# Scales of selected aspects of kinesthesis*

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Fifty male Ss made judgments of (1) thickness by finger span, (2) extent of arm movement, (3) heaviness of lifted weights, (4) force by handgrip, and (5) speed of arm movement. The method was fractionation: halving the magnitude of each stimulus. Comparisons were made in terms of the size of the exponent of the sensory scale.

The present study compares the judgments of Ss in five aspects of kinesthesis–thickness by finger span, extent of arm movement, heaviness of lifted weights, force by handgrip, and speed of arm movement. All 50 Ss participated in all five tasks, and the same procedure of ratio production was used. The degree of accuracy with which an individual makes judgments based upon kinesthetic sensation may be defined as the degree to which there is a linear relation between physical magnitudes and sensory magnitudes. A linear relation means an exponent of 1.0. Most of the continua give exponents that are larger than 1.0.

Previous studies of kinesthesis have usually explored a single attribute of the sense. Comparisons among those studies are made uncertain because different Ss participated in each investigation.

Four previous investigations served as models for this study. Stevens and Stone (1959) developed a ratio scale, a category scale, and a JND scale for thickness as measured by finger span. The ratio scale was constructed by magnitude estimation. It was found that subjective thickness grows as a power function of stimulus width, with an exponent of 1.33.

The scaling of extent of arm movement was accomplished by Ronco (1963) by the methods of magnitude estimation, ratio production (halving and doubling), and category production. By halving, the exponent of the power function was 1.08.

Harper and Stevens (1948) derived a psychological scale of heaviness by the method of halving. The results approximated a power function with an exponent between 1.5 and 2.0. Later studies gave as an average an exponent of 1.45 (Stevens & Galanter, 1957).

Stevens and Mack (1959) developed scales of apparent force by the methods of ratio production (halving and doubling), magnitude production, magnitude estimation, and category production. In the summary of ratio production, the authors stated that the "... ratio of the greater to the smaller force of a pair in 2 to 1 subjective relation turned out to be approximately constant at about 1.4/1.0 [p. 407]."

## GENERAL PROCEDURE

The task order and stimuli were randomly arranged and varied from S to S. Ss were blindfolded and used their preferred hands.

The algebraic approach to scaling by fractionation as described by Guilford (1954) was used in data analysis. Using the least-squares procedure, an equation describing the relation of half stimuli to standard stimuli was determined and subsequently was used in the actual scaling of the sensory attribute.

## Experiment 1: Judgment of Thickness by Finger Span

*Method.* A pad of notepaper, 63.7 mm thick and subdivided into 13 sections which increased in equal steps from 2.3- to 63.7-mm thicknesses, was fashioned into a device offering the same stimulus thickness possibilities specified by Stevens and Stone (1959). After the S was presented a given thickness of paper between his thumb and forefinger, he located a thickness which he judged to be half as great as the original. Each stimulus was presented twice to each S (26 trials).

Table 1
Thickness in Number of Sheets of Paper: Ss' Median Responses to Stimuli

| Stimulus | Response | Stimulus | Response |
|---|---|---|---|
| 46 | 23.78 | 480 | 228.15 |
| 108 | 52.95 | 542 | 253.85 |
| 170 | 84.50 | 604 | 284.87 |
| 232 | 114.38 | 666 | 309.62 |
| 294 | 140.62 | 728 | 350.81 |
| 356 | 170.71 | 790 | 362.50 |
| 418 | 206.09 | | |

*Results.* The pairs of stimuli and median subjective half stimuli appear in Table 1.

The function log Sh = 0.9665 log S – .2326 (where Sh represents the "half stimulus" and S is the "whole stimulus") was determined by the least-squares procedure. A psychological unit for thickness to correspond with the physical unit of millimeters has previously been defined by Stevens and Stone (1959): "pak" = the subjective thickness of 2.5 mm. In the present study the same unit with its equivalent of 50 sheets of paper was used to construct the scale of subjective thickness. The method of least squares was once again applied to locate the regression line best describing the function. The relation of log P to log S is plotted in Fig. 1. The power function of psychological thickness upon physical thickness is expressed by $P = .0224S^{0.97}$. The exponent indicates that psychological thickness does not grow quite as rapidly as stimulus thickness. Of the five aspects of kinesthesis investigated in this study, the exponent for thickness (0.97) is nearest to 1.00. If one takes the point of view that the most accurate sense is that which provides a sensory scale with a linear relation to the physical scale, then this aspect would be judged as the most accurate of the five.

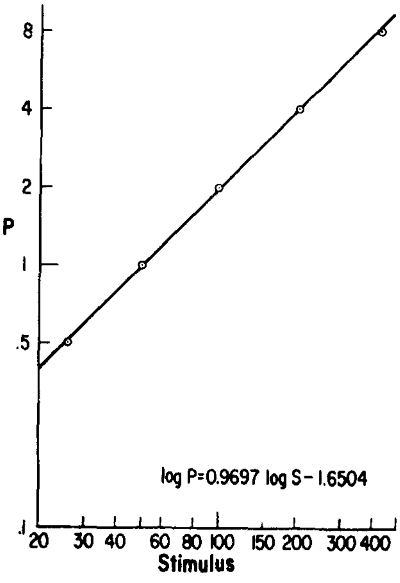


Fig. 1. Relation of perceived thickness (log P) to stimulus thickness (log S).

## Experiment 2: Judgment of Extent of Movement

*Method.* An apparatus to measure distances through which forward-reaching arm movements are taken was constructed according to specifications by Ronco (1963). Following his procedure, the

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Table 2
Extent of Movement in Inches: Ss' Median Responses to Stimuli

| Stimulus | Response | Stimulus | Response |
|---|---|---|---|
| 1 | 0.63 | 11 | 5.85 |
| 3 | 1.74 | 15 | 8.17 |
| 7 | 3.78 | 21 | 12.06 |

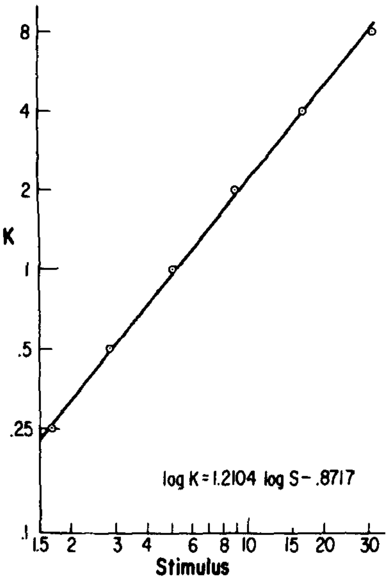


**Fig. 2. Relation of perceived extent of movement (log K) to stimulus distance (log S).**

stimuli presented were movements of 1, 3, 7, 11, 15, and 21 in. Seven trials for each stimulus were given to each S (42 trials).

*Results.* Median responses to each of the stimuli are shown in Table 2.

In his study of extent of movement, Ronco (1963) defined the psychological unit "kine" as the subjective length of a movement of 1 in. (for ease in scaling, this was changed to 5 in. in the present study). Scaling was performed using the function $\log Sh = 0.9581 \log S - .2133$. The relation of log K to log S is illustrated in Fig. 2. The dependence of psychological extent of movement upon physical distance is expressed by $K = .134S^{1.21}$. Since the exponent is greater than 1.0, it suggests that psychological extent of movement grows more rapidly than physical distance.

## Experiment 3: Judgment of Heaviness of Lifted Weights

*Method.* Following the example of Harper and Stevens (1948), eight series of weights, each including one standard and six comparison weights, were used. Because Harper and Stevens did not include the actual physical half-weight among the comparison weights for many of their series, the comparison weight values for the present study were adjusted somewhat (see Table 3). Another change made was to replace the two heaviest series of Harper and Stevens with lighter series. Three trials per stimulus were given (24 trials).

*Results.* Stimuli and their corresponding median subjective half-stimulus values are indicated in Table 4.

The "veg" unit (the subjective weight of 100 g) previously has been defined by Harper and Stevens (1948). The scale was constructed using the function $\log Sh = 0.9748 \log S - .1571$. The relation of log V to log S is shown in Fig. 3. The dependence of psychological weight upon physical weight is represented by $V = .00131S^{1.43}$. The exponent of 1.43 indicates that psychological heaviness grows more rapidly than physical weight.

Table 3
Weight Series for the Present Study

| Standard Weights (in Grams) | Comparison Weights (in Grams) |
|---|---|
| 20 | 10, 12, 13, 14, 15, 17 |
| 40 | 20, 24, 26, 28, 30, 32 |
| 70 | 30, 35, 40, 45, 50, 55 |
| 100 | 50, 60, 70, 75, 80, 85 |
| 200 | 85, 100, 115, 130, 145, 175 |
| 300 | 125, 150, 175, 200, 225, 250 |
| 400 | 200, 250, 275, 300, 325, 350 |
| 500 | 250, 275, 300, 350, 400, 450 |

Table 4
Heaviness in Grams: Ss' Median Responses to Stimuli

| Stimulus | Response | Stimulus | Response |
|---|---|---|---|
| 20 | 13.18 | 200 | 117.50 |
| 40 | 25.67 | 300 | 188.46 |
| 70 | 41.96 | 400 | 252.50 |
| 100 | 61.70 | 500 | 285.90 |

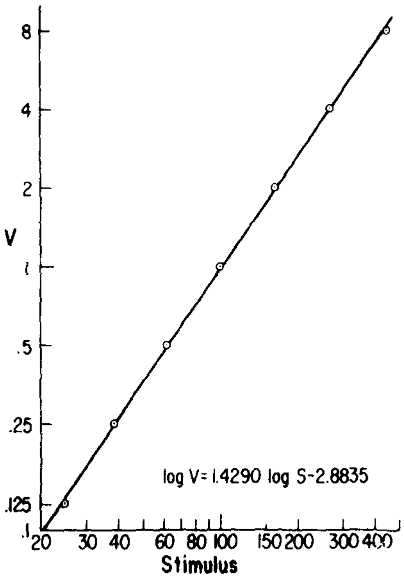


**Fig. 3. Relation of perceived heaviness (log V) to stimulus weight (log S).**

Table 5
Force in Kilograms: Ss' Median Responses to Stimuli

| Category | Median Stimuli | Median Responses |
|---|---|---|
| 1 | 5.47 | 3.45 |
| 2 | 8.69 | 5.83 |
| 3 | 11.73 | 7.75 |
| 4 | 14.33 | 9.62 |
| 5 | 17.33 | 12.15 |
| 6 | 20.58 | 13.64 |
| 7 | 24.41 | 14.90 |
| 8 | 29.46 | 18.25 |
| 9 | 34.89 | 20.25 |
| 10 | 42.50 | 25.17 |

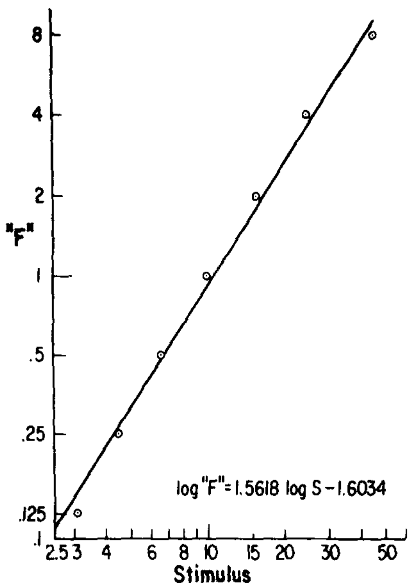


**Fig. 4. Relation of perceived force (log "F") to stimulus force (log S).**

## Experiment 4: Judgment of Force by Handgrip

*Method.* The procedure for this experiment was patterned after that of Stevens and Mack (1959). The S was instructed to squeeze a hand dynamometer with a "light," "moderate," or "heavy" amount of force as the stimulus. He was free to interpret these categories as he desired. The stimuli of five lights, five moderates, and five heavies were randomly presented (15 trials).

*Results.* Force stimulus values were pooled, arranged in order of increasing magnitude, and divided into 10 categories, each with approximately the same number of cases falling within its range. Median stimulus values in each category were computed, and in Table 5 these values are given with their corresponding median subjective half-stimulus values.

The unit "F" (for "force") was defined in the present study as the subjective magnitude of a force of 10 kg. Scaling intensity of force involved using the function log Sh = 0.9457 log S − .1268. The relation of log "F" to log S is illustrated in Fig. 4. The power function is "F" = $.0249S^{1.56}$. The exponent 1.56 indicates that psychological force increases more rapidly than physical force. This is the largest of the five exponents obtained in the present series of experiments.

**Experiment 5: Judgment of Speed of Movement**

*Method.* This experiment was arranged in a pattern similar to that of the scaling of force. Just as stimuli for force judgments were expressed in light, moderate, and heavy categories, in the speed task Ss were asked to perform a forward-reaching arm movement over a 12-in. distance at what they judged to be "slow," "moderate," or "fast" speeds. Traversal times were electronically recorded in 100ths of a second. Five of each category were specified (15 trials).

*Results.* After data were converted from time in seconds to speed in feet per second, stimulus speed values were pooled and arranged in order of increasing magnitude. From this order 10 categories were formed with approximately the same number of cases falling in each category, and the median value of each category was determined. Median stimulus speeds and corresponding median subjective half-speeds are presented in Table 6.

The unit "S" (for "speed") was defined as the subjective speed of a movement performed at the rate of 1 ft/sec. Scaling of speed of movement was accomplished using the function log Sh = 0.9842 log S − .1733. Figure 5 illustrates the relation of log "S" to log S. This function is expressed by "S" = $.283S^{1.54}$. The exponent 1.54 suggests that psychological speed of movement increases more rapidly than physical speed of movement.

Table 6
**Speed of Movement in Feet Per Second: Ss' Median Responses to Stimuli**

| Category | Median Stimuli | Median Responses |
|---|---|---|
| 1 | 0.44 | 0.27 |
| 2 | 0.82 | 0.56 |
| 3 | 1.15 | 0.71 |
| 4 | 1.51 | 0.95 |
| 5 | 1.92 | 1.28 |
| 6 | 2.49 | 1.70 |
| 7 | 3.00 | 2.03 |
| 8 | 3.82 | 2.59 |
| 9 | 4.78 | 2.86 |
| 10 | 6.33 | 3.58 |

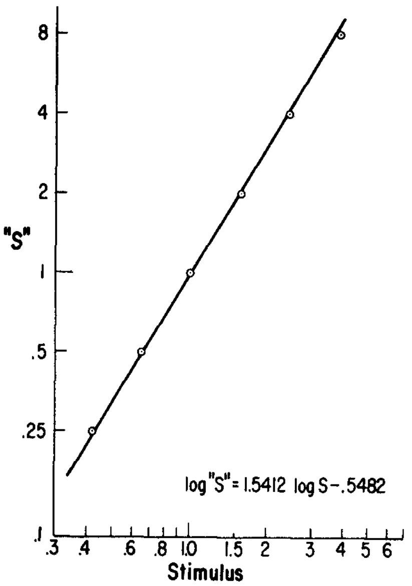


**Fig. 5. Relation of perceived speed of movement (log "S") to stimulus speed (log S).**

## DISCUSSION

**Thickness**

Stevens and Stone (1959) reported a function of $P = 0.296S^{1.33}$ in ratio scale derivation by the procedure of magnitude estimation. The exponent 1.33 signifies greater deviation from a linear relation with physical magnitudes than was evidenced in the present study (0.97). The discrepancy is presumably due to differences in the apparatus and procedure.

**Extent of Movement**

The difference between the exponent obtained in the present study (1.21) and the exponent 1.08 obtained by Ronco (1963) might be attributed to different testing situations and different apparatus.

**Weight**

Stevens and Galanter (1957) have reported the function $V = 0.00126W^{1.45}$ for weight judgment data. The exponent corresponds closely to that obtained in the present study (1.43).

Goude (1962) derived the function $R = 0.0000288S^{1.896}$, where R represents the same parameter as V above and S is equivalent to W. The exponent 1.896 may not be out of line with those of the Stevens and Galanter study and the present study, for Goude used the task of ratio estimation wherein the S deals with less common ratios than halving.

**Force**

A power-function exponent of 1.7 was reported by Stevens and Mack (1959) for the portion of their study of force judgments in which magnitude estimation was used. This exponent may be comparable to that obtained in the present study (1.56), since magnitude estimation does not offer the reference point that is inherent in halving.

**Speed of Movement**

These results cannot be compared with others, for no previous study in which speed of movement was scaled is known to the writer.

**Summary**

The present evidence indicates that task performances in most aspects of kinesthesis are nonlinearly related to the physical scale. A linear relation between physical magnitudes and sensory magnitudes was most nearly approximated in the judgment of thickness by finger span (exponent of 0.97), but other Es have obtained exponents for finger span greater than 1.0. Divergence from linear correspondence, as suggested by the measured exponents, increased in the order: 1.21 (extent of movement), 1.43 (heaviness of lifted weights), 1.54 (speed of movement), and 1.56 (force).

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