35885

NAME OF AUTHOR/*NOM DE L'AUTEUR* Paul Brickett

TITLE OF THESIS/*TITRE DE LA THÈSE* Muscle Activity and Lifting Movements in the Size-Weight Illusion

UNIVERSITY/*UNIVERSITÉ* Simon Fraser U.

DEGREE FOR WHICH THESIS WAS PRESENTED/ *GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* M.A

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1977

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* Dr. Christopher M. Davis

Permission is hereby granted to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

L'autorisation est, par la présente, accordée à la BIBLIOTHÈQUE NATIONALE DU CANADA de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans l'autorisation écrite de l'auteur.

DATED/*DATÉ* 2 Aug. 1977 SIGNED/*SIGNÉ*

PERMANENT ADDRESS/*RÉSIDENCE FIXÉ* [redacted]

NL-91 (3-74)

MUSCLE ACTIVITY AND LIFTING MOVEMENTS IN THE SIZE-WEIGHT ILLUSION

by

Paul A. Brickett

B.Sc., University of Illinois, 1973

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
IN THE DEPARTMENT
OF
PSYCHOLOGY

SIMON FRASER UNIVERSITY
July 1976

APPROVAL

Name: Paul Alan Brickett

Degree: Master of Arts

Title of Thesis: Muscle Activity and Lifting Movements in the Size-Weight Illusion

Examining Committee:

Chairman: L. Kendall

C. M. Davis
Senior Supervisor

H. Weinberg

A. R. Blackman

A. Chapman
External Examiner
Assistant Professor
Simon Fraser University

Date Approved: 29 July 1977

PARTIAL COPYRIGHT LICENSE

Title of Thesis/Dissertation:

Muscle Activity and Lifting Movements
in the Size-Weight Illusion

Author:

(signature)

Paul Brickett

(name)

Aug 3, 1977

(date)

ABSTRACT

The size-weight illusion, the persistent tendency for larger objects to be perceived as lighter than smaller objects of the same weight, has been found to be related to the manner in which objects are lifted. The present study was designed to investigate lifting movements and preparatory muscular activity in relation to perceived weight.

Fourteen subjects lifted large and small cans by their handles using wrist flexion movements and made direct estimates of the weight of each can. The myoelectric activity of the forearm flexor and extensor muscles was recorded along with vertical displacement of the can during each lift.

Results confirmed the finding that cans judged as lighter were lifted with greater acceleration and velocity. Myoelectric recordings revealed that muscle activity occurring prior to the lift was significantly related to weight judgement. This preparatory muscular activity is interpreted in relation to the mechanical aspects of the lifting task.

The results of this study and other research are discussed with respect to the motor theory of weight perception and the specific assertion that for objectively equal weights, perceived lightness is directly related to increased muscular activity.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The idea that perception is characteristically an active, exploratory process is exemplified by the act of lifting an object for the purpose of perceiving its weight. "Heaviness," the subjective impression corresponding to the physical property of weight, is primarily an interpretation of the afferent information derived from a variety of exteroceptive and proprioceptive sensory mechanisms responding to the performance of lifting.

However, much of the published research on heaviness has neglected the lifting process and concentrated instead on either: 1) psychophysical scaling, the relationship of stimulus magnitude and intensity of sensation, or 2) psychophysical methodology, or else 3) the curious phenomenon of the size-weight illusion. The two leading individuals in the history of psychophysics, Fechner and Stevens, have each made contributions to the psychophysics of weight perception. Fechner (1860/1966), following Weber, performed numerous experiments with lifted weights as part of his development of the classic psychophysical methods and his logarithmic psychophysical law. Stevens, although most of his research concerned visual or auditory perception, has utilized his method of direct magnitude estimation and his power law in investigations of weight perception (Stevens & Galanter, 1957; Stevens, 1974).

Fechner's law and Stevens' law both state that heaviness can be equated with an algebraic function of weight. Research on the third topic mentioned above has clearly shown that the perceived weight of an object is also a function of another physical property of the object, size. The size-weight illusion (SWI) refers to the fact that a pound of lead is heavier (in the meaning used here) than a pound of feathers. Charpentier in 1891 was the first to demonstrate that the larger of two equal weights is consistently judged as lighter. An equivalent statement of this finding is that the denser object is perceived as heavier.

Theories of the SWI

This last consideration has led to the "density theory" of the SWI (Huang, 1945a), which states that a judgement of heaviness is based, in part, on a judgement of density. This explanation is consistent with Woodworth's (1938) "confusion theory" of illusions and the idea that an observer's evaluation of a particular stimulus dimension is involuntarily influenced by other salient features of the total stimulus context. Koseleff (1958) performed a phenomenological investigation of density. A typical example of his findings is the report of one of his subjects after encountering the SWI: "The smaller box appears more dynamic, more condensed. It has greater strength, it strikes harder. The experience of heaviness is more intense" (p. 71).

Huang (1945b) studied the perception of density with more rigorous psychophysical methods. He found that subjects could make reliable judgements of density for objects of varying weight. This result led him to suggest "the possibility that the perception of density, like that of weight, is one of the fundamental and immediate psycho-physical functions of the organism" (p. 82).

In the same paper, Huang, anteceding Whorf, notes: "In some Chinese dialects, there are different expressions for "heaviness" corresponding to the distinction between weight and density" (p. 81).

The idea that heaviness is based on a combination of weight and density led Thouless (1931b) to cite the SWI as an example of his "law of phenomenal compromise" which states that if two perceptual cues conflict, the resulting experience is a compromise between them.

Thouless (1931b) proposed one of the earliest psychophysical models of the SWI with the application of his formula for "phenomenal regression to the real object" (1931a) to weight judgement data, and the calculation of an index of the degree to which heaviness is influenced by density. Thouless' formula is similar to the one developed by Brunswik in 1928 (cited in Tolman, 1935) and which is currently referred to as Brunswik's ratio (Rock, 1975).

Relatively recent psychophysical studies have proposed various increasingly sophisticated models to account for heaviness in terms of density. Karube and Tanaka (1964) had their subjects judge the size of stimulus objects independent of the weight judgement task. Heaviness was formulated as a power function of the ratio of objective weight and subjective size. These investigators then made a commendable attempt to cross-validate their equation by predicting perceived weight for a variety of different common objects (book, pebble, etc.) on the basis of perceived size. The results, however, were only fair.

The necessity of the distinction between perceived size and objective size (volume) has been emphasized by Koseleff (1957). In one experiment a small object held in the hand was viewed either directly or through a convex or concave lense.

The perceived weight was less for the magnified object and greater for the minified object. Another ingenious experiment used a pair of three-dimensional Müller-Lyer figures to manipulate perceived size, resulting in a similar influence on heaviness.

Other studies in psychophysical scaling have avoided large variations in perceived size by restricting the stimulus objects used to standard laboratory weights. Sjöberg (1969) assumed that heaviness and perceived size could be described as power functions of the corresponding physical properties when other factors were held constant. He formulated heaviness for objects of varying size as proportional to the ratio of power functions for weight and size. Anderson (1970) suggested an averaging model in which heaviness equals a weighted average of a positive function of weight and a negative function of size. J. C. Stevens and Rubin (1970) related magnitude estimates of heaviness to a family of power curves for which the exponent increases with volume. These authors also made the interesting observation that the power curves they found, when extrapolated, seemed to converge at a point corresponding to the heaviest weight that could be lifted under the conditions used. In their experiment each weight was lifted by a wooden knob attached to the top of the object. The authors report that some subjects had difficulty lifting the maximum weight of 6.4 kg, and that the point of convergence of the power functions was just greater than this at 8-9 kg.

A study by Cross and Rotkin (1975) was designed to investigate this finding. Their stimuli were similar to the objects used by J. C. Stevens and Rubin, but subjects were allowed to use both hands to grasp the weights. In this case, the family of power curves found converged at 18 kg, about twice the value J. C. Stevens and Rubin found for one-handed lifts.

The converging power functions found in both of these studies also indicate that there is a reduction in the SWI for heavier objects. In opposition to this, a study by Birnbaum and Veit (1974) reported that the SWI was increased for heavier weights. However, in this experiment much lighter weights were used (50-400 gm), and the subjects gave category scale ratings of the difference in heaviness of two objects lifted simultaneously with both hands. Category scales have been found to yield characteristically different results when compared to magnitude estimations (S. S. Stevens & Galanter, 1957).

Another problem with the converging power curves model is that it predicts a decrease in the SWI for light weights when the point of convergence is lowered. As Cross and Rotkin point out, women and children should exhibit the SWI to a lesser degree because in general, they cannot lift as heavy weights as men can. Experimental findings show the contrary, that the SWI is greater for women (Wolfe, 1898) and children (Scripture, 1895; Robinson, 1964).

Additional evidence that the SWI cannot be explained solely in terms of density has arisen from further implications of the assumption that additional stimulus cues are used in the judgement of weights. Thouless (1931b), in his work discussed above, considered the logical possibility that size might also act as a direct cue for heaviness, in which case phenomenal compromise would tend to make larger objects seem heavier. Thouless regarded the SWI as evidence that density predominates over size in determining perceived weight. He went on to suggest that although size, weight, and density cannot all be independently varied, experimentation with a wide range of weights and sizes might find critical values beyond which the SWI is reversed.

This suggestion was investigated in a study by Howard (1954). In his experiment a volume range of 6 cc to 8000 cc was covered with standard weights of density .15 gm/cc which were matched to variable weights of density 11.35 gm/cc (solid lead). The usual SWI occurred for the medium to heavy weights, but all nine subjects matched the 1.0 gm and 1.9 gm standards with heavier variable weights which illustrated a significant reversal of the SWI. Howard interpreted this reversal to be due to the inability of the subjects to discriminate the very light weights and thereby obtain any indication of density, in which case judgements were based on more obvious size cues.

A recent experimental investigation of the influence of visual cues other than size have posed more cogent objections to the density theory of weight judgement. Harshfield and DeHardt (1970) presented their subjects with cubes of identical size and weight, but different external composition (e.g. balsa wood, mahogany, steel). When the cubes were lifted, the apparently denser objects were ranked as lighter. One control group of subjects showed that a reversed ranking resulted when the objects were viewed but not touched. Another control group lifted the cubes blindfolded and ranked the objects about equally, demonstrating that tactile texture cues had little influence on judgements. This apparent-density illusion also offers a plausible explanation for the earlier finding that the color of objects affects weight judgement (De Camp, 1917). These results are inconsistent with the density theory because that theory predicts that, as in the SWI, there is some additive combination of weight and density cues and therefore an object with greater apparent density should be judged as heavier, the reverse of the actual findings.

A number of additional experiments, which will be discussed in another context, also point out the inadequacy of the density theory. It will suffice here to mention one other similar illusion first reported by Usnadze (1931), and referred to as the "volume illusion." When two spheres of equal size but different weight are held in the hands, the heavier is usually perceived as smaller. This is another example of contrasting effects of size and weight cues, rather than an additive combination. Usnadze (1931) performed another experiment relevent to other theoretical explanations of the SWI. In what he called the "pressure illusion," weights with equal bases but different heights were placed on the subject's resting hands. Under these conditions the usual SWI was found to occur.

As an explanation of these findings and the results of other experiments with completely different perceptual tasks, Usnadze theorized that the perceived difference between two stimulus objects creates a corresponding "Einstellung" or "mental set." Furthermore, this "Einstellung" generalizes to other stimulus dimensions of the compared objects. For the SWI, the "Einstellung" produced by the perceived difference of large vs. small generalizes to the dimension of heavy vs. light. The resulting contrast between the "Einstellung" and the actual sensations of weight cause the illusory judgement, according to Usnadze (1931; English summaries available in Huang, 1945a, and Bzhalava, 1958/1962).

As discussed by Huang (1945a), Usnadze's theory emphasizes that it is the perceived difference between two objects that is responsible for the formation of the "Einstellung" and from this the illusion, and so the theory would not predict an effect of size on perceived weight for a single object judged independently. Following Huang's suggestion for a test of this deduction, Ross (1969) had subjects match a visible weight to one blocked from view, both of them lifted by strings. Results showed that the SWI did indeed occur. Usnadze's "Einstellung," then, does not seem to be a necessary condition for the SWI.

The Motor Theory

In contrast to the previously discussed "central" theories (those which emphasize the processing of sensory information at the highest levels of the nervous system), the importance of the efferent activity corresponding to the execution of lifting is stressed in what will be referred to here as the "motor" theory of weight perception (Müller & Schumann, 1889). Martin and Müller (1899) proposed that the SWI occurs because an individual has learned from life's experience that there is a positive correlation between size and weight, and due to this "Einstellung" he lifts larger objects with greater exertion, and when the object rises up in the air faster (surprise!), it is felt to be lighter.

This theory emphasizes the influence on judgement of the kinesthetic sensations which arise during the lift, rather than the "sensations of innervation" associated with the muscular exertion. Müller and Schumann thought the "Einstellung" to be unconscious, and did not consider the motor theory to support the idea of "sensations of innervation" (Boring, 1942).

It should be noted that although both Müller and Usnadze used the same term "Einstellung," the German word has a very broad definition. Usnadze (1931) distinguishes his concept of a temporary mental set induced by stimulus differences from what he refers to as the "motorische Einstellung" of Müller and Schumann.

Although the motor theory is referred to as the "classical theory" of the SWI (Huang, 1945a), subsequent research on lifting movements and the associated muscular activity related to the SWI has been both infrequent and inconsistent.

Loomis (1907) took kymographic records of the movements executed in the simultaneous lifting of two boxes with both arms. He reported that the larger object was lifted faster on the first trial, but not on subsequent trials, although the SWI continued to occur.

In an often quoted study, Payne and R. C. Davis (1940) recorded electromyograms (EMGs) as a measure of the activity in the lifting muscles during a weight comparison task which did not involve the SWI. One subject repeatedly lifted a single standard weight followed by a variable weight. When the EMGs recorded during pairs of lifts for individual variable weights were grouped on the basis of judgement, it was found that a judgement of "heavier" for the variable weight was related to greater muscle activity during the variable lift and less activity during the preceding standard lift. This is not what would be predicted from the motor theory of the SWI.

One problem for interpreting these results is the possible confounding effects of time error due to both the influence of the standard lift on the variable lift and also that of the previous variable lift acting on the next standard lift.

Time error, originally investigated by Fechner (1860/1966), can have a major effect on the SWI. In a study by Werber and King (1962), subjects lifted a standard cylinder followed by a taller comparison cylinder of equal weight, with the result that 37 out of 72 subjects judged the larger object as heavier, an unusual failure of the SWI.

The relationship of time error to muscle activity in a weight comparison task was investigated by Freeman and Sharp (1941). They found that when the second lift followed the first by a short interval (4 sec) there was increased muscle tension and a preponderance of "lighter" judgements (positive time-error), while a longer interval (8-30 sec) produced smaller EMGs and also "heavier" judgements (the more common negative time-error). / The "muscular fading trace" found by these researchers, if considered as a direct measure of "Einstellung," affects weight judgements in a manner consistent with the motor theory. Although referred to as "time error," the reliable effect of the time interval between paired-comparison lifts could just as well be considered as the "time-weight illusion."

A number of additional weight illusions have been demonstrated by some recent research directed at the motor theory. In a series of experiments performed by McClosky (1974), subjects matched the weights of two beakers grasped simultaneously with each hand. The first experiment used wide and narrow beakers, and the usual SWI was evident. The following two experiments used two different methods to increase the inward force required to grasp one of the otherwise identical beakers. When elastic bands attached to a wire frame around the beaker opposed closure of the fingers, the beaker felt lighter. In the third experiment, a coating of petroleum jelly made the beaker slippery and produced a similar effect on judgement.

Another illusion resulting from experimental manipulation of lifting movements has been demonstrated by C. M. Davis, Taylor, and Brickett (1977). Subjects were instructed to lift identical cans either "gently" or "vigorously." Paired-comparison judgements revealed that cans lifted vigorously felt lighter. The explanation proposed for these illusions, consistent with the motor theory, is that an experimentally-induced increase in the activity of the muscles effecting the lift produces a decrease in perceived heaviness.

Other recent research has investigated the lifting movements and muscular activity coincident with the occurrence of the SWI. C. M. Davis and Roberts (1976) filmed their subjects lifting large and small cans in a paired-comparison task. The experience of the illusion was related to greater peak velocity and acceleration for the large can, as predicted by the motor theory.

The role of muscular activity in the SWI has been investigated directly for both lifted objects and also isometrically supported weights. With regard to the latter condition, it should be recalled here that Usnadze (1931) cited his demonstration of what he called the "pressure illusion" as an argument against Muller and Schumann's motor theory because lifting was not required for the experience of this illusion. Bzhalva (1958/1962) has recorded EMGs from the forearms of subjects while they supported two equal weights of different size and found that the EMG level was greater in the arm supporting the larger object. Although the interpretation provided by this author was based on Usnadze's "central set" theory, these results are also consistent with the motor theory.

Emg activity during active lifting was studied by Jarrard (1960). At the beginning of the experiment subjects lifted large and small 1 kg blocks in a task designed to let them experience the SWI. In the main part of the experiment a block was repeatedly lifted by means of a cord attached to the subject's middle finger. Subjects were instructed to lift the block as many times as possible, for four separated series of lifts. One group of subjects lifted first the small block, then changed to the large block. The other group had the reverse order. Compared to two control groups which used identical blocks in each series, the group that was switched from the large to the small block made fewer lifts before exhaustion and also produced greater EMGs while lifting the small block. The complimentary effect was found for the group switched from small to large. These results would not be predicted from the motor theory, but are difficult to interpret because of the large fatigue effects present. Fatigue has been found to increase the "sense of effort" for isotonic contractions (McClosky, Ebeling, & Goodwin, 1974) and might interact with the SWI in some unknown way.

The final study to be discussed is the basis for the present research. C. M. Davis and Brickett (in press) had subjects lift large and small cans by wrist flexion following "ready" and "lift" signal lights. Forearm-flexor EMG was recorded with respect to these signals. For those paired-comparison trials showing the SWI, the EMG activity before the "ready" signal for the second lift compared to the EMG level just after the "lift" signal of the first lift was significantly different for small-large and large-small pairings, in the direction predicted by the motor theory.

Design Considerations for the Present Research

One feature of the paired-comparison method is that each judgement reflects the combined perceptions obtained for two lifts, together with confounding factors such as time error. The results of the previous study did in fact show a sizable time-error effect on EMG amplitudes. Other research has found that time error in comparative weight judgements cannot be eliminated by a simple combination of the results obtained from two presentation orders (Woodruff, Jennings, & Rico, 1975). Alternatively, the psychophysical method of direct magnitude estimation could be used to obtain a separate judgement of heaviness for each lift. Cross and Rotkin (1975) investigated "time error" for magnitude estimations of lifted weights (the degree to which one estimate is influenced by the preceding estimate) and found no effect when the judged objects varied in volume but were of equal objective weight.

Another consideration in regard to the previous study is the use of imperative stimuli, "ready" and "lift" lights, which to some extent make lifting a reaction time task and itself contributes to muscle activity (R. C. Davis, 1940). "Ready" and "lift" signals were also used by C. M. Davis and Roberts (1976) in their study of lifting movements in the SWI. It is not known what effects these signals might have on lifting movements. In everyday life however, weight perception is rarely the objective of a reaction time task. Experimental findings of greater generalizability might be obtained by eliminating such imperative signals.

The present study has attempted to incorporate these considerations into the experimental method described below. In this experiment no imperative signals are used; subjects perform voluntary lifts and make a direct weight estimate for each object (cf. Fries & Holmberg, 1968). Furthermore, in contrast to previous studies, in this investigation both EMG activity and the corresponding lifting movements are recorded for each lift. It is hoped that by this means a quantitative evaluation of lifting movements and particularly the accelerative forces involved in lifting will allow a more meaningful interpretation of preparatory muscle activity. Finally, with consideration to the biomechanical complexity of even such a relatively simple lifting movement as the wrist flexion used in this experiment, it is deemed important to record EMGs derived from both the agonist effector muscles (the forearm flexors) and the antagonists (the forearm extensors). The following study was conducted to investigate the relationship of these peripheral responses to perceived weight in the SWI.

METHOD

Apparatus and Data Recording Specifications

The experiment was conducted in an electrically shielded room connected to an adjoining control room by a partially silvered window. The subject's chair had a modified right arm rest with a flat, padded surface. The test stimuli were four large and four small white paint cans, each of which weighed 500 gms. The large cans were 10.6 cm in diameter and 14.6 cm high (1290 cc in volume and .26 gm/cc in density), and the small cans were 7.4 cm by 8.0 cm (344 cc and 1.45 gm/cc). All cans were fixed with identical rigid wire handles 10 cm in width and extending 20.5 cm above the base of the can. An unmodified brass balance weight with "500 gm" stamped on it was used as the standard stimulus.

A Hewlet-Packard 2116B computer with a 10-bit multiplexed analog-to-digital converter, CRT display, and magnetic tape storage was used on-line for data collection and control. The computer was triggered for data acquisition by the lifting-movement transducer built into the small table from which the cans were lifted. A permanent magnet in a funnel-shaped plastic encapsulation was positioned over a hole in the metal plate on the top of the table. When a stimulus can containing another magnet was placed on the table this device firmly attached itself to the recessed bottom of the can and was pulled up through the hole for the extent of the lift. A wire leading out the lower part of this device was connected to circuitry that triggered the computer at the beginning of a lift when the rim on the base of the can broke electrical contact with the metal plate.

Lifting movements were transduced by means of a length of low-stretch dial cord which ran from the bottom of the magnetic device straight down under the table, around a pulley on the shaft of a potentiometer and terminated with a 20 gm lead weight. The potentiometer, a 10-turn Amphenol precision Micropot, had a manufacturer's specification for linearity tolerance of .25% and was individually selected for low turning-torque. The tangential force required on the 5.0 cm circumference nylon pulley to overcome friction in the pot was measured to be equivalent to 5 gms. The magnetic device, with the lead counter-weight, weighed a total of 57 gms. Therefore, for each lift the equivalent mass added to the 500 gm can was an estimated 62 gms. The output voltage of the potentiometer corresponding to the vertical displacement of the can was sampled by the computer during the course of each lift to produce the lifting-movement record.

Two channels of EMG were amplified with Grass model 7P5 ac preamplifiers and model 7 driver amplifiers set for a minimum half-amplitude frequency bandpass of 10-500 Hz. The gain of the amplifiers was adjusted at the beginning of each recording session for a level that would just accomodate the maximum EMG amplitude produced during the practice lifts.

The computer software for data acquisition and control was developed by Howard Gabert, P. Eng. The program named NT00 (for "negative time") continously stored digitized data in a circulating buffer in memory and thereby allowed the sampling epoch for each trial to start at some fixed time before the occurrence of a trigger signal. A total of 1024 points per channel were collected for each trial. Data were sampled over a 2.25 sec epoch which included .8 sec prior to the lift trigger signal and 1.45 sec during the course of the lift.

Immediately following each trial the acquired data were displayed on a large (8x10 in.) CRT, and then stored on digital magnetic tape.

Subjects

Fourteen male and female university students participated in this study and were paid for their services. All subjects were initially unfamiliar with the SWI.

Procedure

Each subject participated in two sessions on different days. The first day was a practice session intended to familiarize the subject with the weight estimation task and did not include EMG recording. Except for this and a fewer number of trials in the practice session, the instructions, stimuli, and procedures were the same for both days.

EMGs were recorded from four Beckman surface electrodes affixed to the subject's right forearm at the standard flexor and extensor locations (J. F. Davis, 1959). The subjects's forearm was positioned palm-up on the arm of the chair and restrained at the wrist with adhesive tape. Polystyrene blocks, grooved to fit the handles of the cans, were attached to the palmar surface of the subject's first and third fingers over the middle phalanges.

Subjects were instructed to keep their forearm horizontal, their palm and fingers straight, and to lift each can by wrist flexion only. Furthermore, each lift was to be a smooth up-and-down motion and the can was not to be "dandled."

The subject was asked to make a number of practice lifts until the experimenter determined that the subject was following the lifting instructions consistently. The subject was also instructed that at the beginning of each trial when the experimenter placed a new can on the lifting platform the subject was to raise his or her hand so that the polystyrene blocks just made contact with the can handle, but was not to exert any force on the can until the experimenter said "go ahead." Immediately after each lift the subject was to give an estimate, in grams, of the weight of the can. Also, each estimate was to be an independent judgement.

At this point before the first trial, a 500 gm balance weight was placed in the subject's hand for approximately 30 secs. The subject was told that this standard weighed exactly 500 gms, and that all the cans to be judged "weigh something in the neighborhood of 500 gms."

For each one of the following trials, the experimenter selected one of the eight cans from a box out of the subject's view and placed it on the lifting table. When the experimenter was assured that the subject's hand was in position and that the computer was ready to accept data, the experimenter gave the "go ahead" signal. After the subject lifted the can and made a weight judgement the experimenter recorded the judgement, briefly inspected the digitized data displayed on the CRT in the adjoining room, and exchanged cans for the next trial.

Large and small cans were lifted alternately with an interval of approximately 20 secs between each lift. The subject was given a short break at least once during the session and also whenever exhibiting signs of fatigue. A maximum of 100 trials constituted one session.

Initial Data Treatment

The digitized data for each trial included two channels of raw EMG, the lift displacement record, and also a marker channel encoded with the computer trigger signal which indicated the time the can was not in contact with the table. Initial processing of each EMG record consisted of full-wave rectification about a baseline determined by the mean of all 1024 data points.

The lift displacement records were used to compute estimates of velocity and acceleration for each lift. The vertical velocity and acceleration at each point on the displacement record were estimated by the first and second derivatives of a quadratic curve which was fit by least-squares to the 51 consecutive displacement values centered at that point. No estimates could be made for the first and last 25 points in each record, but these were sampled either before the lift began, or near the end of the lift. It was judged necessary to use for each curve-fit a total of 51 points, sampled over an interval of 112 msec, in order to achieve a reasonably smooth acceleration estimate.

A small percentage of the recorded trials were found to have been sampled prematurely due to a spurious computer trigger signal generated before the lift by a brief break in the electrical contact between the can and the metal plate on the lifting table. This artifact was probably caused by irregularities in the bottom rim of the can and by the subject "jiggling" the can just before lifting it. These trials could be easily recognized by the "noise" in the marker channel. A computer program automatically checked the marker channel on each trial and identified those with this artifact. Less than seven percent of all recorded trials were thus identified and rejected, leaving a total of 1270 trials for the 14 subjects.

RESULTS

Judgements

The weight estimates of all 14 subjects are shown in Figure 1. Each point plotted with a symbol represents a single judgement for one of the large or small cans lifted in alternating order over the duration of the session. Straight lines connect successive judgements for each size can. One result evident in these plots is that all subjects, to varying degrees, experienced the size-weight illusion; the average weight estimates for small cans were greater than those for large cans. An initial concern in this study was whether or not this "size effect" would be maintained over the duration of a session including 100 trials. As Figure 1 shows, there is little evidence of diminution of the size effect for repeated judgements of the same eight cans. This result confirms earlier pilot research which found that the size-weight illusion persistently affected the weight estimations of all three subjects who each made close to 400 judgements over four sessions.

Figure 1 also shows the great variability in weight judgements, both between and within subjects. The difference between the most extreme estimates given by individual

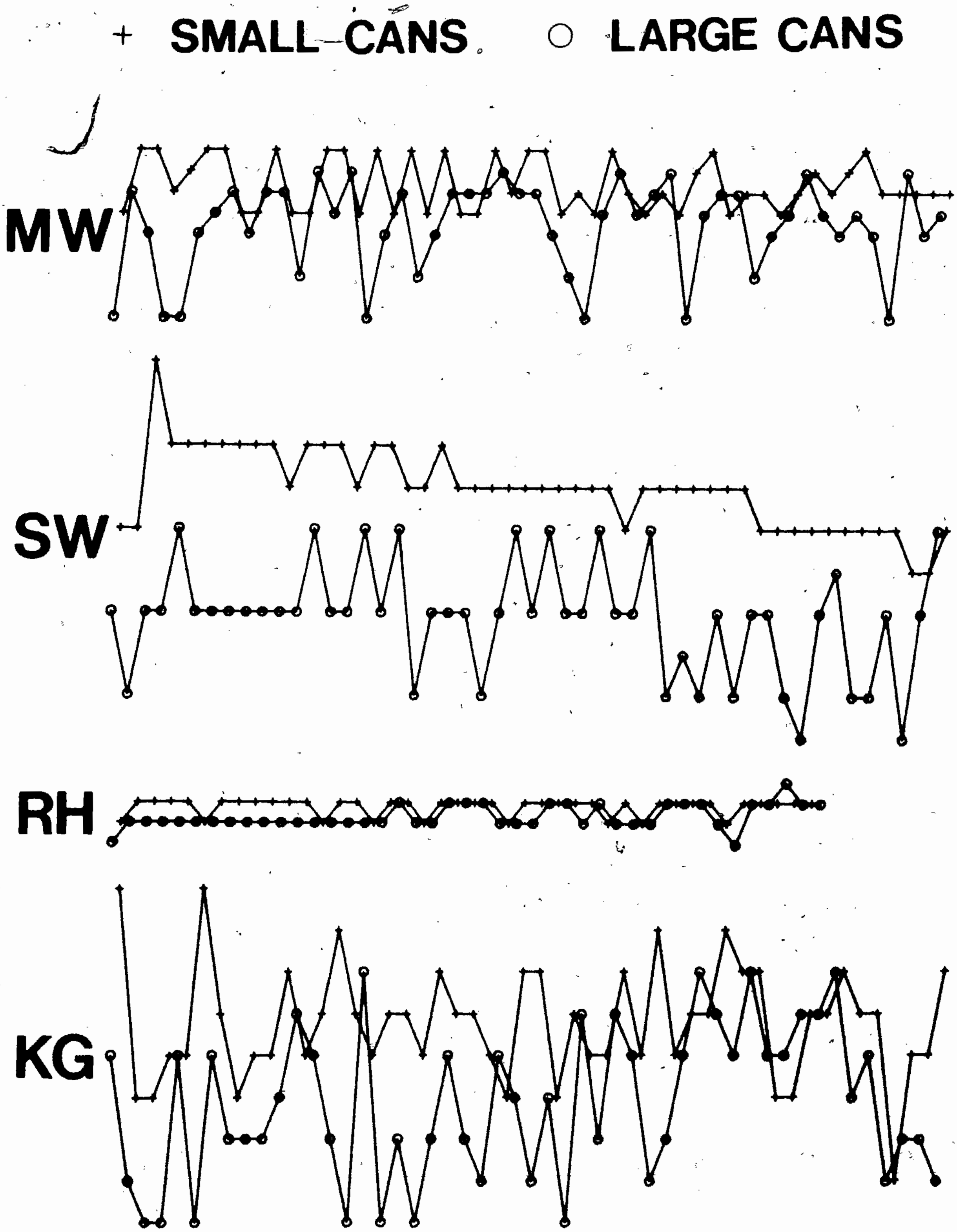
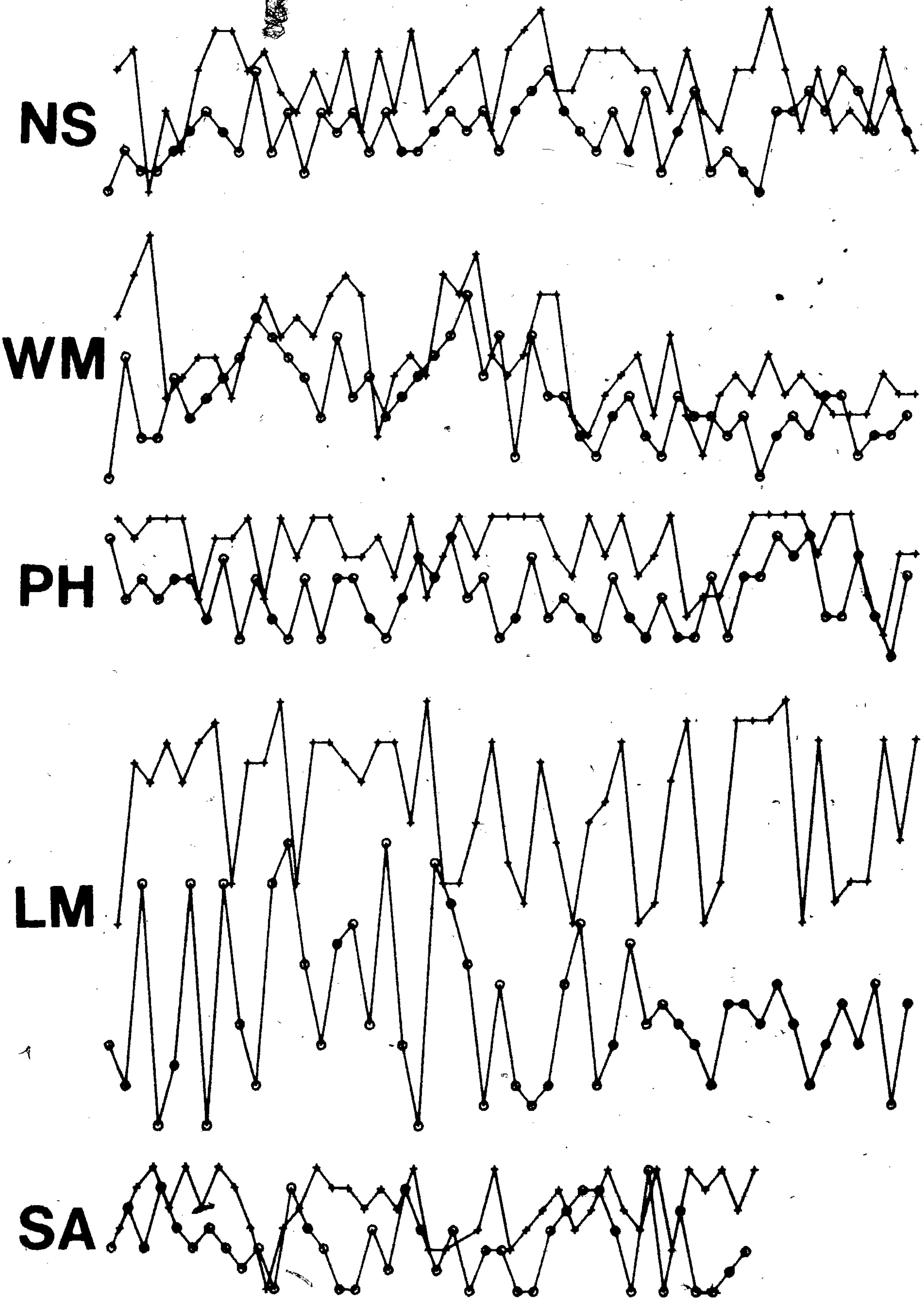
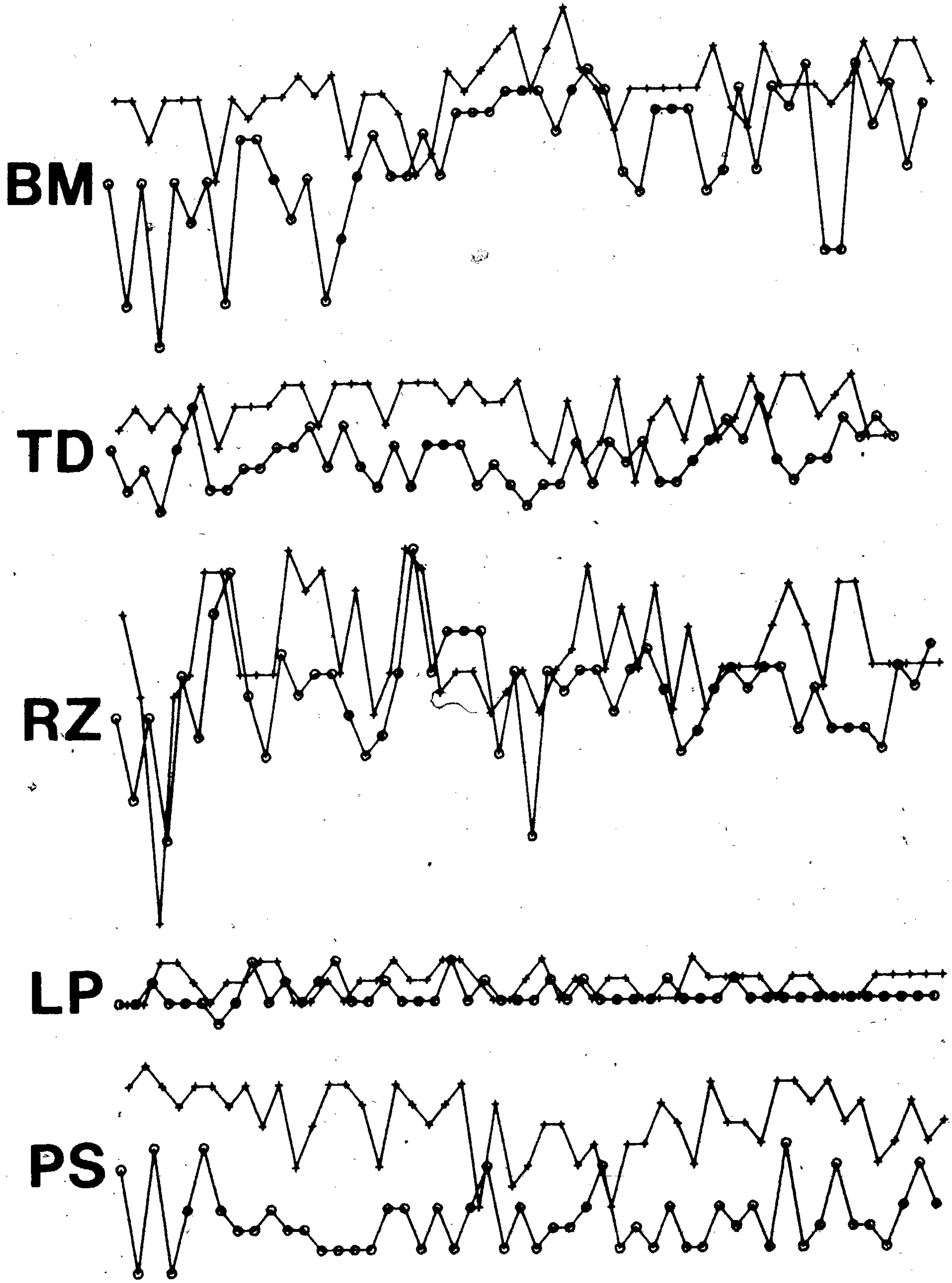


Figure 1. Relative weight estimations. Fourteen subjects.


NS
WM
PH
LM
SA


BM
TD
RZ
LP
PS

subjects ranged from 75 to 575 gms. Figure 1 does not show the absolute magnitude of the weight estimates because each plot has been re-adjusted to fit on the page. However, the mean weight estimate for all trials of different subjects varied from 275 to 570 gms. This was a sizable constant error considering that the weight of each can, plus the attached lift transducer, actually amounted to 562 gms. A post-hoc explanation of this result is that the small size of the standard weight (approximately 65cc) induced a SWI effect on the weight estimates of the relatively larger cans.

Lifting Movements

The analyses of lifting movements and EMGs are based on those trials which survived the automatic artifact-screening procedure performed by the data analysis software. For the remaining 1270 trials the maximum values of vertical displacement, velocity, acceleration, and initial deceleration were found. For each subject the Pearson correlation for these four variables and estimated weight was computed. Table I presents the mean correlations and the single-sample Student's _t_ values which test the null hypothesis that the correlation is zero. Although the correlations are quite small, velocity, acceleration, and deceleration are significantly related to the magnitude of weight estimates.

Table I

Correlations of Weight Judgements and Lifting-Movement Variables

Lift Variable	Mean r	t (13)
Maximum Height	-.03	-
Maximum Velocity	-.15	3.67**
Maximum Acceleration	-.15	3.67**
Maximum Deceleration	-.10	2.61*

* $p<.05$
** $p<.01$

Table II

Mean Values of Lifting-Movement Variables for Extreme Judgements

Lift Variable	Small-Heavy	Large-Light	t (13)
Maximum Height (cm)	4.8	4.9	-
Maximum Velocity (cm/sec)	12.7	14.1	4.06**
Maximum Acceleration (cm/sec^2)	98.	114.	3.60**
Maximum Deceleration (cm/sec^2)	52.	59.	2.12

** $p<.01$

Larger values for these variables occur for lighter judgements. This finding corresponds closely to the results found by C. M. Davis and Roberts (1976).

In order to make a closer comparison of these results with those of the previous studies which used the paired-comparison method, extreme-group analyses were also done for both lifting movements and EMGs. For each subject, the small can trials in the upper quartile of all judgements for small cans were compared to the large can trials in the lower quartile of judgements for large cans. To avoid having to arbitrarily select from a number of trials given the same judgement, the cutoff was set at that judgement level nearest the quartile division.

Table II presents the average values for these same lift variables when the extreme judgement groups are considered. The results are essentially the same, except that maximum deceleration is not significant at the .05 level. Figure 2 shows the acceleration and velocity records averaged for all 14 subjects.

The mean acceleration values in Table II are of particular interest because they provide an estimate of the amount of force exerted in lifting. The mass of each can plus the lift

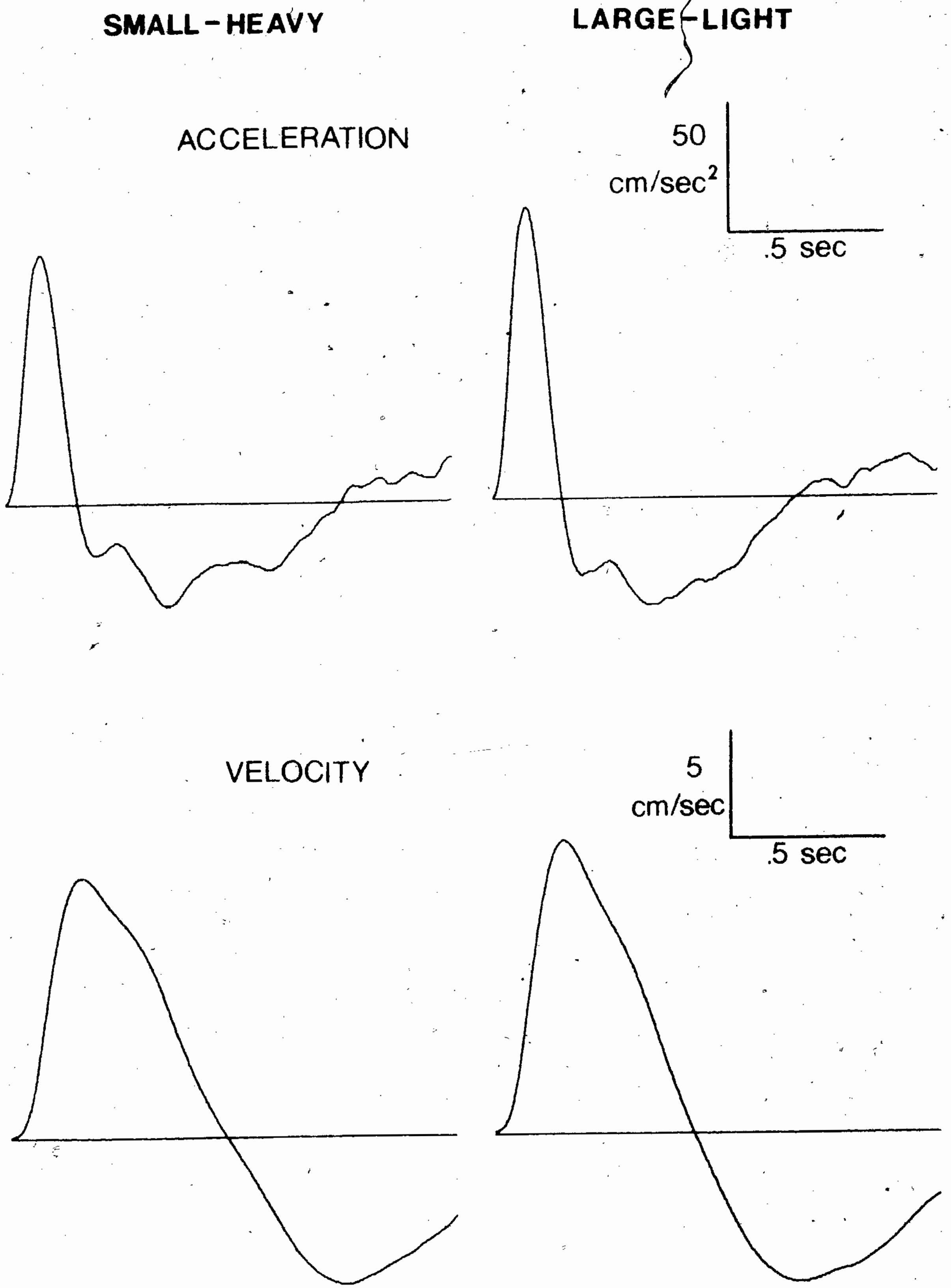


Figure 2. Acceleration and velocity averages.

transducer device was equivalent to 562 gms, so a force of 557,000 dynes was required just to support the can. The acceleration values in Table II correspond to additional forces of approximately 56,000 and 64,000 dynes for small and large cans, respectively, or 10.0% and 11.6% of 557,000 dynes. It should also be noted that the difference in the maximum total force exerted on large and small cans is only about 1.5% of the total.

For all trials the maximal acceleration occurred shortly after the beginning of the lift at an average of 55 msec for both large and small cans.

EMGs

Figure 3 presents the grand average for all 14 subjects of the rectified and averaged flexor and extensor EMGs for the two extreme groups of trials. The averages for each subject were re-scaled prior to averaging in order to equalize differences in the amplifier gain used. No major differences are detectable in these plots.

As a means of investigating very small differences in the EMGs, the averages for the two groups of trials for each subject were subtracted and the differences integrated from

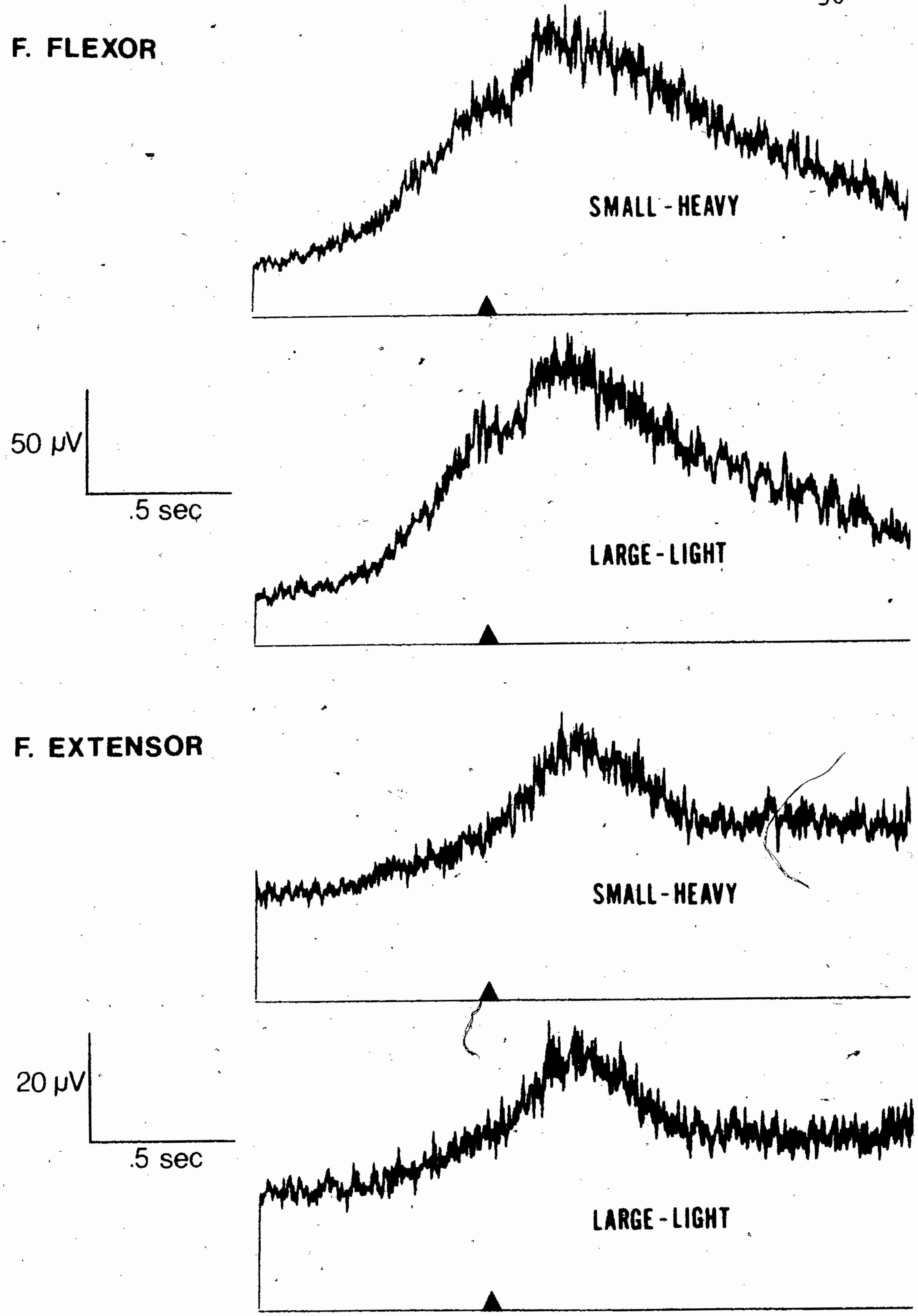


Figure 3. Rectified, averaged EMG.

the start of the sampling period (.8 sec before the lift). Figure 4 presents these integrated differences for each of the 14 subjects and both f. flexor and f. extensor derivations. Greater EMG amplitude for the large can group of trials corresponds to an upward deflection in the plots. The most obvious feature of these plots is that, up to the lift, the f. extensor EMGs were greater for the large can trials for 13 of the 14 subjects. The single subject exhibiting contradictory data is SW, whose weight judgements shown in Figure 1 show decreasing estimates over the course of the session. This resulted in the small--heavy group of trials coming predominantly from the first part of the session, while the large--light trials were taken from the later trials. The integrated differences for the f. flexors plotted in Figure 4 are less consistent, but there is a trend towards lower amplitudes for the large can trials.

In order to evaluate these impressions the pre-lift period was divided into two intervals, one 100 msec interval just before the lift, and an earlier interval including the first 700 msec of the sampling period. Table III presents the Pearson correlation of weight estimate and mean EMG amplitude for both of these intervals as well as the total 800 msec sampled prior to the lift. A negative correlation indicates that greater EMG activity is related to lighter judgements.

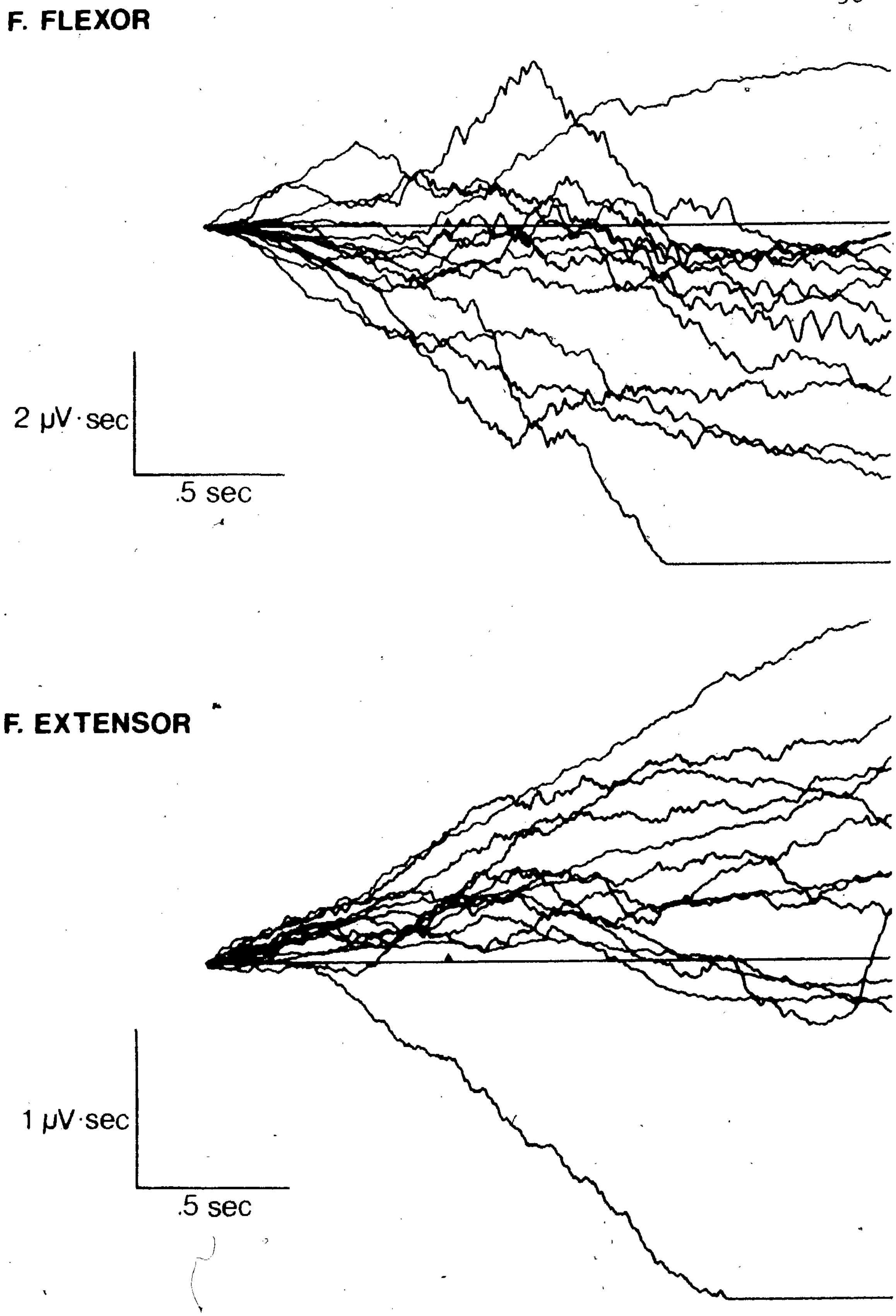


Figure 4. Integrated EMG differences (large minus small).

Table III

Correlations of Weight Judgements and Pre-Lift EMG

Pre-Lift Interval	Mean r	*t* (13)
-100 msec to lift		
f. flexor	-.04	1.24
f. extensor	-.07	1.89
-800 msec to lift		
f. flexor	.07	1.51
f. extensor	-.09	2.60*
-800 msec to -100 msec		
f. flexor	.10	2.00
f. extensor	-.09	2.67*

* $p < .05$

The correlation of early f. extensor amplitudes and weight is found to be statistically significant at the .05 level. Table IV presents the mean EMG levels for the extreme groups of trials. The _t_ values are negative when the mean amplitude for the large can trials is smaller than that for the small can trials. The results of this analysis are similar to the previous correlations except that early f. extensor activity is found to be significantly smaller for the large can lifts.

Table IV

Pre-Lift EMG for Extreme Judgements

	Mean Rectified EMG (microvolts)		
Pre-Lift Interval	Small-Heavy	Large-Light	*t* (13)
-100 msec to lift			
f. flexor	91	93	.49
f. extensor	30	32	2.12
-800 msec to lift			
f. flexor	49	46	-2.62*
f. extensor	23	25	2.75*
-800 msec to -100 msec			
f. flexor	43	39	-2.86*
f. extensor	22	24	2.67*

* $p < .05$

DISCUSSION

Weight perception is a complex process, "complex" in the sense of having multiple sources of variability. The present study attempted to relate variance in the judgements of objectively equal weights to two measures of the efferent expression of this process: lifting movements and precursory muscle tension.

Lifting movements were found to be related to perceived heaviness in the manner predicted by Martin and Müller (1899) and as demonstrated by C. M. Davis and Roberts (1976). Müller and Schumann's description of how an object "In die Luft Fliegens" corresponds to the more quantitative present finding of greater acceleration and velocity in the lifting of large cans subsequently judged to be light. The evidence presented here, closely confirming the results of C. M. Davis and Roberts (1976), indicates that speed of lifting can be considered as one of the factors most clearly involved in the SWI.

The question of why it is that larger objects are lifted faster than smaller objects has not been a major concern of the present research, but the results of this experiment possibly have some bearing on those theories of the SWI which deal with this question. Many of the proposed explanations of the SWI hold that an individual has an expectation that a larger object is heavier, and therefore applies greater strength in lifting it (e.g. McClosky, 1974; Ross, 1969; early studies reviewed in Huang, 1945a). The various explanations differ on what is meant by "expectation." Flournoy (1894, cited in Huang, 1945a) postulated a hereditary disposition by which an unconscious cerebral impulse adjusts itself automatically to the probable weight of an object, determined by, among other factors, the visible volume. Other writers have suggested that the tendency to lift larger objects with greater muscular exertion is the result of the empirical association of size and weight built up by past experience in handling objects (e.g. Müller & Schumann, 1889). What should be emphasized, however, is that "expectation," as used in this context, does not denote what is commonly meant by this term, i.e., a consciously formulated prediction regarding some future event. Indeed, it can be inferred from the well-documented persistence of the SWI (e.g., Thouless, 1931b) that the experience of the illusion does not require the observer to maintain a prediction about the relative weights of large and small objects. If this was necessary, after making the first judgement that a larger object is lighter, the SWI should be reversed when the same objects are judged again. In the present research, subjects were familiarized with the eight cans during the initial practice session in which they all experienced the SWI. In the following session, the subsequent repeated estimations for the same eight cans continued to exhibit the SWI, as shown in Figure 1. At the end of the experiment most of the subjects were questioned directly about what they believed the actual weights of the cans to be. All the replies indicated that most of the small cans were remembered as being heavier than most of the large cans.

Further evidence that the SWI depends on immediate sensory data rather than conscious knowledge comes from experiments such as the one done by Koseleff (1957), referred to earlier, in which the perceived weight of an object held in the hand was found to change in the direction consistent with the SWI when the object was viewed through a lense. Another experiment (Huang, 1945a) has shown that when the subject is told the size of the object lifted, but visual and tacto-kinesthetic cues are eliminated, the illusion is very much reduced. Finally, the weight illusions produced by experimental manipulation of either the force required to grasp the weights (McClosky, 1974) or the speed with which they are lifted (C. M. Davis, Taylor, & Brickett, 1977) cannot be explained with reference to "expectation."

Although conscious, verbalizable "expectation" is not, therefore, the determining factor in weight illusions, it is nevertheless an empirical fact that constant errors in weight judgement do occur for objectively equal weights that differ on some other physical dimension (e.g. volume, or material), which, for most common objects, is correlated with weight and could usually be used to predict weight. In some unknown manner these various visual and tactile cues presented by an object are integrated into a plan of action for lifting the object, as exemplified by the influence of size on lifting movements found in this study.

When the size of an object is not related to its actual weight this influence of size cues on lifting movements has a detrimental effect on weight perception and the SWI occurs. In our everyday lives, however, the more common situation is that the weight of an object is directly related to its size. When this is the case, the expenditure of more exertion in lifting larger objects of greater weight will therefore result in lifting movements that are kinematically similar. Roberts (1974) found that there was no significant difference in acceleration for the same large and small cans as used in the present study when the weight of the large can was increased to 705 gms, and after subjects had had practice lifting the cans. This finding, and other evidence, led Roberts to suggest that there is a relative constancy in the acceleration with which common objects are lifted, but that this constancy breaks down and the SWI occurs when an object's size is unrelated to its weight. This statement, of course, completely coincides with Müller and Shumann's original proposition of the motor theory of weight perception.

Given that the size cues presented by an object are in some way integrated into a plan of action for lifting the object, the other major concern of the present research involved how this plan is put into action. More specifically, what are the events in the lifting musculature that occur prior to the lift and are related to subsequent weight judgement? Any interpretation of this preparatory muscular activity must also consider the biomechanical aspects of the lifting task as well as the dynamics of the succeeding lifting movements.

In regard to the latter, analysis of the accelerative forces revealed that the force required to lift the can at maximum acceleration was only 10-12 percent more than the force required just to support the can. This consideration does argue for the importance of the muscle activity preceding the lift for any investigation of the peripheral responses involved in weight perception since approximately 90% of the maximum force exerted in lifting builds up before the start of the lift.

The other relevant aspect of this analysis is that the difference in the force exerted on large and small cans is only about 1.5% of the total. With such a small difference in force, there is no reason to expect to find a large difference in pre-lift EMG if muscle activity is only a function of the maximum force to be exerted during the lift.

Another consideration for this discussion which should be emphasized is that, in the method used for this experiment, all EMGs were sampled with respect to the start of the lift, at which time the vertical force exerted on each can had to be just slightly in excess of 557,000 dynes in order to raise the can at that point. This factor, together with the small difference in maximum force, would predict that EMG amplitudes should be similar for all trials near the time of the start of the lift. For the 100-msec-to-lift interval there is not a statistically significant difference or correlation for either muscle groups. However, both f. flexors and f. extensors tend to show greater activity for large cans judged to be lighter. If reliable, this effect could be explained as increased antagonistic functioning of the two muscle groups resulting in no net change in force.

For the different pattern of flexor and extensor muscle activity occurring earlier before the lift, the interpretation suggested here involves the specific aspects of the particular lifting task used for this study. Subjects lifted cans using wrist flexion, but they were required to keep their palm and fingers straight. Compared to the hand at rest, this position requires contraction of the extensor muscles to produce extension at the metacarpophalangeal and the proximal interphalangeal joints. The amount of muscle activity required for this task is indicated in Figure 3. The increase in extensor activity into the course of the lift when the wrist is flexing reflects the fact that for this three-joint system (including the wrist), increased extensor tension is necessary to prevent the fingers from curling when a load is supported at the middle phalanges.

The finding of greater extensor activity occurring prior to the exertion of greater flexor force during the lift is consistent with the consideration above, as well as the additional instructions given the subjects to not exert any upward force on the can handle before actually lifting the can. This relationship of early extensor EMG and subsequent lifting performance could represent preparatory muscle activity, or "efferent readiness," specifically adapted to the particular lifting task.

Further speculation on these results would be premature at this time, particularly because of the biomechanical complexity of the lifting task, together with the over-simplifications made in the present study in regard to both the recording and the theoretical analysis of the various functionings of the numerous forearm muscles referred to here as "flexors" and "extensors." The conclusion drawn from the results of this study and other research is that the motor theory of weight perception presents an adequate description of the lifting movements found generally to be related to the SWI, but that preparatory muscle activity must be interpreted in relation to the specific aspects of the particular lifting task. This last statement is based primarily on a comparison of the present results with those of the previous study by C. M. Davis and Brickett (in press).

In that study forearm flexor EMG was found to have a different pattern of activity over the time interval sampled. Possible reasons for these different results include the reaction-time nature of the lifting task as well as the method of recording EMGs with respect to the signal lights as opposed to the start of the lift. Preparatory muscle activity related to the SWI was found to occur in both of these studies, but the form of the activity found differed.

Constant errors in perception, such as the SWI, as well as most other illusions, are interesting not so much for their own sake, but because they can permit a better understanding of the normal functioning of perceptual mechanisms. The preceptual process involved in the SWI includes the integration of sensory visual information into the structuring of efferent commands for lifting as well as the evaluation of the resulting kinesthetic and proprioceptive feedback. The present investigation has been concerned with a small part of this process, the efferent activity.

REFERENCES

Anderson, N. H. Averaging model applied to the size-weight illusion. Perception and Psychophysics, 1970, 8, 1-4.

Birnbaum, M. H., & Veit, C, T. Scale-free tests of an additive model for the size-weight illusion. Perception and Psychophysics, 1974, 16, 276-282.

Boring, E. G. Sensation and Perception in the History of Experimental Psychology. New York: Appleton Century Crofts, 1942.

Bzhalava, I. T. (The nature of the contrast illusion.) In N. O'Connor (Ed.), Recent Soviet Psychology. Oxford: Pergamon, 1961. (Reprinted from Voprosy Psikhologii, 1958, No. 4, 42-52. Trans. H. Asher.)

Cross, D. V., & Rotkin, L. The relation between size and apparent heaviness. Perception and Psychophysics, 1975, 18, 79-87.

Davis, C. M., & Roberts, W. Lifting movements in the size-weight illusion. Perception and Psychophysics, 1976, 20, 33-36.

Davis, C. M., Taylor, M., & Brickett, P. A weight illusion produced by lifting movements. Perceptual and Motor Skills, 1977, 44, 299-305.

Davis, C. M., & Brickett, P. The role of preparatory muscular tension in the size-weight illusion. Perception and Psychophysics, in press.

Davis, J. F. Manual of Surface Electromyography. WADC Technical Report, 59-184, Dec., 1959.

Davis, R. C. Set and muscular tension. Indiana University Publications, Science Series, 1940, No. 10.

De Camp, J. E. The influence of color on apparent weight. Journal of Experimental Psychology, 1917, 2, 347-370.

Fechner, G. Elements of Psychophysics (H. E. Adler, Trans.). New York: Holt, Rinehart and Winston, 1966. (Originally published, 1860.)

Freeman, G. L., & Sharp, L. H. Muscular action potentials and the time-error function in lifted weight judgements. Journal of Experimental Psychology, 1941, 29, 23-36.

Fries, I., & Holmberg, L. Habit and susceptibility to the size-weight illusion. Psychological Research Bulletin (Lund University, Sweden), 1968, 8, 1-4.

Harshfield, S. P., & DeHardt, D. C. Weight judgement as a function of apparent density of objects. Psychonomic Science, 1970, 20, 365-366.

Howard, I. P. An experimental and theoretical analysis of the size-weight illusion. Durham Research Review, 1954, 1, 47-53.

Huang, I. The size-weight illusion in relation to the perceptual constancies. Journal of General Psychology, 1945, 33, 43-63. (a)

Huang, I. The size-weight illusion and the "weight-density illusion." Journal of General Psychology, 1945, 33, 65-84. (b)

Jarrard, L. E. The role of visual cues in the performance of ergographic work. Journal of Experimental Psychology, 1960, 60, 57-63.

Karube, K., & Tanaka, Y. Analysis of factors that determine subjective weight. Japanese Psychological Research, 1964, 6, 163-172.

Koseleff, P. Studies in the perception of heaviness: I. Acta Psychologia, 1957, 13, 242-252.

Koseleff, P. Studies in the perception of heaviness: II. Acta Psychologia, 1958, 14, 109-130.

Martin, L., & Müller, G. E. Zur Analyze der Untershiedsempfindlichkeit. Leipzig: J. A. Barth, 1889.

McCloskey, D. I. Muscular and cutaneous mechanisms in the estimation of the weights of grasped objects. Neuropsychologia, 1974, 12, 513-520.

McClosky D. I., Ebeling, P., & Goodwin, G. M. Estimation of weights and tensions and apparent involvement in a "sense of effort." Experimental Neurology, 1974, 42, 220-232.

Müller, G. E., & Schumann, F. Ueber die psychologischen Grundlagen der Vergleichun gehobener Gewichte. Archives für die Gesamte Physiologie, 1889, 45, 37-112.

Payne, B., & Davis, R. C. The role of muscular tension in the comparison of lifted weights. Journal of Experimental Psychology, 1940, 27, 227-242.

Robinson, H. B. An experimental examination of the size-weight illusion in young children. Child Development, 1964, 35, 91-107.

Rock, I. R. An Introduction to Perception. New York: Macmillan, 1975.

Roberts, W. L. A preliminary investigation into a consistency in the acceleration of objects lifted by wrist flexion. Unpublished M.A. thesis. Simon Fraser University, 1974.

Ross, H. E. When is a weight not illusory? Quarterly Journal of Experimental Psychology, 1969, 21, 346-355.

Scripture, E. W. Thinking, Feeling, Doing. Meadville, Pa.: Flood and Vincent, 1895.

Sjöberg, L. Sensation scales in the size-weight illusion. Scandinavian Journal of Psychology, 1969, 10, 109-112.

Stevens, J. C., & Rubin, L. L. Psychophysical scales of apparent heaviness and the size-weight illusion. Perception and Psychophysics, 1970, 8, 225-230.

Stevens, S. S. Psychophysics: Introduction to Its Perceptual, Neural, and Social Prospects, (G. Stevens, Ed.). New York: Wiley, 1975.

Stevens, S. S., & Galanter, E. Ratio scales and category scales for a dozen perceptual continua. Journal of Experimental Psychology, 1957, 54, 377-411.

Thouless, R. H. Phenomenal regression to the real object. I. British Journal of Psychology, 1931, 21, 339-359. (a)

Thouless, R. H. Phenomenal regression to the 'real' object. II. British Journal of Psychology, 1931, 22, 1-30. (b)

Tolman, E. C. Review of Wahrnehmung und Geganstandswelt--Grundlegung einer Psychologie vom Gegenstand her. von E. Brunswik. Psychological Bulletin, 1935, 32, 608-614.

Usnadze, D. Über die Gewichtstäuschung und ihre Analoga. Psychologie Forschung, 1931, 14, 366-379.

Werber, M., & King, D. J. An investigation of the response mechanism of the size-weight illusion. Journal of General Psychology, 1962, 66, 85-100.

Wolfe, H. K. Some effects of size on judgements of weight. Psychological Review, 1898, 5, 25-54.

Woodruff, B., Jennings, D. L., & Ricó, N. L. Time error in lifted weights as affected by presentation order and judgement mode. Perception and Psychophysics, 1975, 18, 98-104.

Woodworth, R. S. Experimental Psychology. New York: Henry Holt, 1938.