SUBJECTIVE INTENSITY OF COFFEE ODOR

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The aim of this study was to develop a method for presenting controlled intensities of olfactory stimuli derived from natural coffee, and to determine, by the method of magnitude-estimation, how the subjective intensity of this odor grows with stimulus-concentration.[1] Since the 'psychophysical law' relating psychological magnitude to physical magnitude on a wide variety of prothetic sensory continua has repeatedly turned out to approximate a power function, it was to be expected that the apparent strength of the coffee odor would be proportional to the concentration raised to a power.[2] Some earlier experiments with benzaldehyde, carried out with an apparatus not too well suited to the purpose, seemed to confirm the power function.[3]

Extensive research by Jones has also confirmed the power function for olfactory stimuli.[4] For nine organic compounds he found the value of the exponent of the power function to range from about 0.4 to about 0.6. The procedure used was simple sniffing from wide-mouthed bottles which contained various proportions of the organic substance mixed in oil.

Apparatus. To avoid some of the uncertainties that characterize efforts to control the exact concentration of an odor when it is sniffed from an open bottle, or is forced into the nose by 'blast injection,'[5] a technique was developed involving the use of 'sniffing-bags.'

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[1] The method of magnitude-estimation is described in S. S. Stevens, The direct estimation of sensory magnitudes—loudness, this Journal 69, 1956, 1-25. For its relation to other psychophysical methods, see Stevens, Problems and methods of psychophysics, *Psychol. Bull.*, 54, 1958, 177-196.

[2] Stevens, On the psychophysical law, *Psychol. Rev.*, 64, 1957, 153-181.

[3] These results are reported in T. S. Reese, Magnitude estimation of smell, Honor's thesis in Psychology, Harvard University, 1957. See also Stevens, *op. cit.*, 1957, 166.

[4] F. N. Jones, Scales of subjective intensity for odors of diverse chemical nature, this Journal, 71, 1958, 305-310; Subjective scales of intensity for three odors, this Journal, 71, 1958, 423-425.

[5] Carl Pfaffmann, Taste and smell, in S. S. Stevens (ed.), *Hanbbook of Experimental Psychology,* 1951, 1162-1165; Jones, A comparison of the methods of olfactory stimulation; blasting vs. sniffing, this Journal, 68, 1955, 486-488.

contents of the bag in the course of a normal sniffing process. This technique has the advantages that only the gas in the bag enters the nostrils and the process of sniffing is effectively carried out under normal atmospheric pressure.

The problem of finding a suitable material for the bags was given considerable attention. The ideal material needs to be impermeable, free of odor, thin, and flexible. These requirements seem to be met reasonably well by a material made of plastic and aluminum ("Scotchpak" 20A20, manufactured by Minnesota Mining and Manufacturing Co.). If the Scotchpak is thoroughly cleaned with soap and water it can be rendered essentially odorless. It can readily be made into bags by heat-sealing the edges. For the present experiment, bags with a volume of 4 liters were made by heat-sealing the edges of two triangular pieces 15 in. across the base and 17 in. high. The neck of the bag was wrapped tightly around a 4-in. section of glass tubing of 7 mm. interior diameter.

A nose-piece was attached to the tubing in the neck of each bag. It consisted of two glass plugs, each about the size of the end of a thumb, and so positioned that the plugs could be seated tightly and comfortably over the entrances to the nostrils. The plugs were made of ground Pyrex ball-joints 18 mm. in diameter with a 7 mm. bore, and were fastened to a fork leading to the tube that led in turn to the bag. To make the ball-joints fit the typical nostrils, their axes were set at an angle of 60° toward one another. It was also necessary to grind flat the two facing surfaces of the balls to make room between them for the septum of the nose. The angle between these flattened surfaces was about 30°. The distance between the balls was about 5 mm.

The nose-piece was connected to the bag by a short section of polyethylene tubing. This tubing was closed off by a clamp which could be easily opened by *O*. The entire assembly of bag, nose-piece, and clamp could be handed to *O*, and he in turn could place it quickly to his nose, open the clamp and inhale the contents of the bag.

For the experiment with coffee, different concentrations of the odor were manufactured by mixing odor and air in various proportions. An appropriate amount of air 'saturated' with coffee was first put in the bag and then the bag was filled with pure air. The odorous part of the mixture was obtained by running air at a slow, uniform rate through a half-pound of ground coffee contained in a gas-washing bottle. The output of this bottle was filtered through a 1-in. pack of glass wool which served to trap the coffee dust. The amount of odor placed in a bag was metered by timing its flow into the bag. The rate of flow was held constant by means of a constant driving pressure, and the relative concentrations in the different bags was determined by the relative duration of the injection of the odor. Only the relative concentrations need be known to test whether subjective intensity grows as a power function of concentration and to determine the size of the exponent.

One disadvantage of the method was that, although the observations could be made in a matter of 10 min., the washing of the bags and the preparation of a new series of stimuli required from 1 to 2 hr.

Procedure. The method of magnitude-estimation was used to obtain a ratio-scale of the subjective intensity of the odor of coffee. Five concentrations covering a range of almost 100 to 1 were prepared, each concentration in a separate bag. The *O* was first told how to hold the bag to his nose, and how to open the valve and take a generous sniff of the contents. He then practiced by actually sniffing from a bag

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containing a medium concentration of the odor. He was then told that he would be given the bags one by one and that his task was to estimate the intensity of the odor in each bag. The intensity in the first bag was to be called '10,' and O's task was to assign numbers to the various intensities proportional to their apparent strength.

The stimulus-odor called '10' was the middle concentration of the series. Since the bags were kept behind a screen, O did not know how many different intensities were to be judged. Actually, each of the five concentrations was judged twice by each O. Between the first and second runs, the standard was presented a second time. The order of presentation of the stimuli was different for each O. An experimental session lasted from 5 to 10 min., and 20 to 30 sec. elapsed between the presentation of successive bags.

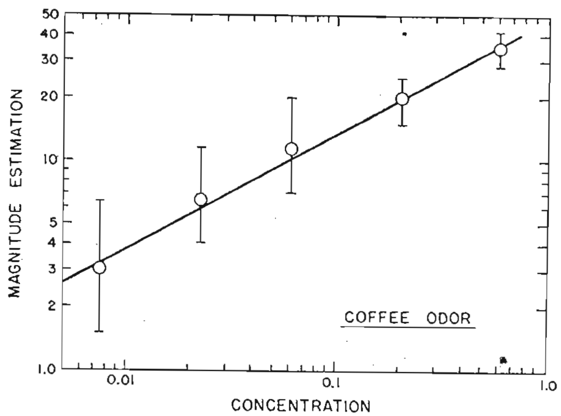

FIG. 1. MEDIAN MAGNITUDE ESTIMATIONS OF THE SUBJECTIVE INTENSITY OF COFFEE ODOR AS A FUNCTION OF CONCENTRATION
(Vertical bars show the interquartile range.)

Results and discussion. The medians of the magnitude-estimations by 12 men are shown in Fig. 1. It is clear that these results approximate a straight line in a log-log plot, and, therefore, that they confirm the power law. In this case the slope of the line, and hence the exponent, is about 0.55.

In addition to the 12 men, a group of 8 women made judgments. Their results also approximated a power function but the slope was of the order of 0.3. This lower slope was due mainly to the fact that the judgments of three of the women were almost random. One of the women said there seemed to be little or no difference among the stimuli. Although there may be a sex difference here, it is rather more plausible to assume that

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this small sample happened to include a few women who are inconsistent estimators of apparent magnitude. As pointed out elsewhere, one occasionally encounters people who use numbers and make estimates in rather strange ways.[6]

The combined results of all 20 Os, both men and women, produce a power function with an exponent of about 0.45. Although this value is based on a larger set of data, it seems probable, on the present evidence, that the exponent determined for the men alone (Fig. 1) is more representative of what additional measurements will show. This, however, remains to be seen.

The vertical lines in Fig. 1 mark the interquartile ranges of the magnitude-estimations. The distribution of the judgments is such that the medians coincide fairly closely with the geometric means. This type of distribution appears to characterize many of the experiments that use the method of magnitude estimation.[7]

In the course of the work that led up to the experiments on coffee, several exploratory experiments were conducted. Two of these studies bear on the subjective scale for heptane, which Jones found to be a power function with an exponent of about 0.59. Using sniffing bags made of polyethylene, we ran an experiment on 18 Os and obtained an exponent of about 0.6. Since there were certain difficulties with this experiment, including a tendency for the polyethylene to become contaminated, the experiment was repeated on 10 Os with the Scotchpak bags. The exponent then turned out to be about 0.68.

In the present state of the difficult art of controlling the olfactory stimulus, these various experiments seem to confirm one another about as well as can be expected. They suggest that the subjective intensity of the odor of heptane grows as a power function of the concentration, and that the exponent is of the order of 0.6. On the basis of the present evidence, it appears that there is also a power function for coffee and that its exponent is probably a little smaller than the exponent for heptane.

Although a direct tie-up between these subjective scales and recordable physiological processes is not yet possible, it is interesting to note that nerve potentials recorded from the olfactory bulb of a rabbit seem to grow with concentration roughly in the same manner as apparent intensity. Mozell found that the integrated spike discharge "increased approximately

[6] Stevens, this JOURNAL, *op. cit.*, 1956, 1-25.
[7] See, for example, J. C. Stevens, Stimulus spacing and the judgment of loudness, *J. exp. Psychol.*, 56, 1958, 246-250.

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as a negatively accelerated function of concentration."[8] Such negative acceleration is consistent with the fact that the exponent of the power function is less than one. Whether this correspondence is more than a coincidence is difficult to say.

The sensory transducer involved in olfaction seems to behave as a 'compressor' in the sense that its output is a decelerating function of stimulus input. In this respect it resembles the auditory and visual transducers.[9] It contrasts with certain other modalitites (*e.g.* electric shock and kinesthetic force) in which sensory magnitude grows as an accelerating function of stimulus magnitude. For these modalities the exponent of the power function is greater than 1.0. 'Compression' is an obvious advantage in vision and hearing where the sense organ must handle stimulus inputs covering ranges of billions to one, but this principle hardly seems applicable to olfaction where the effective stimulus-ranges commonly encountered are mostly of the order of hundreds to one.[10] Despite the lack of any obvious biological utility, the sensory epithelium seems to behave as a compressive system.

Olfaction forms an exception to the rough relation noted elsewhere, that sensory continua for which the effective stimulus ranges are shorter have larger exponents.[11] A curious and possibly significant fact about smell is its limited dynamic range—subjectively speaking, the strongest odors we usually encounter are not many times more intense than the faintest odors.

Summary

A 'sniffing bag' was developed to facilitate the presentation of controlled concentrations of odorous gas, and this technique was applied to the scaling of the subjective intensity of natural coffee odor by the method of magnitude estimation. For a group of 12 men the subjective intensity of coffee was found to grow as the 0.55 power of the concentration. A group of 8 women gave a function with a flatter slope, but it is suggested that this result is probably not representative.

Two exploratory experiments with heptane gave evidence of a power function with an exponent of the order of 0.6. The fact that the apparent intensity of odors grows as a power function of the concentration is consistent with the law that appears to govern other sense modalities.

[8] M. M. Mozell, Electrophysiology of olfactory bulb, *J. Neurophysiol.*, 21, 1958, 183-196.

[9] Stevens, Measurement and man, *Science*, 127, 1958, 383-389.

[10] Cf. Mozell, *op. cit.*, 183-196.

[11] Stevens, Cross-modality validation of subjective scales for loudness, vibration, and electric shock, *J. exp. Psychol.*, 57, 1959, 201-209.

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RESISTANCE TO EXTINCTION IN THE FISH AFTER EXTENSIVE TRAINING WITH PARTIAL REINFORCEMENT

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The effect of partial as compared with consistent reinforcement on resistance to extinction in the fish *Tilapia macrocephala* was studied in two recent experiments, the first under conditions of massed practice,[1] and the second under conditions of widely spaced practice.[2] The response of the animal in each case was to strike at a target introduced into its living tank; the measure of performance was latency of response; and the index of resistance to extinction was number of trials to the criterion of five successive failures to respond in 30 sec. In both experiments, resistance to extinction was *less* after partial than after consistent reinforcement, at least initially. When the animals of the first experiment were subjected to a series of extinctions separated by reconditioning sessions, the paradoxical effect found in higher forms gradually made its appearance; resistance to extinction declined progressively in both groups, more rapidly in the Consistent than in the Partial, until the resistance of the Consistent Group was less than that of the Partial Group. The present experiment was designed to inquire into the cause of this shift in relative resistance to extinction.

One possibility to be considered is that the process which makes for greater resistance to extinction in the partially reinforced rat also operates in our fish, but more slowly, its effects being felt only after a much larger number of training trials. A second possibility is that the process in question does not operate in the fish, and that the shift in relative resistance which appeared in our first experiment is attributable to the more rapid development in the Consistent Group of a discrimination between the events of training and extinction. From the first point of view, a larger

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[1] Jerome Wodinsky and M. E. Bitterman, Partial reinforcement in the fish, this Journal, 72, 1959, 184-199.

[2] Nicholas Longo and M. E. Bitterman, The effect of partial reinforcement with spaced practice on resistance to extinction in the fish, *J. compar. physiol. Psychol.*, 53, 1960, 169-172.

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