfully judge the brightness of white lights of different luminances and sounds of different acoustic energies. Furthermore, Stevens reported, when the individual is assigned numbers with no predetermined scale limits, the numbers which the individual gives (N) could be accurately related to the instrumental measure of physical luminance (L) or acoustic pressure (P). The relation between the numbers and the physical measures of energy was a curve, concave downwards, so that the physical energy grew more rapidly than the numbers did. This curve was rectified into a straight line when the logarithms of the numbers that the individuals assigned were plotted against the logarithms of energy measures. The equation of this straight line is written as:

$$\text{Log Number} = P \text{ Log Intensity} + \text{Log } k$$

The straight line always had a slope (P) less than 1.0, whether for loudness or for brightness (such slopes for other stimuli may often times exceed 1.0).

A straight line equation such as the one above means that the sensory intensity (indexed by N, the magnitude estimate) grows according to a power function of physical intensity:

$$N = kI^P$$

For light and for sound, the exponent is approximately 0.33. Table I shows the wide range of power functions which have been reported for different sensory modalities.

Properties of power functions

If power functions truly describe the relations between sensory magnitude and physical intensity (as they seem to, from a quarter of a century of extensive investigation), then experimenters have at their

Table I

Representative Exponents of the Power Functions Relating Psychological Magnitude to Stimulus Magnitude

| Continuum | Exponent | Stimulus condition |
|-------------------|----------|------------------------------------|
| Loudness | 0.60 | binaural |
| Loudness | 0.54 | monaural |
| Brightness | 0.33 | 5° target -- dark - adapted eye |
| Brightness | 0.30 | point source -- dark - adapted eye |
| Lightness | 1.20 | reflectance of gray papers |
| Smell | 0.55 | coffee odor |
| Smell | 0.60 | heptane |
| Taste | 0.80 | saccharine |
| Taste | 1.30 | sucrose |
| Taste | 1.30 | salt |
| Temperature | 1.00 | cold -- on arm |
| Temperature | 1.50 | warmth -- on arm |
| Vibration | 0.95 | 60 cps -- on finger |
| Vibration | 0.60 | 250 cps -- on finger |
| Duration | 1.10 | white-noise stimulus |
| Repetition rate | 1.00 | light, sound, touch and shocks |
| Finger span | 1.30 | thickness of wood blocks |
| Pressure on palm | 1.10 | static force on skin |
| Heaviness | 1.45 | lifted weights |
| Force of handgrip | 1.70 | precision hand dynamometer |
| Vocal effort | 1.10 | sound pressure of vocalization |
| Electric shock | 3.50 | 60 cps -- through fingers |
| Tactual roughness | 1.50 | felt diameter of emery grits |
| Tactual hardness | 0.80 | rubber squeezed between fingers |
| Visual velocity | 1.20 | moving spot of light |
| Visual length | 1.00 | projected line of light |
| Visual area | 0.70 | projected square of light |

disposal a powerful tool for quantifying some of the underlying processes of sensory perception.

For example, the exponent of the power function (P) indicates the rate at which sensory intensity grows with corresponding changes in physical intensity. When P is less than 1.0 (as it is for odor), sensory intensity grows as a decelerating function of physical intensity. Large ratios of physical intensity (e.g., percentage changes in concentration) are transformed into smaller ratios of change of sensory magnitude. For instance, an exponent of 0.5 might be encountered in evaluating the odor intensity of amyl butyrate. This means that 10-fold changes in concentration of amyl butyrate would be perceived as $(10)^{0.5} = 3.2$ -fold changes (approx.) in subjective sensory magnitude of odor strength. Knowing the power function exponent allows the experimenter to predict sensory shifts. When P exceeds 1.0, the opposite effect occurs. The sensory system expands the physical ratios into large sensory ratios. For instance, an exponent of 1.5 characterizes the perceived roughness of sandpaper (against the grit size of the particles). This means that the 10-fold change in grit will be expanded to an approximate $(10)^{1.5} = 32$ -fold increase in perceived roughness. Finally, when P = 1 (as it does when we evaluate the lengths of lines), the same 10-fold change will

show up only as a 10-fold change in line lengths.

Magnitude estimation of odor intensity is usually performed by presenting to the individual a series of odorants, either from stoppered bottles (called the sniff-bottle method) or from air flow systems, in which the odorant is first saturated, to a relatively high initial percent saturation (e.g., 95%-100%), and then diluted with known volumes of clean, odorless air, to produce streams of lower odor intensity.

If the experimenter presents to an individual a series of different concentrations of one odorant alone, and asks the individual to assign magnitude estimates to the odorant, he can obtain a dose-response curve, relating the strength of perceived odorant intensity to physical concentration. If the experimenter presents two or more odorants to the individual in the same session, he can obtain relative odor intensities, as perceived by the individual smelling, independent of whether the odorants have been systematically varied along the concentration gradient.

Determining power function exponents. In order to adequately develop appropriate psychophysical functions, the experimenter should consider the following general guidelines.

In choosing a diluent, if it is to be a liquid, make sure that the odorant is entirely dissolved in the liquid, and if the odorant is a complex perfume (e.g., Chanel No. 5), make sure that during the course of the study sufficient samples and replicate samples are developed to guard against fractional distillation, and a consequent change in intensity/character.

Determine the range of odorant concentrations. The range will depend upon the criteria of the study. A large range will provide a good estimate of the overall dose-response, or psychophysical function (large may be a range that exceeds 10/1 or 1 log unit). Smaller ranges, for more specific product testing and cost reduction studies, may be ranges of 2-3/1 (or even smaller).

Present the stimuli in random order and instruct panelists to assign a number that matches the intensity of the odorant, with bigger numbers signifying greater odor intensities, and vice versa. With a large range of stimuli, approximately 20 readings are required, at most, to develop a good estimate of power function. With a small range the accuracy of the data increases systematically with increases in the number of ratings. The function becomes more clearly delineated with the increasing number of replicate ratings. This replicate is extremely important for cost reduction substitutions and concentration shifts, when minor shifts may produce moderate cost savings.

The mean or median ratings (from all of the replicates) can be plotted, both in linear and in log-log coordinates, vs. concentration. The linear curve should be relatively flat—a large increase in concentration should produce a smaller increase in judged odor intensity. The log-log curve will usually turn out to be linear, except at the region near threshold, where the curve steepens. The linear portion can be described by the equation

$$\log (\text{Magnitude Estimation}) = n \log (\text{Concentration}) + \log k \text{ (or ME} = kC^n\text{)}.$$

For odor, the typical dose-response relation is a power function, of the form shown above. The exponent is always less than 1.0, suggesting that the olfactory system compresses the wide range of physical concentrations to a much smaller range of odor intensity. Table II presents a list of representative power function exponents.

Table II

Some Power Function Exponents

| Odorant | Exponent | Diluent |
|--------------------|----------|---------|
| Amyl acetate | 0.13 | Liquid |
| Anethole | 0.16 | Liquid |
| l-Butanol | 0.31 | Liquid |
| l-Butanol | 0.64 | Air |
| l-Butanol | 0.66 | Air |
| Butyl acetate | 0.58 | Air |
| Butyric acid | 0.22 | Liquid |
| Coumarin | 0.33 | Air |
| Citral | 0.17 | Liquid |
| Ethyl acetate | 0.21 | Liquid |
| Eugenol | 0.27 | Liquid |
| Eugenol | 0.64 | Air |
| Geraniol | 0.20 | Air |
| Guaiacol | 0.20 | Liquid |
| l-Heptanol | 0.16 | Liquid |
| l-Hexanol | 0.15 | Air |
| D Menthol | 0.24 | Liquid |
| Methyl salicylate | 0.20 | Liquid |
| l-Octanol | 0.24 | Liquid |
| l-Pentanol | 0.21 | Liquid |
| Phenylethanol | 0.19 | Liquid |
| Phenyl acetic acid | 0.12 | Liquid |
| l-Propanol | 0.52 | Air |
| Iso-valeric acid | 0.21 | Liquid |

In very practical terms, the power functions allow the experimenter to gauge the sensory effect that a reformulation may have upon the perception of fragrance intensity. For instance, if the perfume oils are increased by 20%, this may reflect only a $(1.2)^{0.5}$ (approx.) or a 10% increase in subjective intensity. For cost reduction purposes, knowledge of the exponent will allow the product developer to determine whether a substantial reduction in cost, by lowering concentration, also produces a commensurate reduction in perceived odor intensity. It should not, since halving the concentration produces only a 30% or so loss in odor intensity.

Even if the experimenter does not wish to develop a dose-response function, nonetheless, he has at his command a method for evaluating the relative odor intensities of two or more materials. By presenting them to the individual in the same session, and by instructing the individual to evaluate them according to the same scale, the experimenter can determine the ratio of magnitude estimates, and estimate their relative subjective odor intensities. Such an exercise is extremely valuable for quality control, where a variety of different products must be evaluated, and in which the experimenter must assure himself that the odorous intensities of the products lie within certain pre-specified bounds.

Relation between magnitude estimation function and molecular properties

Many odorants exhibit different power function exponents which vary according to molecular properties. Experimenters have attempted to relate the exponents to some of these properties. Two decades ago, Jones^{4,5} found that most of the exponents that he found were the same (around 0.5), for a diverse set of odorants with different properties. Somewhat later, Cain,² exploring the homologous series of

straight chained aliphatic alcohols (propanol through decanol), found a high inverse correlation between water solubility and odor intensity exponent. Decanol, which was the most fat soluble and the least water soluble, exhibited the lowest exponent, whereas propanol, the most water soluble, exhibited the highest exponent.

A more systematic exploration, using many different chemicals, was reported by Laffort and Dravnieks.⁶ They found that three operative parameters of molecular structure acting in concert were predictors of the power function exponent. These molecular parameters are:

$\text{Alpha} = \text{Apolar Factor} = V_b/100$ (V_b = the mole volume of a substance at its boiling point, which is proportional to the actual volume of the molecule).

$\text{Pi} = \text{Proton Factor} = H \times (V_b^{0.8})/50 + 0.8$ (H = hydrogen bonding index).

$\text{Electron Factor Epsilon} = 20r/v - 4$ (r/v = highest volume polarizability of the atoms in each molecule). The ratios of the increments of mole refraction, and the increments of molecular volume at boiling point, p , are calculated for each part of the molecule. Then, only the highest ratio in the given molecule is considered.

By using these three molecular indices, they were able to predict the power function exponents for the aliphatic alcohols, as obtained by Cain,² as well as for acetone and geraniol. The correlation between the predicted and the obtained values was 0.97 for the two data sets.

One of the most recurrent problems which confront psychologists working in direct sensory scaling is the question as to the validity of power functions to describe the magnitude estimation scale. Many researchers in electrophysiology find S shaped (sigmoidal) curves, suggesting saturation at the higher concentrations. The subjective perception of odor intensity, however, would not exhibit such a saturation, were it to be described simply by a power equation (which makes no provision for saturation).

There are really two questions here: the appropriateness of power functions for fitting odor intensity ratings and whether power functions should be used if there is saturation in the olfactory system.

Appropriateness of power functions for fitting magnitude estimates. Traditionally, magnitude estimations of sensory intensity have been fitted by power functions. Usually, magnitude estimations are log-normally distributed (that is, the estimates themselves form a skewed, or non-normal distribution, but the logarithms of the estimates do fall along a normal, Gaussian distribution). In log-log coordinates, the magnitude estimations plot out as straight lines vs physical intensity. In odor, this range of intensity is a short one. Other equations might just as easily fit the data (e.g., linear, logarithmic, exponential). However, for those continua in which physical intensity can vary over a range of 10^5 - 10^8 (such as sound pressure or light energy), the psychophysical functions also turn out to be power functions.

Hence, for pragmatic reasons, if for no other, the

power function makes a good approximation for the dose-response relation odor, if magnitude estimation methods are used.

Is there saturation at the receptor? Olfactory research in animals, especially with the methods used by electrophysiologists continue to show that as the odor concentration is increased the response first increases, and then levels off at high concentration levels. Yet, psychophysically there does not appear to be a flattening of the intensity function for odor. In many other sensory continua (e.g. taste, brightness, loudness) there is also failure of the psychophysical function to flatten out at high intensities, where the electrophysiological records would indicate otherwise.¹⁰

The reason for the failure to saturate, whether in odor or taste, may be simply that the odorant or taste material has failed to become sufficiently concentrated to stimulate the upper sensory intensity regions that are possible. Solubility limitations in liquid and in air preclude many odorants from reaching a sufficiently high concentration so that they evoke the highest possible sensory response. Hence, at 100% saturation in air the odorant may only evoke 50%-60% of the maximum possible response. Only when sufficiently high concentrations are reached with substantially intense stimuli (sensorially) can we be sure the olfactory system really saturates.

Summary

Magnitude estimation represents a radical departure from many of the traditional methods for assessing fragrance intensity. The latter, traditional methods, relied upon threshold measures, equal-intensity matches between pairs of odorants, or category scales (scales limited from 1-9). In all those approaches the scientist never considered the possibility that the human being could assess odors adequately, and with a scale possessing ratio properties. Yet, as experimental evidence accrues, it appears quite reasonable to conclude that we can assess fragrance intensity, reliably, reproducibly from one laboratory to another, and with scales that appear to have ratio properties.

The future potential of magnitude estimation in particular, and sensory scaling in general, is quite bright. For the first time we are provided with a method that allows the scientist to map the characteristics of subjective odor intensity using powerful measuring tools. Furthermore, because the ratio scale is meaningful subjectively now, just as it has always been for objective, instrumental measures, we are in a position to (a) first determine relations among physical aspects of molecules, and (b) map those relations into relations among the intensities of subjective perceptions of the same molecules.

Odor Exponents References

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