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WEBER'S LAW IN ILLUSIONS.

BY

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In a former article[1] I reported some measurements on illusions of weight. Since then it has occurred to me that we may not only measure an illusion, but also use this measurement as a means by which to determine some other mental factor whose relation to it is known. An experimental attempt at this subject revealed another problem which is involved in the first and, at the same time, affords a field in which the two may be solved together. This second problem, which, on account of the outcome of the experiments, proves to be the most important, is this: Does Weber's law depend upon the so-called real intensity or upon the apparent intensity of the stimulus?

As a most distinct and manageable case in which to carry on the investigation I selected the illusion of weight which is due to the knowledge of the size of the object lifted. The apparatus consisted of three pairs of cylinders (*A*, *B* and *C*) of the same weight, 80^{g}, and the same diameter, 37^{mm}; but of different lengths, *A* being 20^{mm}, *B* 120^{mm} and *C* 50^{mm}. The cylinders were made of polished hard rubber; in external appearance they were similar in all respects except length. The bottom plates were screwed in and could be removed by turning them three-fourths of a revolution by a key. A steel pin rose from the center of each bottom-plate for the purpose of receiving different weights consisting of circular disks with holes in the centers to fit this pin. There were two sets of these weights; one of 1^{g} to 15^{g} by one-gram steps and the other of 5^{g} to 40^{g} by five-gram steps. The adjustment of the weight by this method was suggested by Dr. MEUMANN, of Leipzig. It is a modification of Professor JASTROW's muscle sense apparatus.[2]

Twenty students in experimental psychology were examined and asked to give their judgments regarding the heaviness of the weights but to make no correction, allowance, or guess, based upon knowledge of the

[1] SEASHORE, *Measurements of illusions and hallucinations in normal life*, Stud. Yale Psych. Lab., 1895 III 1.

[2] I am under obligations to Professor BLISS for facilities and suggestions, and to members of his class in the New York University summer school, 1896, for assistance as observers in the present experiments.

illusion involved. As has been proven (pages 5–9 in my investigation cited above) the illusion of weight persists, but is not so strong when the fact of the illusion is known; therefore, observers who are aware of the illusion and those who are not aware of it fall into two distinct classes. In the present experiments even the details of the illusions of weight and of this illusion in particular were demonstrated before the observers until all were conversant with the facts in question. Therefore, the illusion here measured is not the maximum. The preparatory demonstration was, however, made by a different set of cylinders in which the diameters varied so that none of the observers knew the exact extent of the illusion in the present apparatus.

The aim was to determine two classes of facts: (1) the threshold, or least perceptible difference, for each pair of cylinders, and (2) the amount and kind of illusion in *A* and *B* respectively when measured by *C* as a standard. The first was determined by the following method: The weights in the continuous series rising by one gram each step were tried until three successive increments had been correctly perceived. The lowest of these was considered a threshold value. The observers were allowed to answer "equal" or "different" and, in the latter case, they were required to point out the heavier. The amount of the illusion was found by determining how much the weight in the *C* cylinder had to be varied from the standard in order to make it equal to the *A* cylinder. The same procedure was repeated for the *B* cylinder. The series of weights which differed by five-gram steps were used in the measurement of the illusion.

The results are given in the Table. One determination was made in the order ΔA, ΔB, ΔC, K, K' of which the results are recorded in the *a*-columns. Then the series was repeated in the reverse order with another complete determination on each point. These results are recorded in the *b*-columns. For the threshold *a* and *b* have the same value, but in the illusion-measurements *a* represents the lowest difference which made these two cylinders apparently equal, and *b* the highest; i. e., in *a* I started from the point of physical equality and continued to the first point of subjective or apparent equality, while in *b* I started with an excessive difference and decreased this until the upper limit of apparent equality was reached.

The experimenter handed the cylinders from behind a screen by pairs, placing them on end side by side in a convenient position upon a baize-covered table. The observer was required to grasp them as nearly as possible in the same manner and lift them always to the same height with the same speed. He was also required to keep them as near to-

gether as possible, and, after having tried them back and forth, to interchange them in position and again compare them in both directions, continuing as long as he thought profitable. Thus the errors of time, speed, place, fatigue, practice, surprise, temperature and order were fairly eliminated.

Subject.	ΔA			ΔB			ΔC			K		K'	
	a	*b*	*E*	*a*	*b*	*E*	*a*	*b*	*E*	*a*	*b*	*a*	*b*
I	4	1	$\frac{1}{9}$	4	3	$\frac{0}{11}$	1	2	$\frac{0}{7}$	10	20	10	20
II	5	3	$\frac{1}{12}$	7	5	$\frac{1}{16}$	4	4	$\frac{1}{12}$	15	15	20	15
III	3	2	$\frac{3}{9}$	3	2	$\frac{0}{9}$	1	2	$\frac{0}{9}$	15	15	15	15
IV	2	1	$\frac{1}{7}$	1	4	$\frac{0}{9}$	1	8	$\frac{0}{13}$	20	25	10	20
V	2	4	$\frac{2}{10}$	3	4	$\frac{0}{11}$	3	1	$\frac{1}{8}$	0	0	10	5
VI	1	1	$\frac{0}{8}$	3	1	$\frac{0}{8}$	3	3	$\frac{0}{10}$	20	20	15	15
VII	3	6	$\frac{3}{13}$	4	6	$\frac{0}{14}$	4	6	$\frac{2}{14}$	10	20	15	15
VIII	4	2	$\frac{0}{10}$	3	3	$\frac{0}{10}$	2	2	$\frac{0}{8}$	20	10	15	15
IX	1	2	$\frac{1}{7}$	6	2	$\frac{2}{12}$	2	7	$\frac{2}{13}$	15	10	10	5
X	3	4	$\frac{0}{11}$	5	8	$\frac{0}{17}$	6	9	$\frac{0}{19}$	20	25	10	20
XI	1	2	$\frac{0}{7}$	3	2	$\frac{0}{9}$	1	1	$\frac{0}{8}$	15	15	15	15
XII	3	1	$\frac{1}{8}$	4	4	$\frac{4}{12}$	3	3	$\frac{3}{10}$	15	10	5	5
XIII	3	3	$\frac{4}{10}$	1	6	$\frac{2}{11}$	3	4	$\frac{2}{11}$	20	15	0	5
XIV	2	2	$\frac{0}{8}$	2	2	$\frac{0}{8}$	3	1	$\frac{1}{8}$	25	25	10	15
XV	1	2	$\frac{1}{7}$	2	7	$\frac{2}{13}$	1	5	$\frac{1}{10}$	15	10	−5	5
XVI	7	1	$\frac{0}{12}$	7	5	$\frac{0}{16}$	2	4	$\frac{1}{10}$	10	20	10	5
XVII	1	2	$\frac{0}{7}$	1	2	$\frac{0}{7}$	3	3	$\frac{2}{10}$	15	20	15	20
XVIII	5	7	$\frac{0}{16}$	6	8	$\frac{0}{18}$	4	5	$\frac{0}{13}$	5	10	10	5
XIX	3	2	$\frac{0}{9}$	6	8	$\frac{1}{18}$	3	2	$\frac{0}{9}$	15	25	15	20
XX	3	6	$\frac{0}{13}$	2	7	$\frac{0}{13}$	4	9	$\frac{0}{17}$	10	25	20	20
A	2.9	2.7	$\frac{0}{9.6}$	3.6	4.4	$\frac{0}{12.1}$	2.7	3.9	$\frac{0}{10.8.9}$	14.5	17.2	11.2	13.0
d	1.1	1.3		1.4	1.7		1.1	2.0		4.2	5.5	4.4	5.6
M	2.8			4.0			3.3			15.8		12.1	
m	1.2			1.5			1.5			4.8		5.0	

The unit of measure is the gram.

ΔA, ΔB, ΔC, the thresholds for the respective pairs.

K, overestimation of A when measured by C.

K', underestimation of B when measured by C.

a, the first measurement.

b, the second measurement.

E, the proportion of errors made; the numerator expresses the number of so-called wrong judgments made out of the total number expressed by the denominator.

A, average; *M*, the mean of the two averages.

d, mean variation; *m*, the mean of the two mean variations. The mean variation for the series may be found by dividing these by 6.3.

The necessity of retaining the same standard throughout the entire experiment was urged upon each observer. The standard of sureness can be seen to some extent in the individual records by comparing the number of errors with the size of the increments. *E* shows the number of actual errors in comparison with the number of possible errors, or the total number of judgments that were made. The comparatively small number of errors in *B* may be accounted for partially by the favorable position of *B* in the order of trials. The *b*-trials in *C* were often disturbed by their proximity to the illusion-trials, and *A* was subject to still more disturbance because of its position as the extreme first and last trials. I call these so-called wrong judgments "errors" in a different sense from that in which the illusions are called errors. The illusions are normal, but what is here called an error is not based upon any such constant factor that is known.

The variation is apparently large, but it must be remembered that it is the individual variation of twenty different observers from their average and that the number of trials on each observer is small. The general agreement of so many is worth more than the consistency of one in a larger number of trials. If we consider the uniformity of the conditions of the observers, subjective as well as objective, we find ourselves justified in taking the averages of these twenty (in all, forty complete determinations on each point) as a fair expression of the answer to the two original questions.

Does Weber's law depend upon the real or upon the apparent weights? If upon the apparent, is there any traceable law? In the present case *A* is overestimated by 15.8^g and seems to weigh 95.8^g in terms of *C* which we assume as a standard and common measure. According to that a physical change of, e. g., 3.3^g in *A* will appear as a change of

$$\frac{95.8}{80} \times 3.3 = 4.0.$$

On the other hand *B* is underestimated by 12.1^g and appears to weigh 67.9^g in terms of *C*. Then a physical change of the same amount, 3.3^g, in *B* will appear as a change of $\frac{67.9}{80} \times 3.3 = 2.8$. There is a coincidence between this theoretical consideration and the above results, but we must seek other relations in the results in order to get a more direct answer.

The ratios for the relation between the respective thresholds and the standard for these particular conditions are:

$$\Delta B = \tfrac{1}{20}, \quad \Delta C = \tfrac{1}{24} \text{ and } \Delta A = \tfrac{1}{29}.$$

These are the constant multiples which would express Weber's law for the same conditions if the measurements were repeated with any standard weight within the limits in which the law is applicable. These are, however, only representative of a large number of possible illusions. As I have proved (pp. 3–5 in the article cited above) within certain limits, the illusion varies directly with the difference in size. We might have made the illusion stronger by making A smaller and B larger, or by obtaining the naïve, "unconcious" judgment of the observers. In such a case we should have gotten a number of thresholds outside of the present extremes. Similarly we might have decreased the illusion down to zero. It is evident then that if we state that Weber's law requires, e. g., $\frac{1}{24}$ of the standard to produce a just noticeable increment on 80[g] we have stated it only for one particular relation between the standard weight and the size of the object. Grant that C is the nearest approach that we can get toward freedom from this one illusion, then the relation of the threshold to this would denote that which is generally expressed by Weber's law. But a large number of conditions, represented by A and B are just as important from a practical point of view, for it is very rare in normal life that we lift objects that give us no illusion. This was preëminently true in the classic experiments on Weber's law. Now, the facts known about the regularity and trend of this illusion justify us in assuming that, if the same proportions between the sizes and the standard weight be retained, the illusion will approach a constant fraction of the standard within the limits of the validity of Weber's law. Therefore, if we had determined the threshold empirically under all possible degrees of illusions like the one under discussion, Weber's law might be expressed for all standard weights within the above assumed limits by as many fractions, like $\frac{1}{24}$, as there are illusory effects such as A and B represent. The fact of this possibility implies an affirmative reply to our first inquiry, namely, that we can use the measurement of one mental characteristic as an index to another; in this case the measured illusion is an index to the threshold. An attempt to state it from such a complexity of conditions might seem hopeless, but the above results give us a key.

First, all overestimation lowers the threshold and all underestimation raises it. Secondly, retaining the notation of the Table, we may formulate the results thus:

$$\frac{\Delta A}{\Delta C} = \frac{C-K}{C}$$

and

$$\frac{\Delta B}{\Delta C} = \frac{C+K'}{C}.$$

The error involved by substituting the empirical results is 5% in the first equation and 10% in the second. Both these, it may be seen from the table, are less than the respective mean variations. Disregarding the illusion (K and K' in the above formulas) as has always been done, the error in substitution would be 15% in the first and 21% in the second equation. Hence Weber's law stands in a much closer relation to the apparent weight than to the physical standard.

If we know the increment needed for an object of a given weight and size, e. g., C, at any standard, and know the amount of the illusion for all differences in size in objects of this weight, we may be able to calculate the threshold of perceptible difference for all such cases. For

$$\frac{\Delta A}{C-K} = \tfrac{1}{23},$$

$$\frac{\Delta B}{C+K'} = \tfrac{1}{23}$$

and

$$\frac{\Delta C}{C} = \tfrac{1}{24}.$$

These give a constant fraction for all the equations, in this case approximately $\frac{1}{23}$. This fraction may be supposed to hold as a constant for all conditions, of which the above A, B and C are representative. Hence, we may state the principle for the dependence of Weber's law upon apparent weight, as

$$\frac{\Delta E}{S+K} = M$$

where ΔE is the threshold of perceptible difference, S the physical standard weight, K the amount of the illusion (which must retain its sign + or — according as it is underestimation or overestimation of the standard), and M a constant.

A question may here be raised as to the reason for and effect of choosing C of this particular size. It was chosen, after some preliminary experiments, because it seemed to correspond fairly to the size that the adopted standard weight might suggest. What would have been the effect of making it larger or smaller than this? It may be possible to detect some law for the dependence of the illusion upon this, but at the present stage of measurements in illusions this factor is negligible and the standard may be chosen of any size which is not so extreme as to introduce other sources of error, such as difficulty in grasping, provided the results are stated in terms of that size. Such results may also be convertible into

terms of each other, for on this theory we may add the illusion of A to the illusion of B and take the sum of these as the expression of the illusion of either A or B in terms of the other. Thus

$$\frac{\Delta A}{\Delta B} = \frac{B-(K+K')}{B}$$

$$\text{and } \frac{\Delta B}{\Delta A} = \frac{A+(K+K')}{A}.$$

The error involved by substituting the actual figures is 5% for the first equation and 7% for the second. Although these are extreme cases the error of the substitution is no greater than that found when the mean, C, was used as a standard. Therefore, within obvious limits, we are justified in choosing the standard of any convenient size in measurements like these.

Just as no one now claims an exact mathematical conformity for Weber's law in any sense, we must construe the above formula liberally. There may be some more determinable factors that must be taken into it; we can never hope to determine and control all such factors. Judgments as to the validity of the law have heretofore been made largely upon experiments that involved the illusion here discussed, or similar ones, and the variations caused by them have been counted as discrepancies in the law. The above data at least justify us in assuming this relation of Weber's law to illusions as a working hypothesis. It promises not only the same degree of comformity as the law has had on the old theory, but also an extension of it both in the degree of conformity and the range of its applicability.