their apparent frequent imitation of the latter, even if only in the sedentary context, makes sense. *Acmaeodera* might thus simply have carried matters one step further, by locking its elytra and taking its hymenopteran rump to the air.

The only other beetles with fully developed elytra known to fly with elytra unspread are the cetoniine scarabs (family Scarabaeidae, tribe Cetoniini) (*2*) (compare Fig. 1, G and H). Although the significance of flight modification in this group remains to be explained, mimicry may again be involved, perhaps only as a contributing factor, and then only in some species. *Euphoria limbalis*, which we have observed on Lignumvitae Key, Florida, has the same darting and hovering flight and lives in precisely the same habitat as a large carpenter bee (*Xylocopa micans*). The bright greenish elytra of the beetle, which impart upon its body the metallic sheen of the bee, heighten the resemblance. Both beetle and bee were seen to feed in numbers on blooming palms. As evidenced by its acceptability to our captive jay, the beetle is apparently edible. *Euphoria limbalis*, like other cetoniines, has the elytra notched where the hindwings project in flight (Fig. 1, part I) in striking similarity to what *Acmaeodera* has evolved in parallel (see *4*).

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1. The observations were made in the Chiracahua Mountains, Arizona, and in Monroe and Highlands counties, Florida. We thank R. Archbold for the use of the facilities of the Archbold Biological Station; Mr. and Mrs. R. Niedhauk for permission to conduct studies on Lignumvitae Key, Florida; and G. H. Nelson, G. C. Eickwort, and R. D. Gordon for identification of the buprestids, Hymenoptera, and scarabaeids, respectively. Report No. 24 of our series, Defense Mechanisms of Arthropods.
2. J. W. S. Pringle, *Advan. Insect Physiol.* **5**, 163 (1968) and references therein. In some beetles the elytra have an intrinsic beat, but they contribute negligibly to thrust.
3. During its 6 years of captivity, the jay was offered no Hymenoptera (except wingless, cryptically colored formicine ants), and was therefore not expected to discriminate against a mimic of Hymenoptera, such as *Acmaeodera*, on sight alone.
4. A cerambycid beetle (*Tragocerus formosus*), mimicking Hymenoptera and supposedly flying with elytra unspread, is figured in R. A. Fisher, *Genetical Theory of Natural Selection* (Dover, New York, 1959).
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Size Discrimination on the Skin

Abstract. *Reasons are given for rejecting the two-point threshold as the standard measure of spatiotactile resolution. As alternative techniques, thresholds were obtained for disc-size and disc-annulus discriminations. Disc-annulus thresholds are comparable to two-point values, but disc-size thresholds are smaller by a factor of 10. Thus, at least part of the cutaneous system is better organized for localization and sizing of a stimulus than for detection of discontinuities in it.*

The two-point threshold is considered the standard measure of spatiotactile resolution. As a result, the major portion of man's integument is thought to be insensitive spatially; thresholds run as high as 48 mm (*1*). This test appears to have emerged from thinking relevant to vision, where it is important to separate objects which must be manipulated. This logic may be appropriate for the fingers or tongue, which are manipulative structures with small two-point thresholds (*1*). However, it makes less sense for the remainder of the skin surface, which serves as a warning system, eliciting reflexive action and visual attention. For these body parts, it would not be as important tactually to separate stimuli as to determine their locus, size, quality, and intensity.

Two-point thresholds are considerably larger than point localization thresholds, and the two procedures differ only in simultaneous versus successive presentation of points. Thus, lateral inhibitory interaction between points would occur only in the two-point determination. Though lateral inhibition appears to sharpen contours (*2*), it may interfere with detection of gaps. In addition, the extensive overlapping of tactile receptive fields should hamper gap detection and facilitate size discrimination.

Our study tested the hypothesis that size discrimination would demonstrate a sensitivity that is not generally recognized for the skin senses. The intent is to develop tests that will reflect underlying physiological processes and anatomical organizations, such as size of field, amount of overlap, extent of lateral inhibition or facilitation, and so forth (*3*).

Four individuals served as subjects. The stimuli consisted of solid plastic cylinders, integral sixteenths of an inch (1/16th inch = 1.59 mm) in diameter, and approximately 4 inches (10 cm) long. Two series of threshold determinations were made. In one series standard and test stimuli were impressed on the same patch of skin on the belly of the forearm (same arm). In the other series, the standard was impressed on the right and the test stimulus on the left forearm or vice versa (other arm).

In both series, threshold determinations were made up and down from four standard stimuli, 4, 8, 16, and 24 sixteenths of an inch. At each standard the up- and down-thresholds were averaged to obtain the difference limen (DL). To obtain an up-threshold a test stimulus was chosen which seemed too big. Then 50 trials were run in which test and standard stimuli were impressed on the skin 0.5 to 1.5 seconds apart. The subjects reported which of the two stimuli, the first or the second, was larger. Order of presentation and, in the other-arm series, association with the right or left arm, were randomized. Threshold was defined as the distance from the standard at which the subject correctly identified the test stimulus as larger 75 percent of the time. If the first test stimulus yielded better than 75 percent correct, a series of 50 trials were run with a smaller stimulus. Threshold was calculated by linear interpolation from the two bracketing test stimuli. The down-thresholds were determined in the same way except that the test was smaller than the standard stimulus.

Care was taken to apply the two stimuli as evenly as possible and without systematic bias (*4*). Stimulus pressure was always firm and sufficient to leave a complete, visible ring on the skin. As a check on the influence of pressure, up and down disc-thresholds were obtained from two subjects under four conditions of stimulus pressure, with a standard of 16 sixteenths. In these series, the stimuli were just sufficient to produce a visible ring (LL), very firm and bordering on noxious (HH), or a combination of these (LH or HL). In the latter two conditions, heavy and light pressures were randomized over presentations of test and comparison stimuli.

Two-point and disc-annulus thresholds were also determined for each subject. The same-arm method was used in both cases. In the disc-annulus determinations the test procedure was the same as for disc size, except that a disc was compared with a ring which had the same outside diameter. Discs and annuli were graduated in ¼-inch steps, and the annuli were ⅛th inch thick. The subject was asked to say whether the first or second stimulus was the ring. Threshold is reported in terms of the inside diameter of the ring.

The stimuli in the disc-annulus determinations were made of aluminum, and temperature appeared to affect their perception as disc or annulus. To eliminate systematic bias, a second set of stimuli was made and one of them heated to 39°C while the other was left at room temperature. In testing, disc and annulus were each "hot" half of the time. Order of presentation, of course, was also randomized.

To determine two-point thresholds, a single stimulus was used. The subject was touched with either one or two points and asked to say which. Twenty-five one-point and 25 two-point touches were given in a series. From series to series, the distance between the two points was graduated in steps of 4 mm.

The results are summarized in Fig. 1. For all four subjects, disc DL's vary between 2 and 6 mm; disc-annulus and two-point thresholds are roughly comparable, ranging around 30 mm. Our values for the two-point threshold are smaller than those usually reported for the belly of the forearm. Nevertheless, every subject has at least one DL and two have several, less than one-tenth the size of the same subject's two-point (or disc-annulus) threshold.

Disc thresholds were essentially unaffected by variations in stimulus pressure. Average thresholds in sixteenths for the pressure control conditions were: HH = 2.1, LL = 2.3, HL = 2.0, and LH = 2.2. These fall well within the range of values obtained with intermediate pressure as shown in Fig. 1 (same arm; standard = 16).

In general, other-arm DL's are larger than corresponding same-arm DL's. The mean other-arm DL for all subjects is 2.62, while the mean same-arm DL is 2.04. The difference is significant at the .05 level by a t-test for correlated means.

Analysis of variance of DL into subjects, subjects by standard stimuli, and linear and curvilinear sources of variation shows significant curvilinearity for

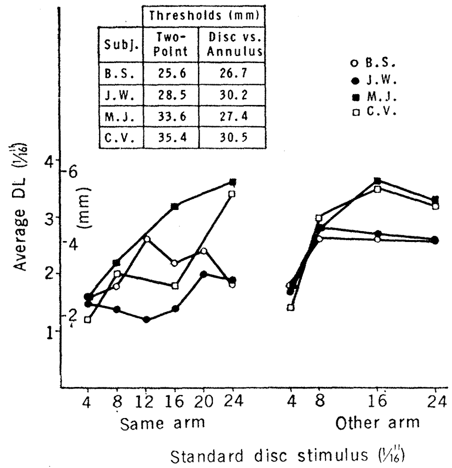

Fig. 1. Difference limens (DL) for four subjects in sixteenths of an inch and millimeters are plotted for standard stimuli that range from 4 to 24 sixteenths of an inch. On the left (same arm), both standard and comparison stimuli touched one arm, while the other-arm condition consisted of one stimulus to each arm. The inset table presents two-point and disc-annulus thresholds for the same subjects. Thresholds at 12 and 20 sixteenths were not included in the statistical analysis.

both same-arm and other-arm DL's. Significance, however, is stronger for other-arm ($P < .001$) than for same-arm DL's ($P < .05$). The chief reason is the smaller variances within arrays for other-arm DL's. The variance due to linearity is virtually the same in the two sets of data. This last point may also be made by fitting regression lines for DL on standard stimulus. The slopes in the two regression equations are shallow (.014 and .013 for same and other arm, respectively). Still, there is an increase in DL as larger stimuli are used; and, as would be expected, the up-thresholds tend to be somewhat larger (.22 sixteenths of an inch on the average) than the down-thresholds. The difference, however, is not significant.

It is not clear from these results what the effective stimulus in the disc discrimination is. It could be either diameter or area. If the psychophysical relation is a power function, as Stevens has argued (*5*), the Weber function would be linear in either case; the difference would reflect itself only in the exponent. In our data the Weber function is curvilinear, but this curvilinearity may be an end effect that derives wholy from the DL's for the ¼-inch standard.

In any case, the main finding is the dramatic increase in sensitivity when judgment is made on size rather than twoness or continuity of an impressed object. In the literature, two-point thresholds for the belly of the forearm are about 40 mm, and point localization thresholds are 9 mm (*1*). Size thresholds, however, lie in the interval from 2 to 6 mm.

In the same-arm method, it might be supposed that some of this sensitivity is dependent upon stimulating the same patch of skin with both the standard and test discs. It turns out, however, that in the other-arm method the DL's, though elevated, are less than 1 mm higher than in the same-arm method. Plainly, therefore, the stimulation of common neural elements is not necessary for low thresholds in size discrimination.

It is necessary to distinguish between gap detection and the discrimination of overall dimensions. In disc-annulus determinations the subject is asked to detect the (unimpressed) interior of a test object, and in the compass test he is asked to discriminate unstimulated skin between the two points, hence, their number—while in discriminating two discs the subject judges the outside or overall dimensions of the test objects. The results of this study suggest that the skin is primarily organized for localization and size discrimination.

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2. V. B. Mountcastle, *J. Neurophysiol.* **20**, 409 (1957); G. von Bekesy, *J. Gen. Physiol.* **50**, 519 (1967).
3. R. P. Kelvin [*Quart. J. Exp. Psychol.* **6**, 23 (1954)] used discs for cutaneous stimulation but did not take difference limens; the discs were used to compare cutaneous and visual perception.
4. An important advantage of working with size discrimination is that all parts of the stimuli need not contact the skin simultaneously. That is, temporal cues are not relevant to discrimination of disc-size or disc versus annulus as they can be for counting the number of stimuli applied in the two-point test. This is an important consideration in view of the irregularities of the skin surface and for clinical testing, where exquisite control of stimulus application is not practical.
5. S. S. Stevens, *Psychol. Rev.* **64**, 153 (1957).

6. We thank B. Sternberg and J. Warinner for assistance. Supported by National Institute of Neurological Diseases and Blindness grant NB-07261.

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