The Consistent Acceleration of Lifted Objects: Implications for Kinesthetic Illusions and the Perception of Weight

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published in
Journal of Motor Behavior
1978, Vol. **10** No. 4, 287-293.

Abstract

In examining films of lifting movements in a study of the size-weight illusion (Davis & Roberts, 1976), a consistency was noted in the values obtained for the maximum accelerations of the objects lifted. While at first surprising, this finding can be embedded significantly in theories relating to kinesthetic illusions and the perception of weight and to theories on the control of general physical movement. This study was designed to confirm its existence. Twenty-four subjects were filmed lifting four objects differing in size, shape, substance, color, and weight. The film was analyzed frame-by-frame and the data were subjected to a two-way analysis of variance. Subjects, 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 due to the experimental task itself.

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. 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. Davis and Roberts (1976) demonstrated these differences more precisely, especially as they related to the accelerations applied to the objects. In a subsequent study, changing the velocity of the lift caused the judgment of weight itself to be altered (Davis, Taylor, & Brickett, 1977).

In examining the physical characteristics of the lifts, we found extremely marked individual differences in height, duration, and mean velocity; but maximum accelerations demonstrated only a (comparatively) modest variability, and no statistically reliable individual differences. In terms of the maximum acceleration, everyone lifted the same objects in nearly the same way.

This consistency, which was surprising at first, seemed on reflection more natural. It is an everyday observation that people (and other animals) are quite skilled at estimating the amount of muscular effort needed to perform any certain action: that they are, in other words, graceful. This is true not only of the adults of any species (who of course have a long history of practice), but also of the young, who develop this skill about the time they begin to move about their environment (Held & Bauer, 1967). 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 (Apgar, Girdany, Mclntosh, & Taylor, 1955; Pasamanick, Knoblock, & Lilienfeld, 1955; Windle, 1963, 1969).

It seemed also that being well coordinated (of which reaching and lifting are facets) is doubtless an innate ability, in Bowlby's (1974) sense of being environmentally stable. It is also, clearly, an ability organized into an hierarchical system (see the discussion in Bowlby, 1974). 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 (Miller, Galanter, & Pribam, 1960). There are some obvious feedback elements in this system (the joint receptors, tendon organs, and muscle spindles, for example), whose sensory input of position or effort modifies on-going muscular activities (Milner, 1970). 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; walking is corrected with reference to the normal gait (the Platonic Form) as well as to the intended destination (the Aristotelian telos). These are controlled by sub-plans and plans, in the terminology of Miller et al. (1960).

The initial muscular effort exerted at the beginning of any action (and the over-all coordination of the entire action) is affected not only by our past experiences (and implicitly by our genetic make-up, which influences how easily 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 neuromuscular system which allows us to move normally in the world and whose misfunctions account for some of the common illusions of weight that we experience. As such, it seemed worthwhile to examine this consistency more closely, to see whether or not there were, indeed, no statistically reliable differences among individuals or among 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 (Huang, 1945; Karube & Tanaka, 1964; Seashore, 1899; Wolfe, 1898); factors which affect the perception of weight also presumably affect the way in which the objects are lifted physically.] Two of the objects were cylindrical half-pint and quart cans, painted white. The small can weighed 486 g, and the large can weighed 705 g, which a pilot study had indicated was sufficient to prevent the occurrence of the size-weight illusion. The third and fourth objects were rectangular solid blocks of unfinished pine, 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 g 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 subjects did not have to raise or lower their hands to grasp the objects, even though they varied in size. The subjects also wore plexiglass guides affixed to the second phalanges of the second and fourth digits of the right hand. These guides had slots into which the wire handles fitted. The subjects' forearms were restrained to prevent lifting by elbow flexion. These precautions 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 counterbalanced order by the experimenter, who set them on a small revolving table in front of the seated subject.

The beginning of the lift was indicated to the subject by a warning light followed 2 sec later by a lift light; these lights were placed directly in front of the subject at a distance of 1 m. The camera (an electrically-driven 16-mm Bolex with a reflex lens) began filming when the warning light came on; it was placed on the subjects' right, perpendicular to the plane of the lift, at a distance of 2 m. After each lift, each subject gave an estimate of the absolute weight of the object in grams (this was intended as a precautionary measure, to insure that the subjects attended to the task of lifting). This was repeated until each subject had lifted each object twice. Only the second set of four lifts was analyzed, the first set constituting a practice trial. The film was developed and projected, and the height of the object measured in each frame (which occupied 1/24th of a second). Velocities and accelerations were then calculated from these data.

Subjects. Twenty-four university students, aged between 18 and 30 yr, were subjects. 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 answered.

Results

The frequency distribution of the maximum acceleration values for each object lifted is shown in Figure 1. It is readily apparent that the distributions for the three heaviest objects were very similar, and that they reflected a generally slower rate of lift than that of the lightest object (the small block). The shape of this frequency distribution is unusual, indicating that the small block was lifted in an atypical manner. It appears that this was the result of the experimental instructions to judge the weight of each object, which resulted in approximately equal forces being applied to all the lifts. This tendency also affected the lifts of the heaviest weight, as well as the lightest, making its frequency distribution a little more compact, although not significantly so. These issues are discussed more fully in the next section, and form the justification for treating the small block separately in our analyses of the data.

A two-way analysis of variance (24 subjects x four objects) was applied to the maximum-acceleration data. The results revealed significant effects for both subjects [$F(23,69) = 3.55$, $p < .001$] and objects [$F(3,69) = 7.03$, $p < .001$]. However, when the data for the lightest object were omitted, the significant object effect disappeared, $F(2,46) = .93$, $p = .57$, confirming the consistency in lifting previously noted.

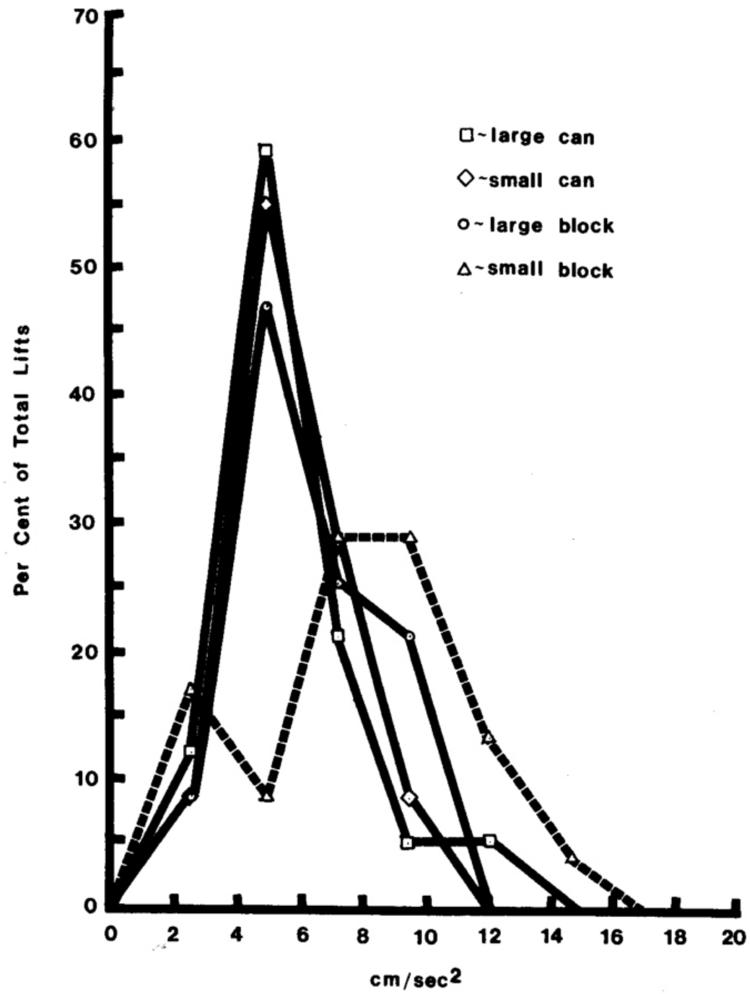

Figure 1. Frequency distributions of maximum acceleration values for the four objects.

Four other lift characteristics were also computed, and the data were subjected to similar analyses. Significant effects of objects were found for mean and maximum velocity [$F(3,69) = 3.14$, $p < .05$; $F(3,69) = 5.40$, $p < .005$, respectively]. But again these disappeared when the data for the small block were omitted, $F(2,46) = .74$, $p = .51$; $F(2,46) = .33$, $p > .50$. No significant effects of objects were found for measures of maximum height [$F(3,69) = .15$, $p > .50$] or maximum deceleration [$F(3,69) = .77$, $p > .50$]. Finally, all measures yielded a significant variation due to subject differences except maximum deceleration for the three heaviest objects, $F(23,46) = 1.65$, $p < .10$].

The consistency of lifting behavior is strikingly demonstrated in Figure 2, which shows almost identical maximum acceleration distributions of the pooled data for the three heaviest objects in the present study and of the values obtained by Davis and Roberts (1976) for their small can of 500 g. [This, incidentally, confirms Martin and Muller's (1899) intuition that it is the larger can in the size-weight illusion that is lifted abnormally, and thus is the source of the illusion.]

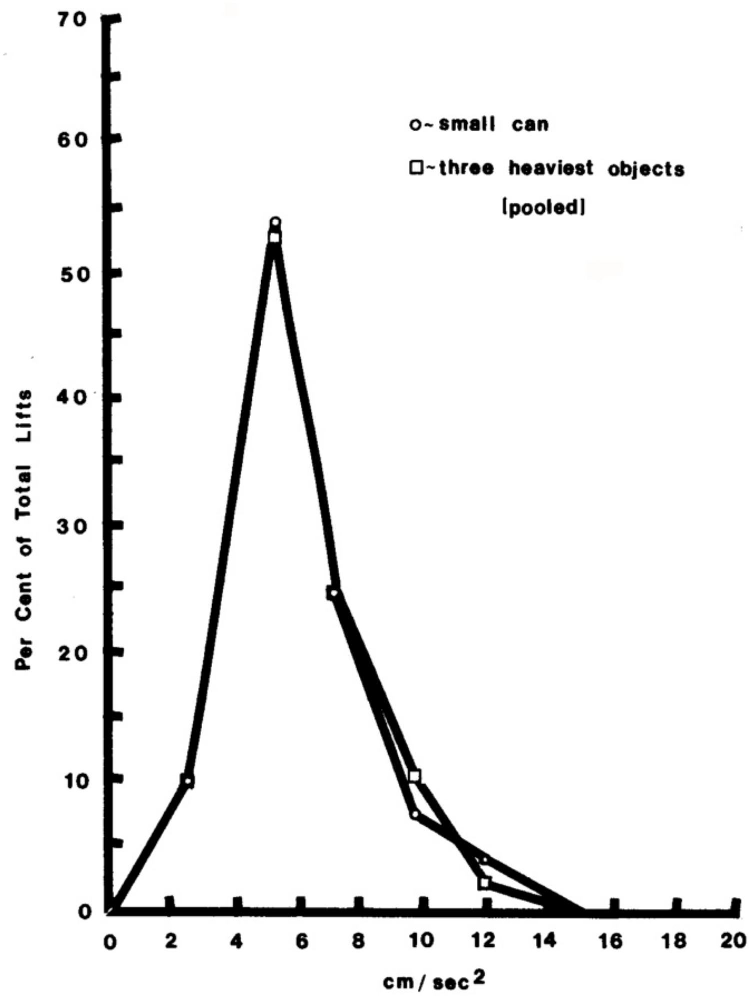

Figure 2. Frequency distributions of the pooled maximum acceleration values for the three heaviest objects and for the small can in Davis and Roberts (1976).

The data from both Davis and Roberts (1976) and the present study support the hypothesis that different objects are lifted similarly. There remains the problem of the lightest object, the small block, which we will now consider in more detail.

Discussion

It appears from the electromyographic study of Payne and Davis (1940) that the muscular strategy used in determining relative weight is to apply approximately equal forces to the objects in question. The one that is hoisted more easily is judged to be lighter.

We had hoped in this study to avoid this by asking for judgments of absolute weight. However, we noticed in running the study that these judgments were not made independently. Most of our subjects were unused to the metric system (judgments were to be given in grams) and often seemed to treat it like a relative rating scale.

That our subjects had reverted to an “equal-force” strategy gained further confirmation from a physical analysis of the lifts. The force needed to reach the modal maximum acceleration of the small wooden block (2.4×10^2 dynes) closely matched the force needed to reach the modal maximum accelerations of the large wooden block and the small white can (2.3×10^2 dynes in each case). The force needed to reach the modal maximum acceleration of the heaviest object, of course, was considerably more (3.4×10^2 dynes).

A third, related, line of reasoning also indicated that an equal-force strategy had been used. Initial muscular force (the “set-to-lift”) is corrected in the course of the lift by feedback from the muscles (see the Introduction). For a heavy object lifted with too-little initial force, maximum acceleration tends to occur later in the lift, as the muscle "gears up" to the task in hand. Likewise, for a light object lifted with too-much initial force, the maximum acceleration occurs earlier in the lift, followed by a reduction in applied force as the muscles readjust to the actual conditions of the lift (Davis & Roberts, 1976).

In the former case, the maximum acceleration reached is not itself necessarily affected by the initial set-to-lift, merely displaced in time. Therefore the force used to accelerate the heaviest object to its maximum would not be expected to match the force applied to the other objects. (Indeed, it is the point of this paper that that force is variable, while it is the maximum acceleration that shows a relative stability.)

In the second case, however, the value of the maximum acceleration is not only displaced in time, tending to occur earlier in the lift, but is also more likely to be greater than usual. This follows from Newton's Second Law. The lighter the mass, the greater the acceleration produced by a given force.

When we examined our data, we found that these time shifts had indeed occurred. We determined the number of lifts with maximum accelerations occurring during the first and second 1/8 sec of the lift (83.3% of the maxima fell into one or the other of these two periods) and during a third period constituting the remainder of the lift. Across these three divisions, we found significant differences in the directions predicted, $\chi^2(2) = 10.3$, $p < .01$. For the lightest object (the small wooden block), maximum accelerations tended to occur early in the lift (62.5% in the first 1/8 sec, as opposed to 20.8% for the heaviest object), while for the heaviest object they tended to occur later (29.2% after the first ¼ sec, as opposed to 4.2% for the lightest object).

So it appears that an unwanted set-to-lift occurred as an artefact of the experimental task. This unwanted set-to-lift caused, we think, the unusual distribution of maximum accelerations found in the lightest object. The small block, by virtue of its lightness, is the most sensitive to any variations in effort, and most susceptible to greater acceleration from a standard force.

While the hypothesized consistency among subjects has had to be rejected in the face of the reliable individual differences reported [for maximum acceleration specifically, $F(23,46) = 1.90$, $p < .05$], this statistical significance itself, plus the relative compactness of the distributions and the concentration of values at the modes, as illustrated in Figure 2, suggest that within-subject variance may be relatively modest; i.e., the subjects may be lifting consistently within themselves, if not with each other.

More importantly, what the near-congruence of the distributions does confirm is a similarity in a physical aspect of the lift despite physical differences in the objects themselves. And this, it seems, is merely a reflection of the greater coordination that characterizes the movements of all animals.

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