ANALYSIS OF FACTORS THAT DETERMINE SUBJECTIVE WEIGHT¹

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The present study was designed (1) to discover the main factors that determine the positive size-weight illusion, and (2) to find an equation which relates the subjective weight with perceived size. Two types of cylinders and a series of cardboard boxes were used. Subjective weight was measured by the method of adjustment, and subjective size was determined by the constant-sum method. Effects of kinetic, tactual, and visual cues were investigated, with the result that visual ones were the most important determinants of the illusion. An equation which relates subjective weight with visual size was found as a first approximation. The limitation of the application of the equation was also investigated.

Many studies have been done concerning the so-called size-weight illusion since Charpentier (1891) demonstrated it. In his experiment, two objects differing in size but equal in weight were presented to subjects, who perceived the smaller object as weighing more than the larger one. This phenomenon has been referred to as a positive size-weight illusion, because the reverse or negative size illusion is said to occur when the object having a smaller volume is perceived lighter than the larger one, though both have same weight.

Charpentier interpreted the positive illusion as a masking influence, i.e., the sensation of weight was altered by differential contact between the subjects and the different size stimuli. A generally accepted explanation of this phenomenon was proposed by Müller and Schumann (1889). The basic idea was that expectancy or set would be the main factor that decided the size-weight illusion. Sub-

jects would usually expect the larger object to be heavier, and, therefore, they would be set to apply greater strength in lifting the larger object. Many authors such as Loomis (1907), Scripture (1897), Whipple (1910), Hollingworth (1931), Eysenck (1943), Littell (1946) and Grimes (1948) supported the set theory. Payne and Davis (1940) applied the electromyographic technique and confirmed the Müller-Schumann muscular set theory.

Another topic which has been extensively studied by many psychologists is the problem of scaling. Many studies have been done concerning the subjective scale of weight since Stevens and Harper (1948) constructed the *veg-scale*.³ The general psychophysical law which relates the stimulus magnitude with subjective magnitude is given in the form of power function, which is written

$$R = aS^b \quad (1)$$

where S is stimulus magnitude, R is subjective magnitude and a and b are constants.

Stevens and Galanter (1957) pointed out that the exponent b of the power

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³ Detailed informations can be obtained in Shiose's review article (1958).

function for subjective weight ranged from about 1.13 to 2.07, the median of which was 1.43. They suggested the equation

$$V = .00126W^{1.45} \quad (2)$$

as an approximate working rule, where V is subjective weight in veg and W is objective weight of stimulus in grams.

As the equation (2) does not include the size parameter, it is impossible to apply the equation for the estimation of subjective weight of stimuli differing in size.

The present study has two purposes; (1) to determine the main factors that determine the positive size-weight illusion, and (2) to find out the relation between perceived size and subjective weight. The first of these concerns the problem of cues, i.e., to find out the cues which play the most important role in the size-weight illusion. The second problem is concerned with an equation which relates the subjective weight with perceived size.

METHOD AND PROCEDURE

The stimuli used consisted of two types of cylinders. The M-series, used as standard stimuli, consisted of aluminium cylinders, 50 mm in diameter and 25, 37.5, 60, 62.5 and 75 mm in height. The C-series, used as comparison or variable stimuli, consisted of a series of aluminium cylinders, 32 mm in diameter and 47 mm in height. The weight of the comparison stimuli was altered by putting dry sand or lead shot into them.

A piece of string with a ring attached to one end or a specially designed stick could be attached to the top of each cylinder. Other special cylinders, devices, and apparatus designed for the special purposes of each experiment will be explained later.

Subjects were surely requested to compare the standard with the variable stimulus by lifting each one successively with thumb and forefinger or thumb and middle finger. PSE was determined by the method of adjustment. The subjective size of the stimuli was determined by the constant-sum method. The sub-

jects were university students majoring in psychology at the University of Tokyo. The number of subjects who took part in the experiments differed from experiment to experiment.

EXPERIMENT I

It is probable that kinetic cues which are related to the size and shape of various stimuli may have some effects on the judgment of weight. Specially designed sticks were attached to the tops of the standard cylinders. The sticks were made of wood of 1 cm thick and shaped like Greek alphabet pi. They were 10, 20, and 40 cm in length and 3, 5 and 8 cm in width. The weight of the standard stimuli was held constant at 90 grams. The lower parts of the sticks as well as the cylinders were covered by cardboard so that the subjects could only see the upper ends of the sticks. Comparison stimuli consisted of 17 cylinders of the C-series weighing 40 to 200 grams with equal intervals of 10 grams. They were arranged in order of weight on a table. The subjects were requested to find a stimulus subjectively equal to the standard. They could freely pick up the standard and comparison stimuli as many times as they wished. Five subjects were used.

The average PSEs of five subjects for nine standards are given in Table 1, and the results of an analysis of variance are presented in Table 2. The results indicate that the effect of stick width is significant at the .01 level, but that of stick height is not significant at the .05 level.

It is highly probable that we can find significant effects for the different width of sticks, as the cues in this case are combined ones of visual and tactual. The subject could not see the difference of height of the sticks but he might be able to perceive the difference through kinetic cues, as moment of inertia differed owing to the difference of the length of the sticks.

Although the effect of height is not statistically significant, the results show a clear

TABLE 1
Average subjective weight of standard
stimuli (in grams)

Height \ Width	3	5	8 cm
10 cm	90	76	66
20	86	72	65
40	78	71	62

TABLE 2
Analysis of variance of the effects of
height and width of the stimuli

Sources of Variance	Variance	d.f.	Mean Variance	F-ratio
Subject	3.7	4	.93	
Width (visual & tactual)	31.2	2	15.60	26.89**
Height (kinetic)	3.7	2	1.85	3.2
W × H	1.2	4	.30	
S × H	7.2	8	.90	
S × W	8.6	8	1.20	2.1
Error	9.2	16	.58	
Total	64.8	44		

** $p < .01$

regularity and we may conclude that kinetic cues have some effect on the judgment of weight.

EXPERIMENT II

The results of Experiment I clearly indicate that tactual and visual cues combined are effective determinants of the judgment of weight. The present experiment was designed to investigate whether tactual cues alone could have some effects on the judgment of weight.

The standard cylinders, F_1 , F_2 and F_3 , were presented by the experimenter on the palms of the subjects in order to keep the kinetic cues constant. All of the standard stimuli were of equal size and shape except their bases. Subject could not see the difference of the bases and the available cues for the differentiation were tactual.

The outer size of each cylinder was 75 mm in diameter and 30 mm in height. Each weighed 150 grams. The areas of

the bases were 4416mm² for F_1 , 706.5 mm² for F_2 and 346 mm² for F_3 . The circumferences of F_1 and F_3 were equal, although the bases of them differed. The sizes and shapes of the cylinders are shown in Fig. 1 and Table 3.

The standard stimulus was put on the left palm of a subject by the experimenter and was presented for two seconds. The subject was requested to compare the standard with a comparison stimulus by picking up the latter with his right hand immediately after the standard stimulus was presented. The number of subjects who participated in this experiment was six.

When a cylinder was put on the palm of a subject, it exerted pressure on the palm. The distribution of the pressure of the stimulus was probably uneven as the surface of the palm was not flat. The situation was further complicated by the fact that it was impossible for the subject to keep the surface of his palm constant, although he was instructed to be very careful not to move his palm or fingers when the stimulus was presented. It was also very difficult for the experimenter to present the stimulus on the same place of each subject's palm, however carefully he tried to do. But it may be possible to assume that the distribution of the pressure was approximately equal when the same stimulus was presented. It can probably be assumed that the distribution coincided roughly with the base of the cylinder.

Even if tactual cues are shown to have some effects, there still remains the problem of finding the determinants of the illusion. Is the area or the circumference of the base of the stimulus the principal determinant of the illusion? The differences between the areas of the bases as tactual cues are equivalent to the differences in density, if the sizes and shapes of the stimuli are kept constant. Therefore, the problem is to determine, which one of the following two factors, circumference or density, controls the size-weight illusion.

If the density of the stimuli is the

TABLE 3
Size of the standard cylinders

Stimulus	Diameter outside in mm	Diameter inside in mm	Height in mm	Circumference in mm	Base area in mm ²
F ₁	75		30	235.5	4415.6
F ₂	75	30	30	94.2	706.5
F ₃	75		30	235.5	346.5

determinant of the illusion, F₃ which has the smallest base, should be judged the heaviest and F₁ which has the largest base should be judged the lightest. If the circumference is a determining factor, F₁ and F₃, which have equal circumferences, must be judged heavier. And if the visual size is the determinant of the illusion, the subjective weight of all the cylinders must be approximately equal.

The results are shown in Table 4. Although the results of the *t*-tests do not

indicate any significant difference between the means, the results are favorable for the factor of circumferences, and we may conclude that the circumference of the cylinder may have some effect on the judgement of weight.

Both experiments show that kinetic cues and tactual cues may have some effects on the judgment of weight. But it should also be pointed out that the only significant result is obtained in the case of combined visual and tactual cues. Therefore, there remains a problem of whether visual size is the most important determinant of the size-weight illusion.

EXPERIMENT III

The results of the preceding experiments strongly suggest that the visual factor may be the most important determinant of the size-weight illusion. But the results also suggest that tactual and kinetic cues may have some effect on the judgment of weight. The third experiment was designed to test the relative contribution of visual and tactual cues to the illusion.

Two standard stimuli were used; a cylinder of the C-series (32×47 mm) and a cylinder of the M-series (50×50 mm), each weighing 150 grams.

PSEs of the cylinder C and cylinder M were measured under four different conditions. Under condition A, the standard stimuli could be seen directly, and the subjects were requested to compare the standard with seventeen comparison stimuli, picking them up one at a time. Visual and tactual cues were given directly under the condition A. Under condition B, the subjects could see the standard, but

FIG. 1. Schematic diagram of the standard cylinders, F₁, F₂ and F₃.

TABLE 4

The subjective weights of three cylinders, equal in visual size but different in tactual size

Stimulus	F ₁	F ₂	F ₃
Subjective weight in grams	107	120	110
Order of subjective weight, expected from density hypothesis	3	2	1
Order of subjective weight, expected from circumference hypothesis	2.5	1	2.5

the tactual cues were eliminated by having the subjects lifted the standard by a ring which was attached to the cylinder by a piece of string. Under condition C, the same apparatus and procedure were used as in condition B, except that the standard stimuli were hidden behind cardboard. All of the visual cues were removed and only indirect tactual cues were given. Condition D was designed to test the effects of pure visual cues on the judgment of weight. A piece of string was attached to the top of the standard as was in conditions B and C, but the standard cylinder was concealed from direct vision by an opaque screen. The cylinder was illuminated from behind and the subjects could see the shadow of the stimulus on the screen. The size of the shadow was changed by altering the distance of the light source from the stimulus. The size of the shadow increased as the distance between the light source and the cylinder decreased and vice versa. This is a simple way of changing the indirect visual size, but there are several defects. Sharpness of the shadow and brightness of background differs with the change of the size of the shadow. Two shadows of different size were used for each standard. In the case of cylinder C, the larger shadow was 20×10 cm and the smaller was 6×4 cm. In the case of cylinder M, the larger one was 16×30 cm and the smaller one was 6.5×6.5 cm. The number of subjects

TABLE 5

Average PSEs of six subjects for cylinders C and M under four conditions (in grams)

Conditions	Cylinder	Average	PSE Difference between C and M
A			
Visual and tactual, direct	C M	147 110	37**
B			
Visual, direct and tactual, indirect	C M	150 127	23**
C			
Tactual, indirect	{ C M	158 158	0
D			
Visual, indirect	{ C M	150	3
Smaller		147	
Larger	{ C M	135	5
		130	

** $p < .01$

was six. The method of adjustment was used to determine PSE.

We should expect significant differences between C and M under the conditions A and B. We should also expect that the difference between the two cylinders must be greater under condition A than that of condition B, if tactual cues have some effects on the size-weight illusion. We may also expect significant differences between the larger and smaller shadows under condition D.

Average PSEs of six subjects for the two cylinders under four different conditions are shown in Table 5, and comparisons between the four conditions are given in Table 6. The results of cylinder C are indicated in the upper left side of the diagonal of Table 6, and the results of cylinder M are indicated in the lower right side of the Table.

The differences between cylinder C and cylinder M are significant at the .01 level under the conditions A and B. The difference between these two under condition A is larger than that under condition B. The results agreed with what we had expected.

TABLE 6
Comparisons between PSEs under four conditions

		A	B	C	Smaller	D Larger	
M	A		-3	-11	-3	12	
	B	17		-8	0	15	
	C	48**	31**		8	23	C
	Smaller	37**	20*	-11		15	
	Larger	20	3	-28**	-17*		

* $p < .05$

** $p < .01$

Therefore, we can conclude that visual cues are the dominant factor controlling the size-weight illusion, although tactual cues also have some effects.

The difference in the effects between the larger and smaller shadows of cylinder M is significant at the .05 level, but that of cylinder C is not significant at the .05 level, although the results are favorable for the illusion.

We can conclude from the results of all three experiments that visual cues are the most important determinants of the size-weight illusion.

Inspection of Table 6, which involves comparisons between conditions, reveals that no significant differences are obtained in the case of cylinder C whereas several significant differences are obtained in the case of cylinder M. The results may due to the fact that cylinder C belongs to the C-series which had been used as comparison stimuli. The subjects could know that the standard was the same type as the comparison stimuli, under conditions A and B, and the knowledge of the subjects might affect the judgment of weight. On the other hand, we can not explain the results under conditions C and D, and this is a problem which needs a further investigation.

EXPERIMENT IV

As visual cues are the most important determinants of the size-weight illusion, it is necessary to take them into considera-

TABLE 7

The size and volume of the standard stimuli.
The size is shown by the length of a side of the cube (in cm) and the volume is given in cubic centimeter

Stimulus	Size (in cm)	Volume (in cc)
1	4	64
2	$4 \times \sqrt{2}$	181
3	4×2	512
4	$4 \times 2\sqrt{2}$	724
5	4×4	4096

tion in the scaling of subjective weight. It is necessary to know the functional relation between the visual size of the stimulus and its subjective weight for the application of the scale to real objects.

Five cardboard boxes were used as standards, the sizes of which are given in Table 7. The size of a box can be designated by the length of a side, as the shape of the box is cubic.

The experiment consisted of two steps, the first step was designed to determine the subjective size of the standard stimuli, and the second step was to determine the relation between the subjective size and subjective weight. The subjective size of the standards was determined by the constant-sum method of comparing all of the possible stimulus pairs. The standard was presented 1 meter away from the subject with the comparison stimuli placed on a table at the same distance. The number of subjects was five.

TABLE 8
The weights of standard stimuli (in grams)

Stimulus		Weight in grams						
1	50	100	150	200				
2	50	100	150	200	250	300	400	
3		100	150	200	250	300		500
4		100	150	200	250	300		500 700
5			150	200	250	300		

The size-weight relation was determined in the second step of the experiment. A standard stimulus, a cardboard box, was presented on the table with a series of comparison stimuli consisted of C-series and the subject was requested to find an equivalent stimulus, comparing the standard with comparison. Table 8 indicates the weight of standards. PSE was determined by the method of adjustment. Ten subjects participated in the second step of the experiment.

The relation between the subjective and objective size of the standards is shown in Fig. 2. The dotted line indicates the relation when the subjective size of the smallest box was chosen as a unit. The result indicates that the relationship, in log-log plot, is fitted well by a straight line.

The subjective size of the cylinder C may be a more convenient unit, as the C-series

FIG. 2. Relation between objective and subjective size of the stimuli. The dotted line indicates the relation when the smallest stimulus used as a unit and the solid line indicates that the cylinder C is used as a unit.

has been used as comparison stimuli. Comparisons between the cylinder C and the standard box 1 and 2 show that it is possible to transform the unit. The result of unit transformation is given by a solid line in Fig. 2.

The results of the second step of the experiment are shown in Table 9. Subjective weight of each standard series of the same size is linear function of the objective weight if they are plotted in log-log coordinates, as is shown in Fig. 3.

Equal weight curves can be derived from these functions. We can estimate from the curves, for instance, the subjective weight of 100 grams for the unit size is equivalent to 110 grams for the box 1, 124 grams for the box 2, 160 grams for the box 3, 190 grams for the box 4 and 240 grams for the box 5. Fig. 4 indicates the equal weight curves, taking log subjective weight on the abscissa and the log equivalent weight on the ordinate. The rela-

FIG. 3. Relations between objective and subjective weight. The figure at each line indicates the size number of the stimulus.

TABLE 9
Subjective weights of five different boxes (in grams)

Stimulus	Weight of standard								
	50	100	150	200	250	300	400	500	700
1	50	95	134	172					
2	45	88	117	153	180	220			
3		57	98	128	150	180	246		
4		54	87	113	132	156		240	
5			72	85	102	120		168	203

tionship between log-size and log-weight is not linear, but we may assume a linear relation as a first approximation. The relation can be written by an equation

$$\log S_e = \log S_s + .1847 \log R \quad (3)$$

where S_e is an equivalent stimulus in grams, S_s is subjective weight at unity size and R is subjective size. The objective weight of a stimulus can be calculated from the equation (3) when its subjective size and weight are known.

We can derive from the equation (3) an equation which relates the subjective weight with objective weight and subjective size. The relation can be written,

$$\log S_s = \log S_e - .1847 \log R \quad (4)$$

or

$$S_s = S_e / R^{.1847} \quad (5)$$

The relation also can be given in the form

FIG. 4. Equal weight lines.

of curves as are shown in Fig. 5. It should also be pointed out that there are some systematic deviations of the curves from the obtained results.

EXPERIMENT V

The equation (5) predicts the subjective weight of an object of which the objective weight and subjective size are known. But the equation was obtained through an experiment using cardboard boxes and cylinders and, therefore, there may be some limitation to the application of the equation. The present experiment was designed to test the general applicability as well as limitations of the equation.

General applicability was tested by predicting the subjective weights of the following objects; a book, a piece of wood, an electric valve, a drinking glass, a pebble, and a weight. Their subjective sizes were

FIG. 5. Relation between subjective size and subjective weight.

TABLE 10
Subjective size and subjective weight of
the stimuli

Stimulus	Subjective size	Weight		
		objective	estimated	obtained
Book	28	470	254	200*
Wood	25	274	151	143
Valve	28	143	77	95*
Glass	7.8	99	68	80
Pebble	2.8	154	127	114
Weight	1.1	150	147	160

* $p < .05$

estimated by the ratio estimation method, comparing the objects with cylinder C. Subjective weights were measured by the method of adjustment.

Table 10 gives data relevant to the general applicability of equation (5). Names of the objects are given in the first column. The second column indicates the subjective size of each stimulus, and its objective weight is given in the third column. The fourth column indicates the weight predicted from the equation. The results obtained are given in the last column. The results of *t*-tests indicate that the differences between the predicted and obtained values are significant at the .05 level in the case of the book and the electric valve.

The results suggest the limitation of the application of the equation. In the case of the book, its size and shape are markedly different from the stimuli used for the derivation of the equation. In the case of the electric valve, its shape and material are quite different from the original stimuli.

DISCUSSION

We can conclude from the series of experiments that the most important determinant of the size-weight illusion is the visual size of the stimulus. But it should also be pointed out that tactual and kinetic cues may have some effects on the judgment of weight. The equation

which relates subjective weight with subjective size indicates the relation in which only these two parameters are contained. Therefore, there remains a possibility that systematic deviation found between the estimated values and results obtained may be due to the factors which are not taken into consideration.

The relation between objective size and subjective volume is linear in the case of boxes and cylinders, but we have not yet obtained convincing evidence that the subjective size is always a linear function of the objective size, however complicated the shape may be. Rather, we have a definite proof against it. Ogawa (1955) has shown that subjective size differs owing to the difference of the shape of the stimulus. Although, the only way of relating size with subjective weight is through subjective size, there remains the problem of whether the difference of size induced by the difference of shape has the same effect on the judgment of weight.

SUMMARY

The present study was designed (1) to investigate the main factors that determine the positive size-weight illusion and (2) to find the functional relationship between subjective weight and perceived size. Two types of cylinders were used as stimuli. In the first experiment, effects of visual, tactual and kinetic cues were investigated, with the results that combined visual and tactual cues were found significant at the .01 level, while kinetic cues were not significant.

The third experiment was designed to test the relative importance of tactual and visual cues on the judgment of weight. Visual cues were found to be determining the size-weight illusion.

The fourth experiment was designed to find an equation which would relate visual size with perceived weight. Five types of cardboard boxes were used as standards. The function can be written in the form: $S_s = S_e / R^{.1847}$. The last

experiment was designed to test the applicability of the equation to real objects. Successful predictions were made in four out of six instances.

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