

A PRELIMINARY INVESTIGATION INTO A CONSISTENCY IN THE
ACCELERATIONS OF OBJECTS LIFTED BY WRIST FLEXION

by

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Abstract

In examining films of lifting movements made during a study of the size-weight illusion (Davis & Roberts, 1973), a consistency was noted in the values obtained for the maximum accelerations of the objects lifted. This consistency, while at first surprising, seemed more reasonable upon reflection, and this study was designed to confirm its existence.

Twenty-four Ss were filmed lifting four objects which differed in size, shape, substance, color, and weight. The film was analysed frame by frame, and the data collected were subjected to a two-way analysis of variance. The results indicated that the Ss, while differing from one another, were consistent in the maximum accelerations they applied to the three heaviest of the four objects. The accelerations of the lightest object differed significantly from the accelerations of the other three, but it seems likely that this was an aberration due to the experimental task itself.

What a piece of work is a man! . . .
in form and moving how express and admirable!
in action how like an angel!

Hamlet, II, ii, 317

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Illusions typically arise when the tacit assumptions underlying the processing of perceptual information are violated. As such, their study is a potentially informative and fruitful approach to our understanding of perceptual-motor systems, providing, as Leucippus asserted of the senses themselves, "a glimpse of the obscure". The illusions arising when the usual relationships of size, material, and weight are altered (Charpentier, 1891; Seashore, 1898; Usnadze, 1931) can provide insight into some of the factors which give rise to our sensations of weight and the formation of judgments of relative weight, as well as providing a clearer picture of how we control the contraction of our muscles.

The theory that the size-weight illusion (and, by extension, all judgments of heaviness) are principally caused by peripheral events, i.e., by the lift itself and the subsequent sensory feedback, is both plausible and venerable. It was first proposed by Muller (Martin & Muller, 1899), who hypothesized that the subject, anticipating

that the larger object would be the heavier, applied too much force in lifting it; and this excess force, by causing the object to be lifted quickly, resulted in a sensation of lightness.

This hypothesis was partially confirmed by Claparede (1901) who, by directly measuring the ascension of both weights, found that the larger was indeed lifted more quickly and with a shorter latency. Loomis (1907) directly measured the entire lift, and found that even when the lift was considered as a whole, the larger weight was still typically lifted with greater force than the smaller. But these two studies, although well-conceived and ingeniously executed, fell into an ill-deserved obscurity, and references to them in the later literature are sparse.

And so psychology drifted into error. People spoke of densities and central mechanisms (e.g., Koseleff, 1958; Helson, 1959), and while some dismissed the peripheral theory as somehow not satisfactory (Nyssen & Bourdon, 1956), others even denied that the lift affected judgment at all (Fourche, quoted in Whipple, 1921). However, Davis & Roberts (1973) demonstrated that not only were the two objects lifted differently, and the larger, faster, but that by changing the

speed of the lift, the judgment of weight could be altered, and the size-weight illusion, one of the grossest and most tenacious of all the perceptual illusions, reversed (Davis, personal communication).

In examining the physical characteristics of the lifts, we found extremely marked individual differences in height, duration, and mean velocity. However, maximum accelerations demonstrated not only a (comparatively) modest variability, but no statistically reliable individual differences: i.e., in terms of maximum acceleration, everyone lifted the same objects in nearly the same way.

This consistency, which seemed at first glance so remarkable, became, upon reflection, more explicable. It is an everyday observation that not only people but other animals as well, are quite skilled at estimating the amount of muscular effort needed to perform any certain action: we move around and up and down with a modicum of grace, and we are seldom surprised by the weight of things when we pick them up. This is true not only of the adults of any species, but also of the young, who develop this skill about the time they begin to move about their environment (Held & Bauer, 1967).

This may be a matter of hours, as in precocial animals, or of months, as in man. Graceful movement is so much considered a normal attribute of animals that its lack in early infancy is taken as prima facie evidence of brain damage (cf. Windle, 1963, 1969; Pasamanick, Knoblock, & Lilienfeld, 1956; Apgar, Girdany, McIntosh, & Taylor, 1955; Jenkins & West, 1958).

Moreover, it seemed that being well-co-ordinated (of which reaching and lifting are facets) is very probably an innate ability: its universality both within and between species, the consistency of its development among individuals, and the obviousness of the evolutionary pressures favoring its selection, all argue strongly for it. Clearly, too, it is an ability that seems to be organized into an hierarchical system (cf. Bowlby, 1972). Walking, for instance, is organized on a spinal level, but is also influenced by events in the brain: by perceptual inputs, for example, and by plans (cf. Miller, Galanter, & Pribram, 1960). There are some obvious feed-back elements in this system (the joint receptors, tendon organs, and muscle spindles, for instance), whose sensory input of position or effort modifies on-going

muscular activities. These modifications can be considered as goal-corrected (in Bowlby's sense): the movement of the hand, arm, and body in reaching, for instance, is corrected with reference to the goal of arriving at and grasping some object; in walking, to the normal gait (the Platonic Form) as well as to the intended destination (the Aristotelian telos): by sub-plans and plans, in Miller, Galanter, and Pribam's terminology.

The initial muscular effort exerted at the beginning of any action (and the over-all co-ordination of the entire action) is affected not only by our past experiences (and implicitly by our genetic make-up, which influences how easily or hardly we profit from our experiences) but also by cues from the environment. When these cues are misleading, the initial muscular force applied may be inappropriate, i.e., either too little or too much for the action in question, and this inappropriate effort will be reflected objectively in abnormal lifts or clumsiness of movement and subjectively in erroneous sensations of weight or effort.

Thus this consistency of acceleration which we had noticed in studying the size-weight illusion seemed

to be an indication of a widely-functioning neuro-muscular system which allows us to move normally in the world and whose misfunctions account for some of the common illusions of weight which we experience. As such, it seemed worthwhile to look at this consistency more closely, to see whether, indeed, there were no statistically reliable differences between individuals or between objects of a familiar nature.

Method

Procedure. These hypotheses were tested by filming individuals lifting objects of different shapes, substances, weights, and colors. (These are, apparently, important perceptual parameters: cf. Huang, 1945; Seashore, 1899; Wolfe, 1898; Darube, 1964. Factors which affect the perception of weight also presumably affect the way in which the objects are lifted physically.) The film, which was shot at twenty-four frames per second, was analysed frame by frame to determine the maximum accelerations. Two of the objects were half-pint and quart cans, painted white, which had previously been used in the series of experiments on the size-weight illusion (Davis & Roberts, 1973). The small can weighed 486 grams, close to its previous weight of 500 grams,

and the large can weighed 705 grams, which a pilot study had indicated to be sufficient to prevent the size-weight illusion from occurring (cf. Nyssen & Bourdon, 1954). The third and fourth objects were wooden blocks, each 8.9 cm. in cross section, one equal in height to the small can, the other, to the large can, and weighing 288 and 486 grams respectively. All four objects had wire handles attached so that they could be lifted from the same height by wrist flexion alone. In this manner, the Ss did not have to raise or lower their hands to grasp the different objects. The Ss also wore plexiglass guides on their fingers; these guides had slots into which the wire handles fitted. This standardized the relative lever lengths through which the objects were lifted, a factor that demonstrably affects the perception of weight, although in no simple manner (Davis, 1973, 1974). The objects were presented in counter-balanced order by the E, who set them on a small revolving table in front of the seated S. Figure 1 shows the experimental arrangement.

The beginning of the lift was indicated to the S by a warning light followed two seconds later by a lift light; these lights were placed directly in front of the S at a distance of one metre. The camera (an electrically

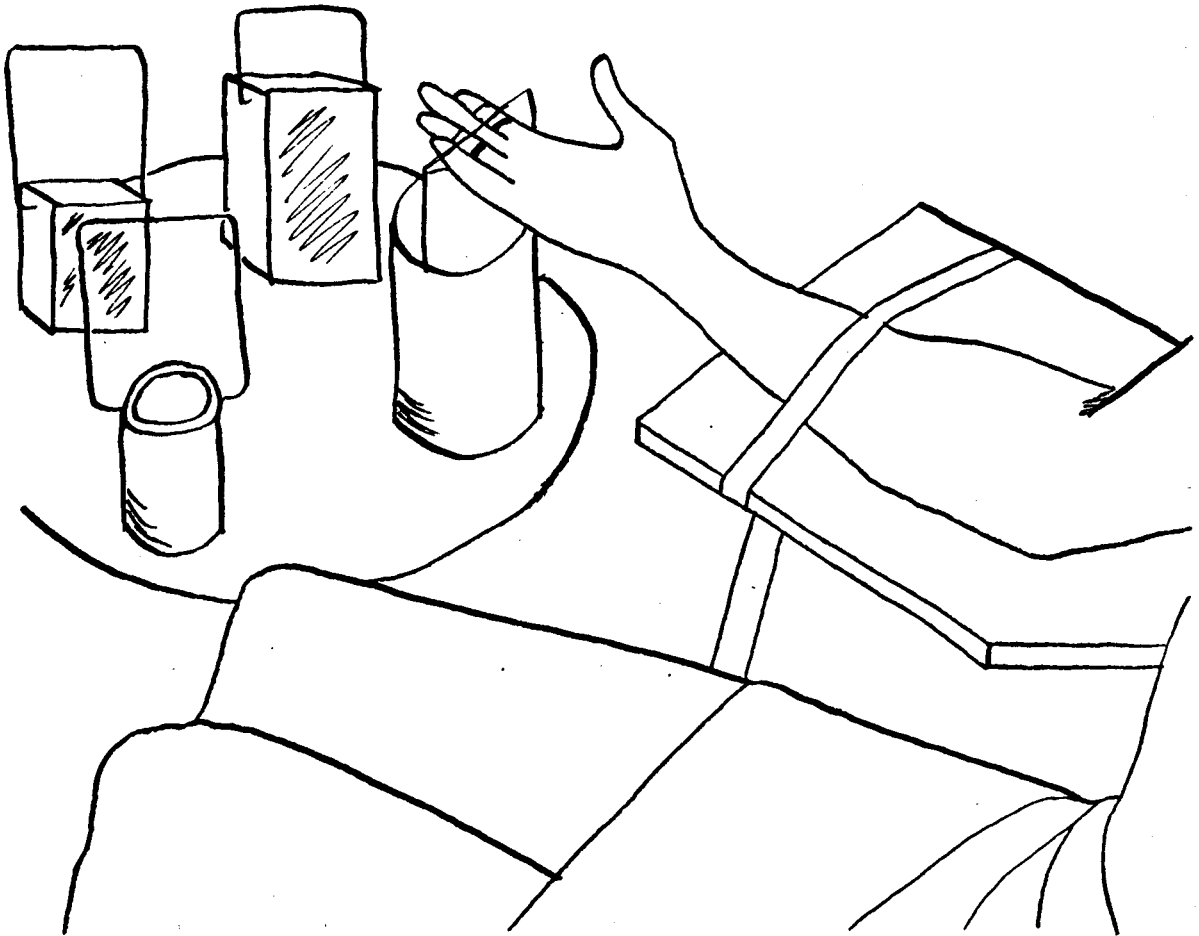


Figure 1: Arm, hand, and arm-rest; table and four objects.
This arrangement minimized the mechanical differences in
the lifts. Note the plexiglass guides on S.

driven 16mm Bolex with a reflex lens) began filming when the warning light came on; it was placed at the S's right, perpendicular to the plane of the lift, at a distance of two metres. After each lift, each S gave an estimate of the absolute weight of the object in grams (this was merely a precautionary measure, to insure that the Ss attended to the task of lifting). This was repeated until each S had lifted each object twice. Only the second set of four lifts was analysed, the first set constituting a practice trial. This seemed an advisable procedure, since the purpose of the experiment was to study lifting movements in familiar situations-- and although it was intended that the objects and the situation should be as straightforward as possible, a laboratory is an unnatural place, and white cans and wooden blocks with wire handles, rare objects. Moreover, a practice trial seemed appropriate since, in our non-laboratory lives, we typically have countless practice trials preceding every action we undertake.

After processing, the film was projected, the distance between the screen and projector being adjusted until the image was life-size. The height of the object

above the table was then directly measured for every frame. The fuzziness of the image prevented this measurement from being more accurate than ± one-fourth millimeter.

Subjects. Twenty-four university students, aged between 18 and 30 years, were Ss. Fifteen were female. They were told that the purpose of the experiment was to gain information on how estimations of weight were formed. The experimental requirements were explained, and any questions were answered.

Results

The frequency distribution of the maximum acceleration values for each object lifted is shown in Figure 2. It is readily apparent that the distributions for the three largest objects are very similar, and that they reflect a generally slower rate of lift than that for the smallest object (the small block). The mean and modal maximum acceleration values for each object are given in Table 1.

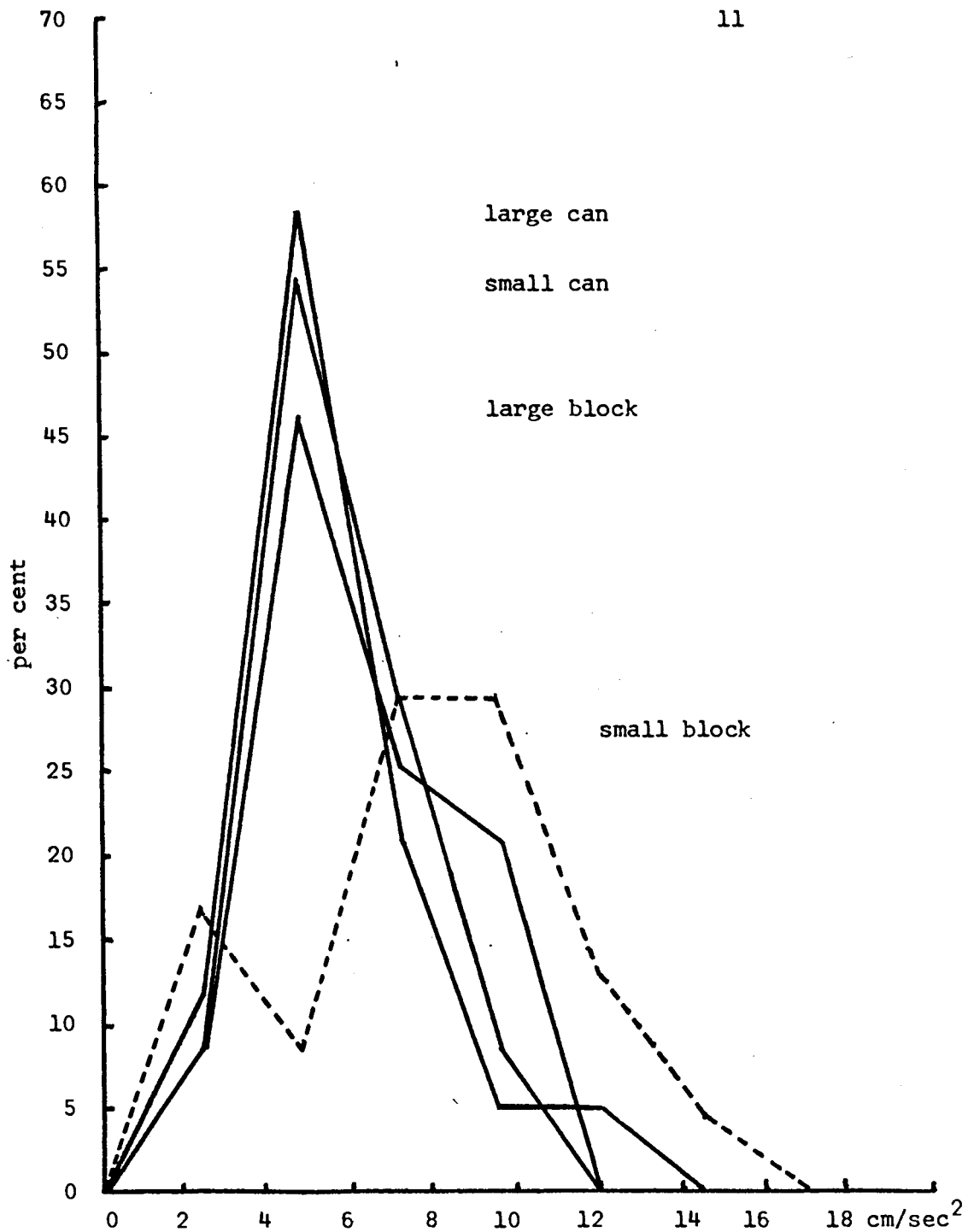


Figure 2. Frequency distributions of maximum acceleration values for the four objects.

Table 1: The mode, mean, and standard deviation of the maximum acceleration values for each object lifted.

	<u>mode</u>	<u>mean</u>	<u>standard deviation</u>
small can	4.8 cm/sec ²	5.7	1.8
large can	4.8	5.5	2.1
large block	4.8	6.2	2.2
small block	8.4	7.8	3.3

A two-way analysis of variance ($24 \underline{Ss} \times 4$ objects) was applied to the maximum acceleration data. The results, shown in Table 2, revealed significant effects for both subjects and objects. However, when the data for the smallest object are omitted, the significant object effect disappears, confirming the consistency of lifting previously noted.

Four other lift characteristics were also computed, and the data subjected to similar analyses. Significant effects of objects were found for mean and maximum velocity, but again these disappear when the data for the small block are omitted (see Table 2). No significant effects of objects were found for measures of maximum height or maximum deceleration. Finally, the only measure which failed to yield a significant variation due to S differences was maximum deceleration for the three largest objects.

The consistency of lifting behavior is strikingly demonstrated in Figure 3, which shows almost identical maximum

Table Two: Results of the analysis of variance

		<u>Four Objects</u>	<u>Three Heaviest Objects</u>
Maximum Height	subjects	F= 27.62, df= 23/69, p<.001	
	objects	F= .15, df= 3/69, p>.50	
Mean Velocity	subjects	F= 8.10, df= 23/69, p<.001	F= 7.51, df= 23/46, p<.001
	objects	F= 3.14, df= 3/69, p<.05	F= .74, df= 2/46, p=.51
Maximum Velocity	subjects	F= 11.24, df= 23/69, p<.001	F= 10.30, df= 23/46, p<.001
	objects	F= 5.40, df= 3/69, p<.005	F= .33, df= 2/46, p>.50
Maximum Acceleration	subjects	F= 3.55, df= 23/69, p<.001	F= 1.90, df= 23/46, p<.05
	objects	F= 7.03, df= 3/69, p<.001	F= .93, df= 2/46, p=.57
Maximum Deceleration	subjects	F= 2.16, df= 23/69, p<.01	F= 1.65, df= 23/46, .05<p<.10
	objects	F= .77, df= 3/69, p>.50	F= .07, df= 2/46, p>.50

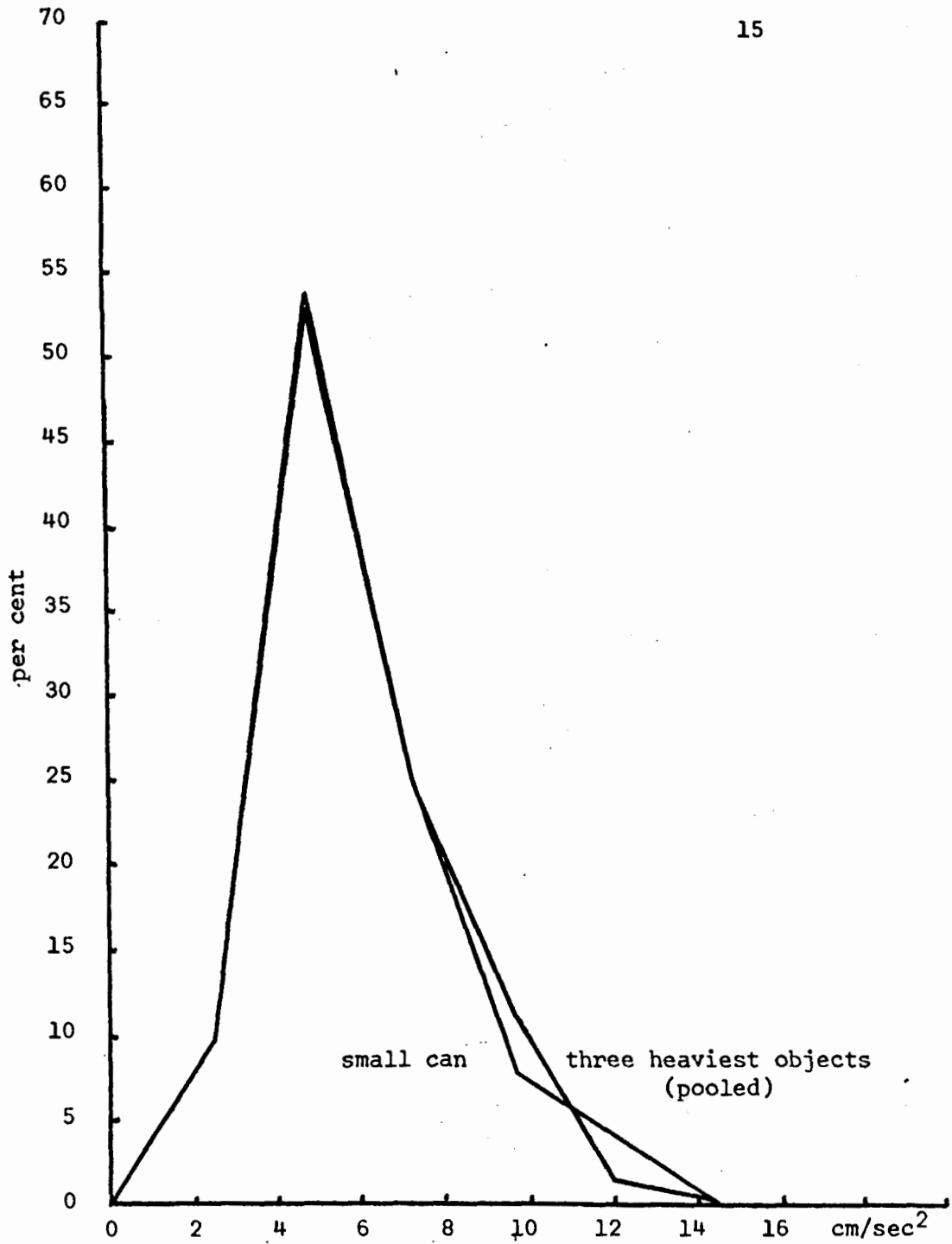


Figure 3. Frequency distributions of the pooled maximum acceleration values for the three heaviest objects and for the small can in Davis & Roberts (1973).

acceleration distributions of the pooled data for the three largest objects in the present experiment and of the values obtained by Davis & Roberts (1973) for their small can. (This, incidentally, confirms Muller's intuition that it is the larger can in the size-weight illusion that is lifted abnormally, and thus is the source of the illusion.)

The data from both Davis & Roberts (1973) study and the present experiment clearly support the hypothesis that people lift different objects similarly and consistently. Provided, that is, that they weigh enough.

Discussion

It appears that while the muscular effort needed for an action can be initially set with precision and consistency over a wide range of activities, it can't be set exactly; and these minor perturbations in force cause a greater variability in the acceleration of lighter objects. For the less mass an object has, the more easily its acceleration can be altered. (And conversely, of course, the heavier the object, the less its acceleration will

be affected by minor variations in the force applied to it. It is probably not accidental that of the four objects, the heaviest was the most consistently lifted, while the lightest elicited the greatest variance.)

From Newton's Second Law, $F = ma$, we know that it takes a force of 2300 dynes to accelerate 486 grams to 4.8 cm/sec², the modal maximum acceleration of the small can, large block, and large can. It takes 2900 dynes to accelerate them to their mean maximum acceleration. The small wooden block, on the other hand, needs a force of 2450 dynes to reach its modal maximum acceleration of 8.4 cm/sec², and 2200 dynes to reach its mean maximum acceleration. It seems as though the lightest weight was being lifted with about the same effort as was applied to the other weights: a proper strategy, if one is trying to determine relative weights, and a perfectly possible one (cf. Payne & Davis, 1941); and one, moreover, that was in these circumstances very likely, since the Ss were given the task of estimating the weights of the objects.

This strategy should, of course, also affect the lifts of the heaviest object, as well as the lightest. If an (approximately) equal initial force was applied to all the objects, the heaviest ought to reach its maximum accelerations at a slightly later time than the others. And indeed there is a marked (although not statistically significant) trend in this direction ($\chi^2 = 6.23$, $df = 3$, $p = .10$). See Table 3.

Table Three: Distribution of maximum accelerations by time.

	First one-eighth second	Second one-eighth second	n	percentage of total lifts in first quarter-second
Small Can	57.1%	42.9%	21	87.5%
Large Can	29.4	70.6	17	70.9
Small Block	65.2	34.8	23	95.9
Large Block	60.0	40.0	20	83.4

84.4% of all maximum accelerations occurred in the first quarter-second of the lift.

That there are limits to the accuracy with which we set the initial effort needed for any activity is not only clear a priori, but is also suggested by the existence of thresholds and j.n.d.s in the estimation of absolute weight (because these estimations depend in part on the physical characteristics of the lift, which depend, in turn, on the muscular tension just prior to the lift) and by the curious fact that for weights of less than three grams, the size-weight illusion is reversed (Howard, 1954)-- a remarkable finding, given the tenacity of the illusion at greater weights, and suggestive in its implications for the nature of the lifts themselves.

Of course, these data point to a level of breakdown at weights far less than 288 grams: which may well be so, since the experimental task imposed on the subjects in this experiment may have had an important effect on how the lightest weight was lifted. But in general, from a simple consideration of the physics of the situation, one would expect more variability in the accelerations of lighter weights, and less in the acceleration of heavier. These parameters, whatever they are, can in principle be easily

established by further observation and the methodology described in this paper.

While the hypothesized consistency between Ss has had to be rejected in the face of the reliable individual differences reported, the similarity of the distributions of the maximum accelerations of the four heaviest weights (the three from this experiment plus the small can from Davis & Roberts, 1973), their relative compactness, and the concentration of values at the modes, constitute, in my opinion, a sufficient experimental confirmation of the hypothesized consistency with which objects of varying sorts are lifted. And this consistency, it seems to me, is merely a reflection of the greater co-ordination that characterizes the movements of all animals.

Appendix 1. Some reflexions on Table 2.

Any experiment involving lifting is profoundly and subtly influenced by the mechanics of the lift, i.e., by the experimental situation itself. For instance, in the analysis of the maximum heights, the main effect for objects was extremely insignificant. This was probably due solely to the physical set-up of the lift: each S tended to lift each object through the entire range allowed: the short arc formed by the flexion of the wrist. It is, therefore, impossible to say whether differences would emerge if Ss were given more physical freedom of movement.

Likewise, the absolute values of the velocities, accelerations, and decelerations would no doubt vary depending on whether the objects were lifted by wrist flexion, elbow flexion, or by some larger movement involving the torso or the legs. However, the consistency of those values would, presumably, persist.

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