mutagenicity of fractions of used crankcase oil activated by rat or trout liver extracts.

We first employed an Ames tester strain with fish extracts to see whether BP could be activated (*10, 11*). To check for BP activation, liver fractions were prepared from laboratory-reared rainbow trout (*Salmo gairdnerii*). Liver (2 to 3 g) was homogenized by hand in a 7-ml all-glass tissue grinder with 6 to 8 ml of buffer (0.05*M* tris-chloride and 0.25*M* sucrose, *p*H 7.5). Homogenates were centrifuged for 10 minutes at 9000*g* and the supernatants were frozen at −70°C. Preliminary experiments demonstrated that the number of revertant colonies produced was dependent on the level of AHH activity in the 9000*g* fractions. No attempt was made, however, to critically quantitate the number of revertant colonies produced with BP over a range of AHH activities. The results compared favorably with those obtained with 3-methylcholanthrene-induced rat microsomes.

Further work was carried out with PAH-enriched fractions from various crude oils and from used and unused crankcase oils activated with rat or fish extracts. Sprague-Dawley rats were used; liver fractions were prepared as for fish. Petroleum samples were made available by the American Petroleum Institute and included Venezuelan bunker, Kuwait crude, Louisiana crude, and a No. 2 fuel oil. The virgin crankcase oils included Texaco, Esso, Gulf, Irving, and Veedol brands. Used crankcase oil was obtained locally. Irradiated samples of the crude oils were also checked, since environmental weathering may produce toxic photooxidation products. Equal volumes of dimethyl sulfoxide (DMSO) and oil were mixed. After centrifugation, the DMSO layer was remixed and recentrifuged. This gave an effective emulsion-free extract. The DMSO served as both a good extractant for PAH and a vehicle for the introduction of chemicals to tester strains. A 100-μl portion of hydrocarbon extract was used in each study. Positive results were obtained only with used crankcase oils (Table 1), and it appears that compounds other than BP or BA are the major mutagenic sources. Mutagenesis was increased in extracts from fish exposed to petroleum for 3 to 4 days (*12*).

This work establishes that fish can produce mutagenic metabolites from PAH and that used crankcase oils, which are released into the terrestrial and aquatic environment in considerable quantities (*13*), may represent a considerable mutagenic threat. At present, it appears that control over crankcase oil disposal is minimal and difficult to regulate (*14*). Benzopyrene and benzanthracene, which are produced in automobile engines (*15*), appear not to be the major mutagenic components. Previous work in this laboratory (*16*) demonstrated that fish taken from environmental sites with a history of oil contamination had elevated AHH levels. In some mammalian systems there is a relationship between AHH activity and susceptibility to hydrocarbon-induced cancers (*17*). The public health hazard of crankcase oil, especially from occupational exposures and dirt road oiling, should also be reassessed.

JERRY F. PAYNE
ISABEL MARTINS

Fisheries and Marine Service, Newfoundland Biological Station, St. John's, A1C 1A1

ANVER RAHIMTULA

Biochemistry Department, Memorial University of Newfoundland, St. John's, A1C 5S7

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10. We previously tried several older tester strains; in this work we used the sensitive TA 98 strain (*Salmonella typhimurium*).
11. There has been some success in producing epitheliomas in fish with the polycyclic hydrocarbons BP and 3-methylcholanthrene, but no internal tumors were produced with BP injections [M. Ermer, *Zool. Anz.* **184**, 175 (1970)].
12. Rainbow trout (*Salmo gairdnerii*) were exposed to surface slicks of Venezuelan crude oil for 3 to 4 days. The slick was created by adding 10 ml of oil to a 16-liter aquarium (*8*).
13. There is evidence that crankcase oils may be a major source of waste petroleum in municipal waste water systems [J. T. Tanacredi, *J. Water Pollut. Control Fed.* **49**, 216 (1977)]. The amount of petroleum hydrocarbons from waste water effluents discharged into coastal waters in 1970 was approximately equal to the quantity reported from oil spills [J. W. Farrington and J. G. Quinn, *ibid.* **45**, 704 (1973)]. Of the petroleum hydrocarbons entering the ocean annually, 2.5 million tons may come from industrial wastes and municipal urban runoff compared to 2.1 million tons from marine transport (*3*).
14. In Canada, the Environmental Impact Control Directorate can account for only 20 percent of the used crankcase oil, which may be dumped, used in landfills or for road oiling, or burned.
15. There is considerable evidence for BP production in automobile engines but BA has also been identified [R. A. Broun, T. D. Searl, W. H. King, Jr., W. A. Dietz, J. M. Kelliber, *Rapid Methods of Analysis for Trace Quantities of Polynuclear Aromatic Hydrocarbons in Automobile Exhaust, Gasoline and Crankcase Oil* (Publication PB-219-025, National Technical Information Service, Springfield, Va., 1971)].
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18. We thank B. Ames for tester strains and J. Neff for samples of reference crude oils. Contribution No. 282 from the Marine Science Research Laboratory, Memorial University of Newfoundland.

26 August 1977; revised 10 February 1978

Psychophysical Functions for Perceived and Remembered Size

Abstract. *Separate groups of people estimated the sizes of perceived or of remembered objects. In three independent experiments, both sets of data were well fit by power functions, and the exponent was reliably smaller for remembered than for perceived size.*

Gustav Fechner (1801–1887) attempted to characterize the functional relationship between the psychological and the physical world and called this enterprise psychophysics. Although Fechner studied only the "lower mental activities" such as sensation, his conception of psychophysics included the "higher mental processes" as well, but he left for the future this exploration and the methods it might employ (*1*). Modern applications of signal detection theory (*2*), multidimensional scaling (*3, 4*), and reaction time (*5*) have revealed intriguing commonalities between perceptual and memorial processes. For example, some evidence (*3, 4*) suggests that a "second-order isomorphism" holds between objects and their (perceptual or memorial) internal representations, in that the structural relations among objects are mirrored by the corresponding functional relations among their internal representations. These perceptual-memorial similarities indicate that remembered stimuli may map onto physical values in the same way perceived stimuli do, but a sensitive comparison of perceptual and memorial psychophysical functions has not been reported (*6*).

We have used magnitude estimation, a direct scaling technique popularized by

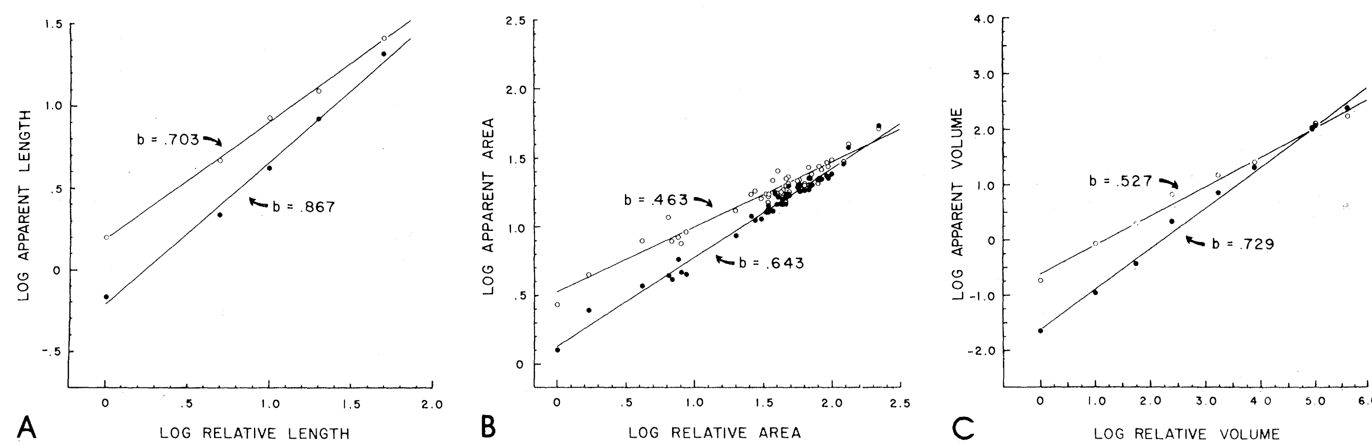

Fig. 1. Apparent magnitude (geometric mean of the magnitude estimates) as a function of relative physical magnitude of the object judged. Best-fitting lines and the corresponding slopes are indicated for the perceptual (filled circles) and memorial (open circles) data. (A) Experiment 1, judged length; (B) experiment 2, judged area; and (C) experiment 3, judged volume.

Stevens (*7*), to determine the psychophysical functions for both remembered and perceived size. We now report that for one-, two- and three-dimensional objects, power functions fit to the memory data have consistently smaller exponents than power functions fit to the perceptual data.

For experiment 1 we selected a simple task that let us control the observer's experience with the stimuli he judged. Subjects were individually tested on two consecutive days. On day 1, 20 undergraduates learned names for five visual stimuli differing only in length (*8*). Black lines 0.2 cm wide and 0.4, 2, 4, 8, and 20 cm long were rear-projected on a milk-glass screen 45 cm from the subject, whose head was positioned in a chin rest. On study trials the experimenter called out the appropriate name (BUP, LEQ, VAF, YEM, or ZID) as each line was exposed, and on test trials the subject supplied the name as each line was projected (*9*). The order of presentation was random, and blocks of 15 study trials alternated with blocks of 15 test trials until the subject completed one 15-trial test block without error. Study trials were then discontinued, and each subject was trained to a 300 percent overlearning criterion (*10*). The session took approximately 25 minutes per person.

After 24 hours, the subjects returned and made magnitude estimates of the stimuli. Ten subjects were randomly assigned to a perceptual (P) and ten to a memorial (M) condition. The P group was given standard magnitude estimation instructions that specified no modulus [a reference stimulus to which an arbitrary value is assigned (*11*)], and these observers then assigned a number to each stimulus as the experimenter presented and named the five lines in a random order. The M group received identical instructions, except that they were told to imagine, rather than view, the line projected on the screen in front of them. Each observer assigned a number to each "imagined" stimulus as the names were called out in a random order.

The geometric means of the magnitude estimates were plotted as a function of relative line length for both groups (Fig. 1A). Since the data appear on log-log coordinates, the slope of the straight line (fit by least squares) may be taken as the exponent of the power function relating apparent length to the objective physical metric. In both cases a power function describes the data well, accounting for more than 99.5 percent of the variation, but the M slope is reliably shallower than the P slope (t = 4.355, d.f. = 9, $P < .002$) (*12*).

In experiment 2, we tried to broaden the scope of our inquiry by using items with which our subjects were already familiar—the states of the Union (*13*). Twenty-six undergraduates were randomly assigned to conditions P and M (N = 13 in each case) and tested individually for one session only. All observers were first given standard magnitude estimation instructions specifying no modulus.

Next, magnitude estimates were requested as the names of the states were read in a random order. Subjects in the P group were told to judge the apparent area of a black outline tracing of each of the 48 contiguous states as it was rear-projected on a screen 50.5 cm in front of them (*14*). Subjects in the M group were instructed to project a vivid image of each state on the same (blank) screen, and to judge its apparent area.

Again, the magnitude estimates as a function of the relative area of the physical stimuli (Fig. 1B) are well fit by power functions, and the M slope is reliably smaller than the P slope (t = 8.14, d.f. = 92, $P < .001$) (*15*). Although the M data are slightly noisier than the P data (r^2 = .934 and .982, respectively), applying a statistical correction for this small regression effect did not substantially diminish the reliable difference between the slopes (*16*).

In experiment 3 (*17*), we used items that were not only familiar to our subjects, but which had probably been manipulated on numerous previous occasions. We hoped to tap memories derived from a degree of intimacy hardly possible with the stimuli used in the previous experiments. The following spherical objects served as stimuli: BB, pea, marble, Ping-Pong ball, tennis ball, softball, volleyball, basketball, and beach ball (*18*). Seventeen undergraduates were randomly assigned to either condition P (N = 9) or M (N = 8) and tested in separate groups by the same experimenters. The names of the objects were read in a random order and followed by magnitude estimation instructions that specified no modulus. Both groups of subjects then estimated the magnitudes of the apparent volumes of the objects as the names were read in a new random order. In the P condition, the objects were displayed at a distance of roughly 1 m as each object was named (*19*).

The data for both groups are well fit by power functions, and the best-fitting line is reliably shallower for the M than for the P group (Fig. 1C) (t = 8.065, d.f. = 14, $P < .001$) (*20*). This difference can hardly be attributed to a statistical regression effect, as the best-fitting lines account for more than 99 percent of the variance in the data points.

In these three independent experiments, the exponents of memory psychophysical functions are consistently smaller than the exponents of perceptual psychophysical functions. The observed difference is not an artifact of regression to the mean resulting from a poorer correlation between the X and Y variables in memory than in perception, because in experiments 1 and 3, the M correlations are no lower than the P correlations, and correcting for the small statistical regression effect in experiment 2 does not eliminate the slope difference. Nor is the P-M difference a spurious product of averaging over subjects, since analyses that first generate exponents for individual observers yield similar results (*21*).

The attenuated memory exponent may mean that memory is characteristically more compressive than perception because of response bias or trace migration (*22*). Alternatively, perception and memory may perform identical power transforms on the input data; the exponents may differ because the memory transformation is applied to the products of the perceptual transformation rather than to the original values. Thus memory is not necessarily more compressive than perception; it is whatever results from applying the perceptual transform a second time. If the perceptual psychophysical function is expansive, the memory exponent ought to be potentiated rather than attenuated; if perception does not transform the input at all (an exponent of 1), then neither should memory. Empirically deciding between these two classes of explanation should be easy.

ROBERT S. MOYER
DRAKE R. BRADLEY
MARK H. SORENSEN
JOHN C. WHITING
DAVID P. MANSFIELD

Department of Psychology, Bates College, Lewiston, Maine 04240

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6. Ekman and colleagues have previously described some important research in memory psychophysics [G. Ekman and O. Bratfisch, *Acta Psychol.* **24**, 446 (1965); U. Lundberg, in *Image and Environment*, R. M. Downs and D. Stea, Eds. (Aldine, Chicago, 1973), p. 332; U. Lundberg and G. Ekman, *Scand. J. Psychol.* **13**, 81 (1972)]. Their work suggests that power functions adequately characterize memory data, but the scatter around their best-fit lines is often large. In addition, they have not tried to experimentally contrast perceptual and memorial psychophysical functions [with one exception, to our knowledge: M. Björkman, I. Lundberg, S. Tärnblom, *Scand. J. Psychol.* **1**, 136 (1960); in this study, however, the memory condition is actually a mix of perceptual and memorial information]—which is the major thrust of our research.
7. S. S. Stevens, *Psychol. Rev.* **64**, 153 (1957). In magnitude estimation, subjects assign numbers to stimuli such that the numbers are proportional to the apparent magnitudes of the stimuli.
8. In all studies reported here, the subjects were naive with respect to both the purpose of the experiment and to psychophysical experiments in general.
9. The assignment of names to stimuli was randomly determined for each subject.
10. For example, if a person needed two 15-trial study blocks to reach the initial criterion of one perfect test block, then the 300 percent overlearning criterion would consist of six additional 15-trial test blocks.
11. These instructions were adapted from D. V. Cross and L. Rotkin, *Percept. Psychophys.* **18**, 79 (1975).
12. Because we wanted our P control groups to approximate the results reported in the standard psychophysical literature, we were somewhat concerned that the slope for P line length only approaches the lower bound of reported exponents for line length. We therefore tested ten additional subjects from the same pool under standard perceptual (SP) magnitude estimate conditions (that is, no names were learned for or presented with the lines, and the experiment required only one session. The slope for the SP group was .918, which does not differ reliably from that of the P group, who learned names for the stimuli (t = 1.355, d.f. = 9, P > .20). The results of this control experiment suggest that, at least under these conditions, learning names for perceptual stimuli does not substantially alter the exponent of the power function (though the effect might become reliable if additional data were collected). These control data also show that the P-M difference in exponents does not depend on the P group's learning names for the stimuli (since the SP versus M difference in slopes was also reliable, t = 5.711, d.f. = 9, P < .001). The t-tests were based on the pooled residual error from the three regression lines; consequently there were 9 d.f. for each comparison, rather than 6 d.f.
13. We were influenced in our experimental design and choice of stimuli by Shepard and Chipman's (*3*) imaginative work on perceptual and memorial shape judgments of states. Our study differs from theirs in that (i) we used a direct instead of an indirect scaling technique; (ii) we required judgments of size (area) rather than shape; (iii) our subjects' judgments can be plotted against an objective physical metric (relative size, area in square miles), thus generating psychophysical functions; and (iv) our direct scaling approach detected reliable differences between the P and M psychophysical functions, whereas their multidimensional scaling analysis emphasized similarities between perception and memory.
14. Each state was traced from a Rand McNally map (scale = 1:4,000,000) in a way which preserved the north-south orientation and was then photographically transferred to a slide for rear-projection.
15. The results of this experiment were replicated on an independent sample of 20 undergraduates. Only 11 states were judged and the states were selected to be equally spaced on a logarithmic scale in terms of their relative area. This procedure was adopted to ensure that the states would be more easily discriminated in memory, since fewer judgments were required and the states judged were less likely to be confused in relative size. The exponents in the memory and perception conditions were .539 and .645, respectively (t = 2.030, d.f. = 18, P < .055). In addition, S. M. Kerst and J. H. Howard, Jr. (*Mem. Cognit.*, in press) have obtained results similar to those of experiment 2 in a completely independent investigation using the 48 contiguous states.
16. This correction was made by determining what the P slope would be if the best-fit P line accounted for only 93.4 percent of the data:

$$b_{\mathrm{P}} = r_{\mathrm{M}}(s_{y\mathrm{P}}/s_{x\mathrm{P}})$$

where b is the slope, s is the standard deviation, and r is the correlation. The resulting slope of .627 still differed from the M slope (t = 7.406, d.f. = 92, P < .001).
17. This study was initially reported at the 48th annual meeting of the Eastern Psychological Association, Boston, Mass., 13 to 16 April 1977.
18. A regulation-sized BB, Ping-Pong ball, tennis ball, softball, volleyball, and basketball were used; the pea, marble, and beach ball were chosen so as to be of "prototypical size," according to the experimenters' subjective estimate.
19. This study was conducted during a regular class period, and the display conditions were informal. The experimenter placed each object in the center of a white sheet, which covered a cafeteria tray, and held out the tray to view as he walked past the seated observers—much as a maitre d'hotel might display a choice lobster thermidor on his way to another customer's table.
20. This result was replicated in a more careful experiment in which each subject was tested individually under controlled conditions and exposed to a different random order of the nine objects. In addition, the perceptual condition differed from that reported in the text in that the subject moved with respect to the object inspected (by walking around it), rather than the reverse. The P and M exponents were .704 and .562, respectively (t = 2.762, d.f. = 21, P < .012). A "static" perceptual viewing condition, which restricted the subject to a stationary view of the object, resulted in an exponent of .648, midway between (and only marginally different from) the preceding exponents. The difference between dynamic and static inspection of the perceived objects was pursued in another experiment, which revealed that active manipulation of the objects prior to each size judgment produced a higher exponent than did passive observation of stationary objects: .715 versus .637 (t = 2.597, d.f. = 14, P < .02). These two follow-up studies suggest the possibility that the M exponent is small because subjects judge the volume of a statically projected image of a sphere. However, the results of a final M experiment did not bear out this hypothesis. In this study, one group of subjects received standard M instructions as in experiment 3, and the resulting exponent (.532) was similar to that obtained in experiment 3 and above. But a second M group, instructed to actively manipulate the imagined spherical objects generated an exponent of .423 (t = 2.593, d.f. = 14, P < .021). Thus, instructions to actively manipulate stimuli seem to have different effects in P and M.
21. The t values for the tests on individual subjects' slopes are: experiment 1, t = 2.267, d.f. = 27, P < .031; experiment 2, t = 2.002, d.f. = 24, P < .055; and experiment 3, t = 2.249, d.f. = 15, P < .038. For experiment 2, the fit of the power functions to each subject's data was worse in condition M than in P (the average percentage of variance accounted for was 89.0 for P but only 62.1 for M). Could a large regression effect at the individual level have been obscured in the group data by some averaging phenomenon but still be responsible for the group slope differences (Fig. 1)? Apparently not, since the variance accounted for by the individual subject's power functions averaged 98.3 percent and 96.1 percent, respectively, for P and M in experiment 1 and 98.2 and 94.5 for P and M in experiment 3. Thus, in these two experiments, there was no large regression effect for individuals that might somehow have produced reliably smaller exponents in the group M data. Whatever the merit of this averaging hypothesis for the data of experiment 2, then, it cannot serve as a general explanation for the slope differences of Fig. 1.
22. For example, suppose that subjects tend to avoid assigning extreme magnitude estimates to remembered objects, so as to be "safe." Such a "response bias" would restrict the range of estimates and therefore produce a shallower slope. If the traces "migrated" toward a more central or prototypical value for the series, this would also restrict the range of the magnitude estimates. A historical parallel to the range restriction effect is the so-called central tendency of judgment or law of sense memory apparently first noticed by Karl Vierordt [*Der Zeitsinn nach Versuchen.* (Verlag der H. Laupp'schen Buchhandlung, Tübingen, 1868)] and subsequently observed by others [for example, G. S. Fullerton and J. McK. Cattell, *Publ. Univ. Penn. Philos. Ser. No. 2* (1892); J. H. Leuba, *Am. J. Psychol.* **5**, 370 (1892); H. L. Hollingworth, *Arch. Psychol. No. 13* (1909); J. G. Needham, *J. Exp. Psychol.* **18**, 530 (1935)]. These studies differ from ours in that they generally used one of the classic psychophysical techniques (such as average error or constant stimuli), stimuli were not named, and the retention intervals were only a few seconds. But their consistent finding that small stimulus values are overestimated and large ones underestimated, sometimes increasingly so for longer retention intervals, resembles the tendency we observed under entirely different conditions.
23. We thank K. Karpoe and P. Sklarew for conducting the second and third experiments cited in (*20*) and D. Seely for assistance in conducting experiment 2.

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