THE UNIVERSITY OF ALBERTA

A FORCE-TIME ANALYSIS
OF A STANDING LONG JUMP

by

ROBERT N. MARSHALL

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ABSTRACT

The primary purpose of this study was to determine the percentage contribution of the arms to the horizontal impulse in a standing long jump. A secondary aim was to examine the effects of altering the standing long jump by the addition of five pound weights to each hand.

One volunteer subject, a twenty-year-old male who was an experienced long jumper with the University of Alberta Track and Field team, was photographed.

From the force traces and film analysis, the following were obtained: 1) the total impulse developed during a jump with and without weights; 2) the impulse associated with the center of gravity of both arms for both jumps; 3) the percentage contributions of the arms to the total impulse; 4) the regions of the jump in which the arms were positively contributing to the impulse, and 5) the physical position of the performer at selected critical regions of force development.

ACKNOWLEDGEMENTS

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To Mr. G. M. Elliott (chairman) for the invaluable assistance provided during this project.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The standing long jump is used in at least fifteen physical fitness or motor ability tests. It has been the subject of much effort to determine the relationship of the distance jumped to such variables as isometric leg extension strength, elbow flexion strength, hip extension strength, ankle plantar flexion strength, angular velocity and acceleration of the limbs, and total force involved in the jump. There has been little published research, however, dealing with the size of the forces involved in long jumping or the effects of the individual body segments on the overall pattern.

In 1964, Eckert published a study dealing with the standing long jump in which she attempted to find the relationships between the isometric leg strength and the calculated angular measures of the lower limbs. No significant correlations were found, except when comparing isometric extensor strength of the hip to the maximum angular velocity and to the angular velocity at maximum angular acceleration of the hip joint.

Roy, cited by Roberts (1971), states that a maximum force of slightly under two times body weight was developed as the vertical component of force in a standing long jump. He also calculated distances, velocities and impulses, although these have not yet been published.

In a paper dealing with the uses of a force platform in athletic investigation, Payne _et_ _al_. (1968) show that the active use of the arms contributes approximately six percent (this author's calculations) to the impulse developed in a vertical jump for maximal height.

It seems that little is known about the horizontal component of force in the standing long jump, in particular the effect of the arms, and thus this study will attempt to determine some of these factors.

The Problem

The major problem was to determine the percentage of the horizontal impulse attributable to the use of the arms in the standing long jump.

Secondary Problems

The secondary problems involved in this study were:

1. to determine if weights in the subject's hands had any appreciable effect on the impulse,

2. to determine the physical position of the performer at selected critical regions of force application in the standing long jump, and

3. to determine the exact point of departure from

the force platform and its relation to the time of zero horizontal force.

Delimitations

The study was delimited to one experienced subject of average build, and no attempt was made to assess the magnitude of the vertical or lateral forces involved in a standing long jump.

Definition of Terms

Standing Long Jump

In this study a standing long jump refers to a jump for maximal horizontal distance which is begun from a stationary position with the feet side by side, approximately hip width apart.

Critical Regions

Critical regions are those regions which appear from the force-time trace to be most important in attaining a good performance, i.e., the regions of minimum or maximum force application, or the regions in which there is a sudden increase or decrease in the force developed.

Force Platform

The force platform was a device used to measure the horizontal component of force in the sagittal plane, built and designed at the University of Alberta by Howell and modified by Marshall (Figure 1).

Impulse

A vector quantity, impulse is the product of the force and the time for which it acts. The total impulse acting on a body is equal to the total change in momentum of the body.

CHAPTER II

REVIEW OF LITERATURE

Standing Long Jump Studies

Clarke (1960) and Barrow (1968) list over fifteen different physical fitness and motor ability tests which include the standing long jump. In an attempt to provide standards of performance in this easily-administered test, many studies have been published relating the distance jumped to such variables as: the type of incentive offered (Caskey, 1968); elbow flexion strength, body weight, hip extension strength, ankle plantar flexion strength, and leg strength (Clarke and Degutis, 1964). In addition to this, studies have been carried out relating the distance jumped to the number of trials necessary to obtain reliable results (Baumgartner, 1970), the standing jump for height (Glencross, 1966), the effects of a six week isometric strength training program (Lindeburg et al., 1963), and to the characteristic likenesses and differences between skilled and unskilled standing long jump performers (Zimmerman, 1956). Cooper and Glassow (1972), and Glencross (1964) analyse the standing long jump in terms of the movements involved and their coordination.

A series of articles has been published by Eckert (1964, 1966, 1968) dealing with the standing long jump and its relationship to isometric strength, angular velocity, angular acceleration, force, and range of motion. She [1964: 305] found

> . . . a significant relationship between isometric extensor strength of the hip and the speed of movement of the hip joint during performance of a standing long jump when the speed of movement was measured at the points of maximum angular velocity, and of velocity at the point of maximum angular acceleration.

but no significant relationships to any of the other variables.

All of the preceding studies seem to indicate that the standing long jump is a complex integration of strength, skill, and motivation, and cannot be easily related to one variable.

The Contribution of Body Segments to the Impulse

Bunn (1964) indicates he is of the opinion that effective use of the arms can increase the distance jumped, and thus presumably increase the total impulse. Payne *et al*. (1968), in studying a standing jump for maximum height found that the arms contributed approximately six percent (this author's calculations) to the vertical impulse of the jump. Ramey (1972) states that in a running long jump the lifting of the arms and leg at takeoff contributes less than twenty percent to the total force. Whether by "total force" he means peak force developed, or total impulse, is not clear.

Sprigings (1972) attempted to determine the impulse contributions attributable to each body segment in a track sprint start, but was unable to differentiate between the impulse generated by a segment and the impulse inherent in a segment.

These were the only studies found which discussed the contributions of the various segments to the movement. There seems to be a lack of information relative to the size of the impulses, and to the percentage contributions of the body segments.

Relationship of Force-Time Recordings to Cinematographical Analysis

Russell (1967) obtained low correlations in the determination of impulse in a swimming sprint start between cinematographic analysis and force-time recordings, but he used a small number of subjects.

Lanier (1968) found no significant difference in the calculation of average velocities from cinematographical analysis or recordings from force blocks, but did state in his study that the relative error in determining velocity by cinematographical analysis was twice as large as by the force block method.

Murray, Seireg and Scholz (1967) used cinematographical analyses and force-time recordings to analyse descending to and rising from sitting and squatting postures, and jumping. They found that the film calculations closely approximated the force recordings in the pattern evolved, but there were differences in magnitude noticed in the peaks and valleys of the force trace. This was hypothesized to be the result of errors made in the process of differentiation, which would show up as the greatest errors at times of maximum acceleration.

In comparing horizontal velocity, movement time and reaction time, Sinclair (1970) reported high relationships between film analysis and force-time graphs.

Roy (Roberts, 1971), studying the standing long jump of children seven to sixteen years of age found a close relationship between the record of vertical force obtained from his force platform and the vertical force calculated from the film. The maximum deviation in this case was nine percent, which indicates that the data on individual body segments can be measured accurately from film, and the anatomical data used in the calculations is acceptable.

Sprigings (1972) found cinematographic calculations provided similar results to force platform recordings in the calculation of the impulse. Sprigings used an integrator to directly record the impulse produced during a sprint start, and found that there was some variation between the two methods when scrutinized frame by frame, but the total impulse measures were in close agreement over the entire sprint start.

CHAPTER III

METHODS AND PROCEDURES

This study was conducted in the Strength Laboratory in the Physical Education Building at the University of Alberta. The possible variables of light, temperature and weather were therefore controlled in this situation.

Subject

The subject was a male university student, an experienced long jumper with the University of Alberta Track and Field team, who was capable of consistently performing a standing long jump of over nine feet. He was five feet, six and one-half inches tall, weighed one hundred forty-four pounds, and was twenty years of age. The subject performed fifteen jumps on the day of the testing after his personal preference for warm-up had been satisfied. Two jumps were used for analysis; one jump was chosen from the jumps without weights, and one was chosen from the jumps with weights.

Apparatus and Methods

Force Platform

The force platform (Figure 1) was designed to measure the horizontal force exerted by the subject, using

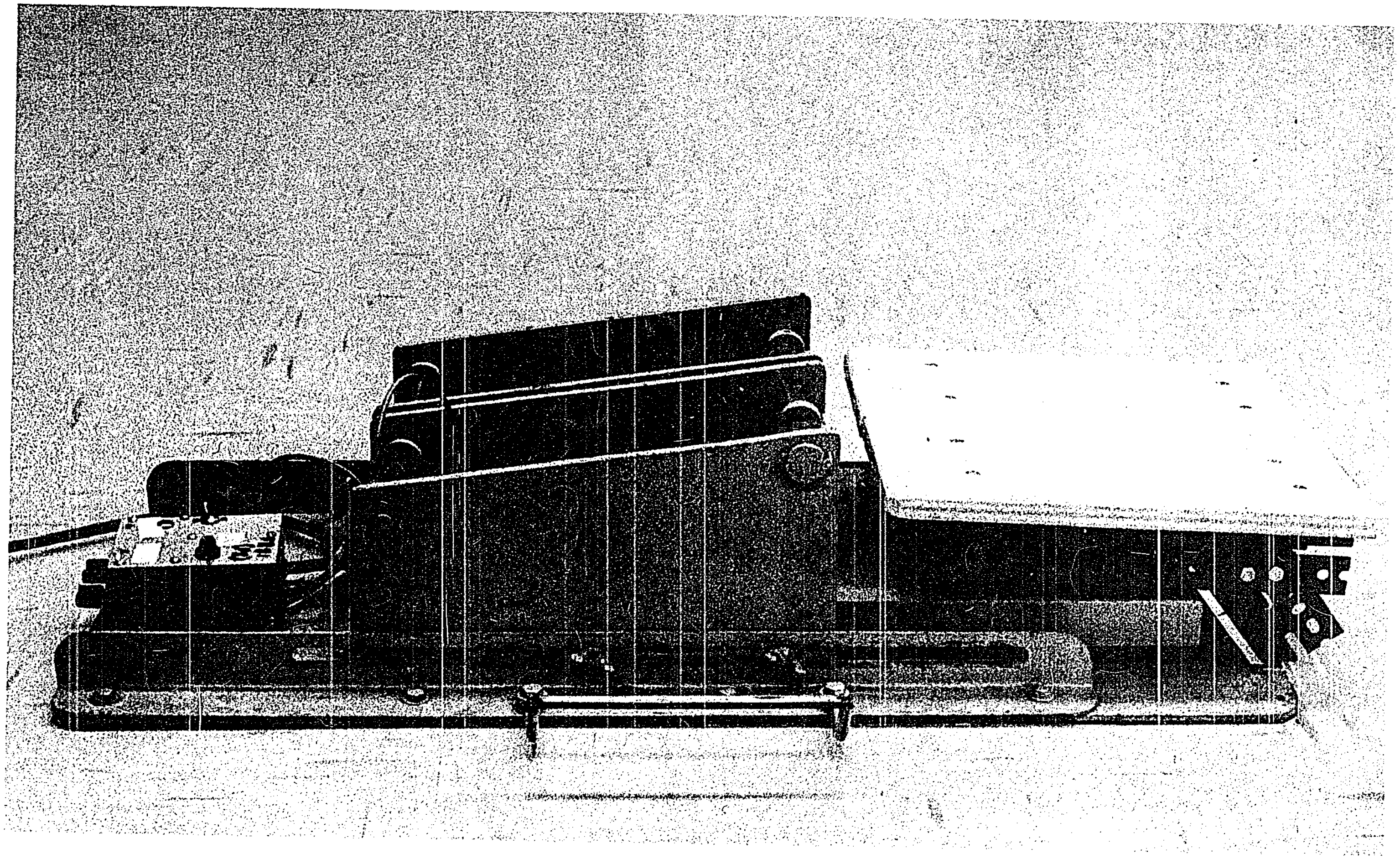


FIG. 1. FORCE PLATFORM

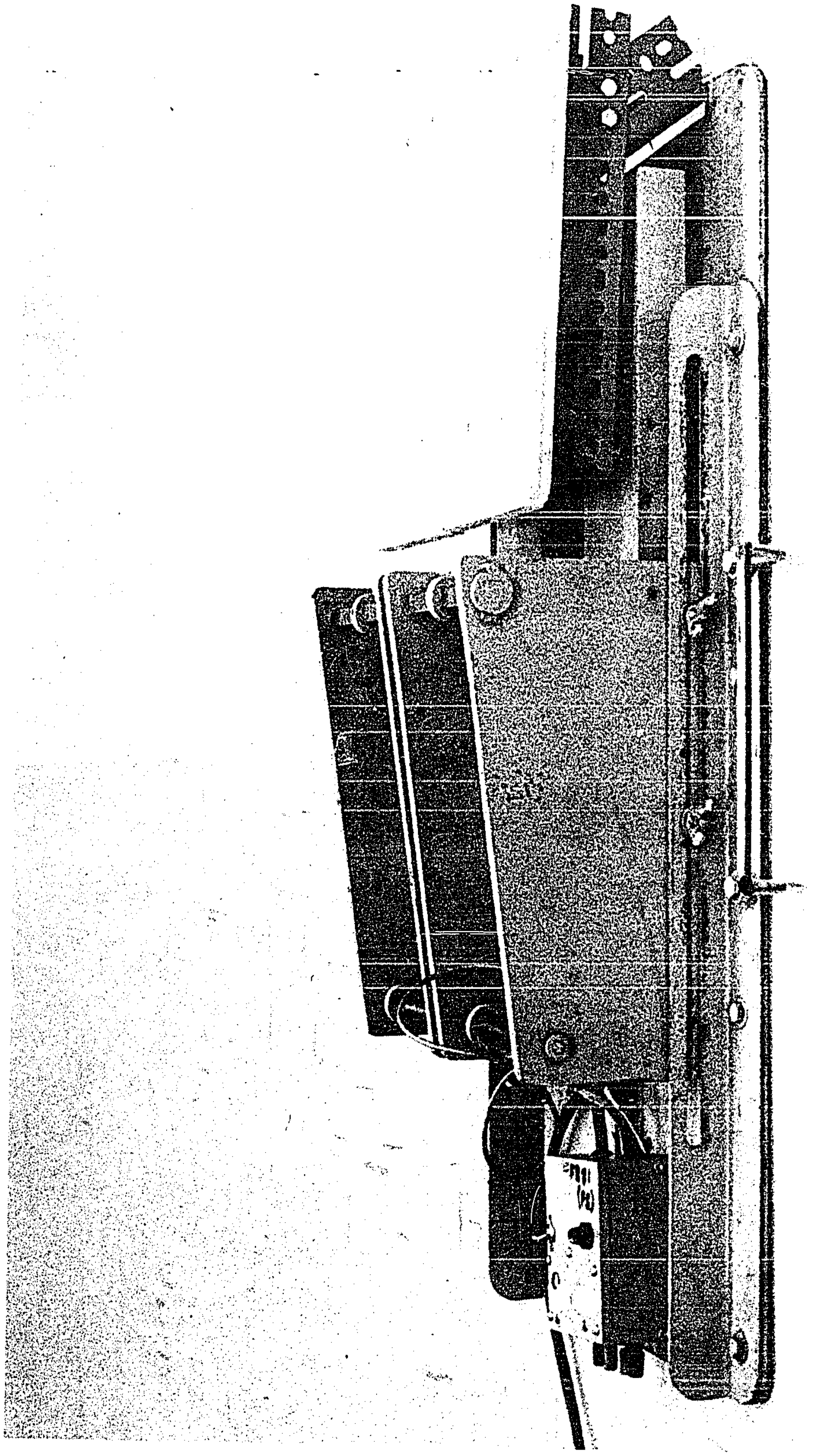


FIG. 1. FORCE PLATFORM

a Sanborn 7 DCDT transducer, which generated a voltage difference proportional to the horizontal component of the force exerted against the platform. This potential difference passed through an operational amplifier and activated the Honeywell Accudata 113 D.C. Amplifier.

The force platform used was a modification of the force blocks designed by M. L. Howell and described by Lanier (1968). They were reconstructed to provide a platform from which the subject could jump, while a reading of the horizontal force exerted could be obtained.

Camera

A sixteen millimeter motion picture camera, Teledyne Camera Systems Millikan Model DBM 54, was used and operated at about one hundred twenty-four frames per second, with Kodak Tri-X Reversal film (ASA 160). This particular camera had internal timing lights which left light traces on the edge of the film at a predetermined rate, controlled by a crystal oscillator (Steinwood Instruments Tri-Pulse Generator, model T.P.G.-3-83). The shutter speed was 1/300 of a second, the lens-to-subject distance was twenty-one feet, and a twelve millimeter lens was used.

Grid

A four-by-eight foot sheet of plywood marked off in six inch squares was placed in the plane of the jump and photographed to provide a means of obtaining accurate distance measurements when the film was projected. Errors due to lens distortion were also minimized by this process.

Timing Apparatus

An apparatus was designed to determine the exact moment of leaving the platform, which consisted of a wire mesh connection between the large toe of the subject's right foot and the platform. Closing this connection caused a galvanometer to deflect, and the opening of the circuit resulted in the galvanometer returning to its zero point.

Recording System

Three channels of the Honeywell Electronic Medical System were used. Each channel consisted of a transducer input, or sensor to detect the signal, a recording device, and electronics to condition the signal and make it compatible with the recording device. One channel was an Accudata 135 ECG-EMG Amplifier, used as an event marker to record the electrical output from the camera, which was equivalent to the frame rate. The other two channels used were Accudata 113 D.C. Amplifiers. One of these channels was also used as an event marker to record the opening or closing of the foot-platform contact, while the other channel was the primary amplifying device. The output voltages from each transducer of the force platform were combined through an operational amplifier adder, reduced by a factor of twenty, and then input to the primary 113 channel.

Operational Amplifier Adder

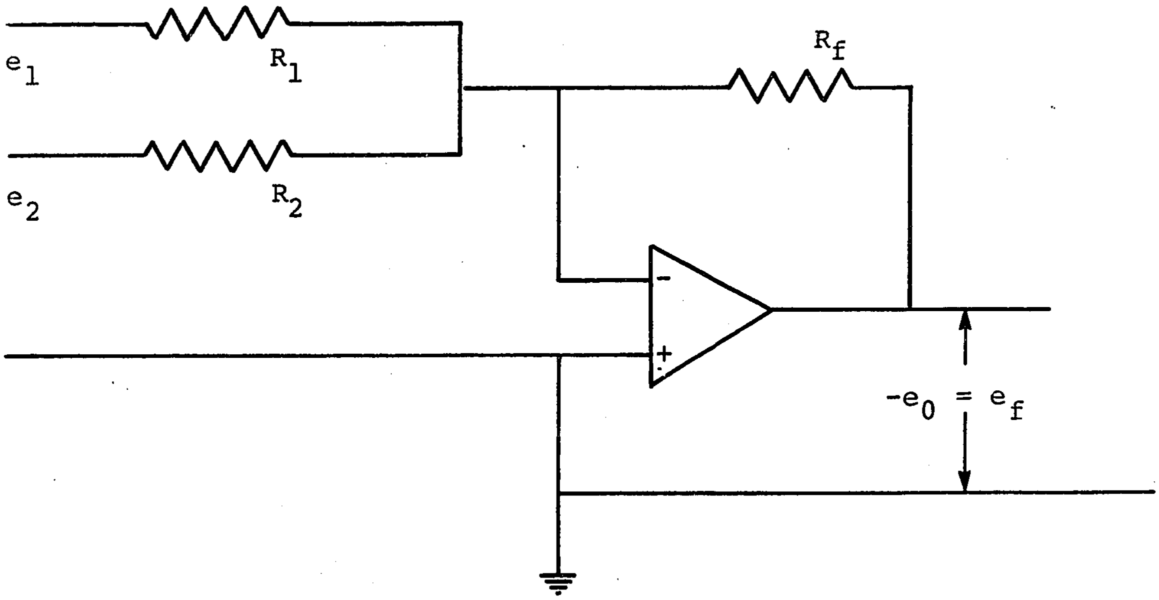
To sum the two voltages from the transducers, an O.A. adder was constructed which also decreased the input voltage by a factor of twenty (see Figure 2), to provide a voltage within a range useable by the recording amplifiers.

Motion Analyser

A Triad Corporation film analyser model V/R-100 was used for the film analysis.

Computer Program

A computer program (Appendix B) developed by Miller was used to assist in the calculations. The program calculates the center of gravity of each segment, as well as the center of gravity of the entire body for each frame. Three modifications of this program were developed: one change provided the center of gravity of the arms combined, and the center of gravity of the body minus the arms; another modification required a change in the segmental weight percentages to compute the center of gravity of the body plus the weights; and the third gave the center of gravity of both arms and of the body minus the arms, taking into consideration the changed values of the segment percentages because of the added weights. A list of these values is shown in Appendix C.



$$e_f = e_1 \frac{R_f}{R_1} + e_2 \frac{R_f}{R_2}$$

$$\text{If } R_f = \frac{1}{40} R_1 = \frac{1}{40} R_2, \text{ then } e_0 = -\frac{1}{20} (e_1 + e_2)$$

FIG. 2. OPERATIONAL AMPLIFIER ADDER

Calculation of Impulse

With the data provided by these programs, distance-time plots of the motions of the total body, the body minus the arms, and both arms were drawn for each of the two jumps analysed. From calculations on these graphs, velocity-time graphs were plotted, and then acceleration-time graphs were calculated and drawn.

In attempting to determine the impulse attributable to a segment, it should be noted that the arms will have an impulse associated with them whether they are moving faster or slower than the rest of the body. For the purposes of this study, if the center of gravity of the two arms was accelerating faster than the center of gravity of the body minus the arms, the arms were considered to have a positive contribution to the impulse.

The areas under the acceleration curves were determined by a "weighing technique," in which the weight of a known area was compared to the weight of the area under the acceleration graph; then by multiplying by the appropriate mass, the impulse was calculated.

Testing Procedures

Calibration

Each transducer was first adjusted by centering the core within the coil to produce an electrical output of zero. When each had been standardized, they were summed through the O. A. adder, and this output was connected to a voltmeter. Weights of twenty and forty pounds were then applied to each half of the platform and the voltage per pound was calculated. The full calibration chart is shown in Appendix A.

On the day of the testing, a calibration curve was produced using the electrical equivalent of weights from ten to three hundred twenty pounds. This curve was used as the basis for measuring the magnitude of the force traces obtained during testing.

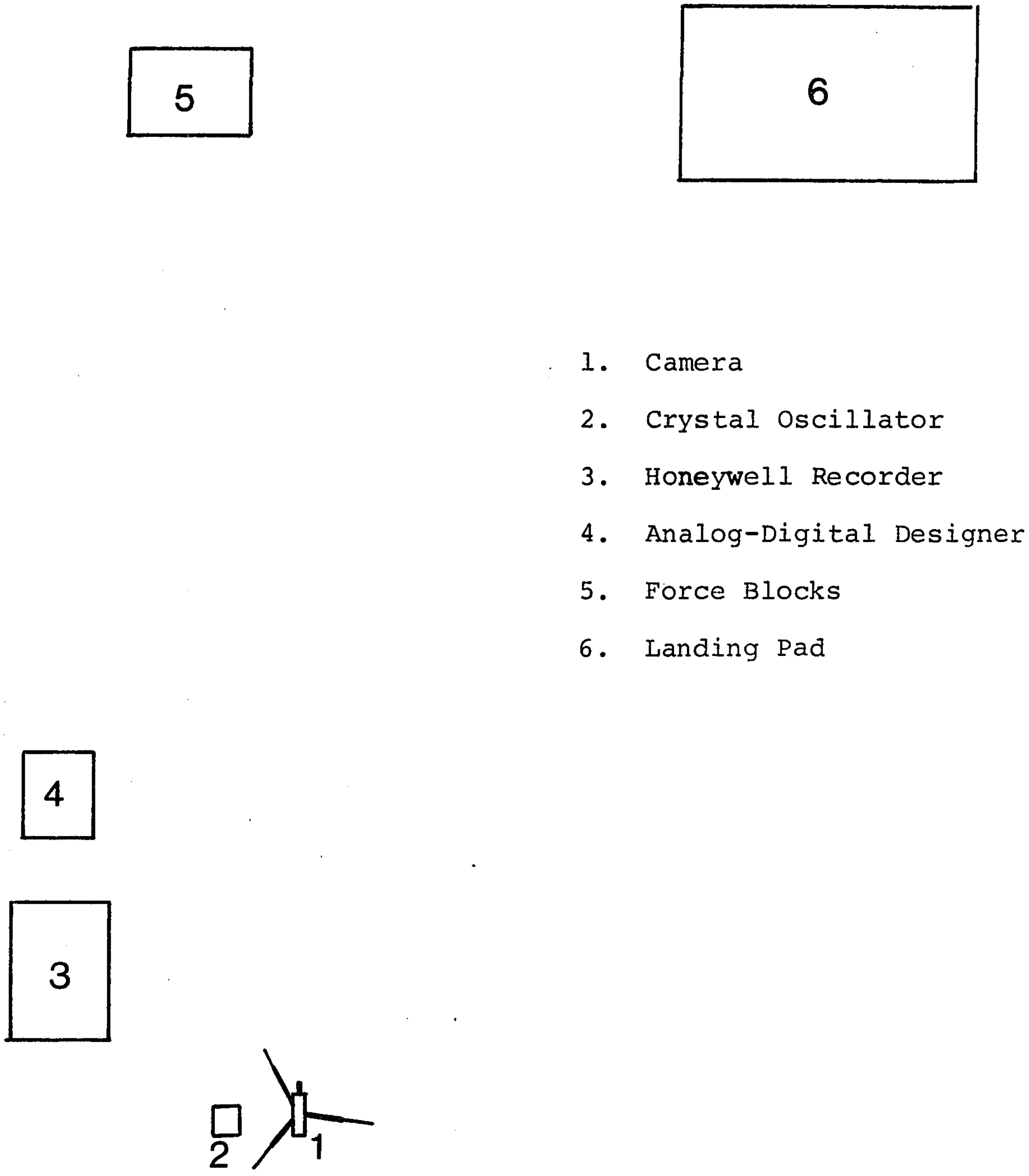
Subject

The surface landmarks associated with the joint centers of the subject's wrists, elbows, knees, ankles, right hip and right shoulder were located according to Williams and Lissner [1962:133], and marked with a black "X" on the skin surface.

The subject performed six standing long jumps for maximal distance from the force platform after his personal preference for warm-up had been satisfied. Then, with a five pound dumbell in each hand, he performed five or six practise jumps after which the subject reported that he felt comfortable jumping with the additional weight. Nine jumps with the subject using the weights were then recorded (Figure 4).

Data Collection

With the subject standing on the force platform, the ultraviolet recorder was started; then the camera was switched on, and when the camera had attained the desired speed (approximately one second) the command "Start" was given and the subject performed a jump. When the subject landed, the camera was turned off, and then the u.v. recorder was stopped (Figure 5).



1. Camera
2. Crystal Oscillator
3. Honeywell Recorder
4. Analog-Digital Designer
5. Force Blocks
6. Landing Pad

FIG. 3. SCHEMATIC DIAGRAM OF TESTING APPARATUS

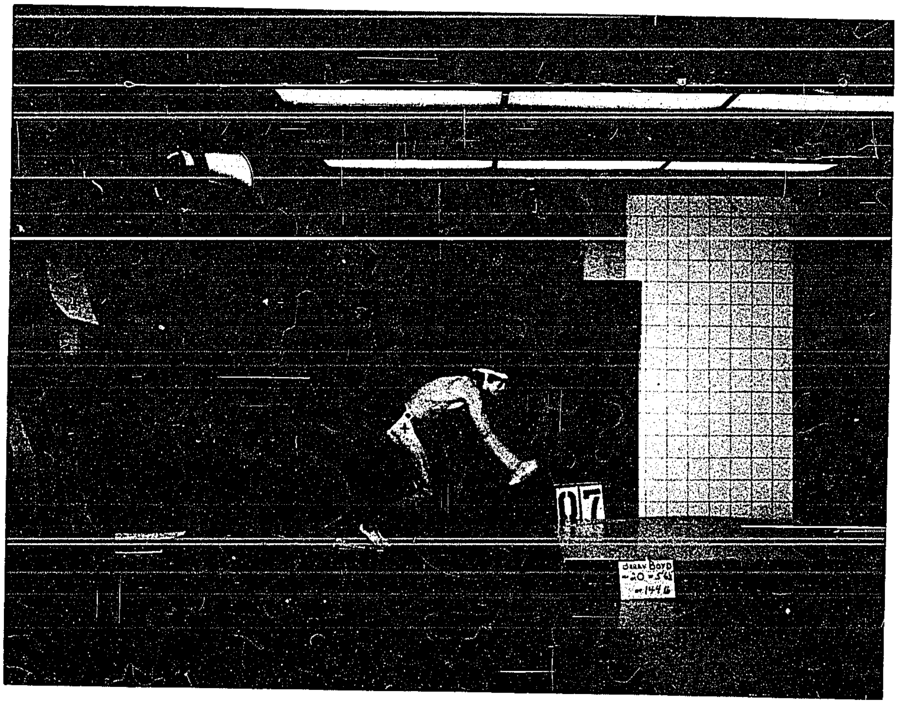


FIG. 4. SUBJECT PERFORMING A JUMP WITH WEIGHTS

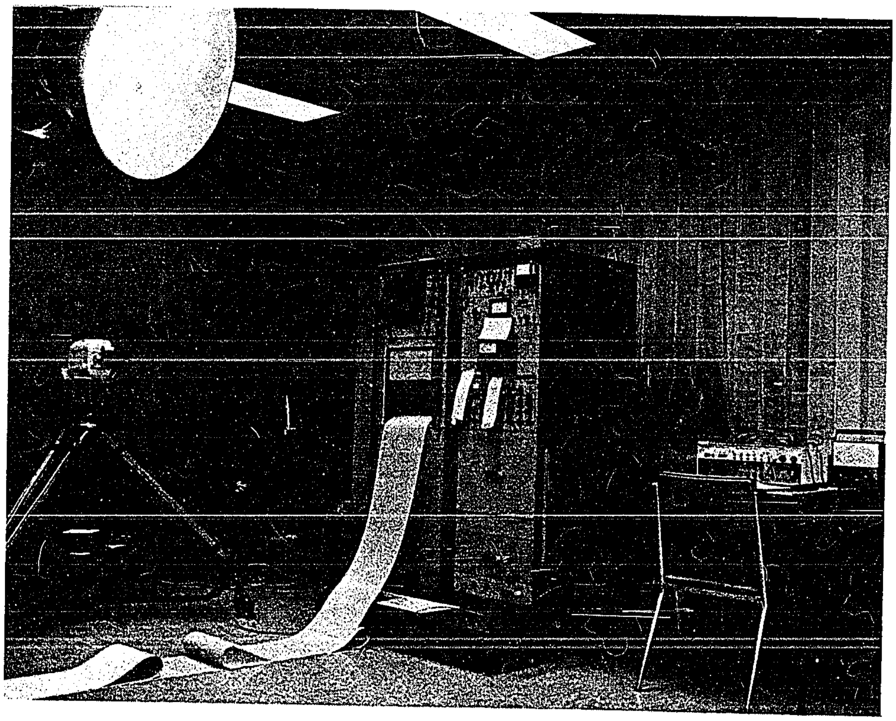


FIG. 5. CAMERA AND RECORDING SYSTEM

CHAPTER IV

RESULTS AND DISCUSSION

Results

The subject performed fifteen jumps, six without weights, and nine with a five pound dumbell in each hand.

Jump six was chosen for analysis because it was the second longest jump in this group, and a better than average force recording was obtained. Number fourteen was chosen also because of a superior force trace and the distance achieved. As well, it was chosen because earlier jumps exhibited variation in the force-time pattern, and a consistent pattern was not achieved until the last three jumps.

Film Analysis

Determination of impulse. The graphs in Figures 6 and 7 show that a positive contribution was made by the arms from 0.147 seconds to 0.293 seconds in the jump without weights, and from 0.242 seconds to 0.371 seconds in the jump with the weights. Using the technique described on page 15 the impulses of the arms and of the body were calculated, and are shown in Table 1.

TABLE 1

Impulse Comparison of the Two Jumps

	Section	Jump Without Weights	Jump With Weights
Horizontal impulse of the total body	A	8.42 lb-sec	2.88 lb-sec
	B	15.44 lb-sec	16.30 lb-sec
	C	24.39 lb-sec	42.66 lb-sec
	Total	48.25 lb-sec	61.84 lb-sec
Horizontal impulse of the arms	A	-2.02 lb-sec	-3.59 lb-sec
	B	7.26 lb-sec	9.19 lb-sec
	C	-3.70 lb-sec	-13.10 lb-sec
	Total	1.54 lb-sec	-7.86 lb-sec
Percentage of the impulse contributed by the arms	A	*16.21%	*35.69%
	B	47.02%	56.38%
	C	*11.64%	*19.02%

*The impulse of the arms was directed in the opposite direction to the desired jumping direction.

Critical regions. The critical regions were determined by the maxima and minima of all three acceleration graphs.

It should be noted that the acceleration graphs varied slightly from the force traces. The variance was most noticeable at the maxima and minima of the graph, since the greatest errors due to double differentiation would be magnified at these points. This has previously been noted by Murray, Seireg and Scholz (1967).

Because the same pattern was evidenced in both the jumps with and without weights, the sets of graphs were split into three sections for the purpose of analysis. Section A was from the start of the graph to the first intersection of the arms and "body minus the arms" graph. The second section, B, was from the first intersection to the second intersection, and the final part, C, was from the second intersection to the point of leaving the platform. These points are clearly marked on Figures 6 and 7.

Instant of leaving the platform. The apparatus designed to determine the exact moment the subject's foot left the platform failed to work consistently throughout the testing period, and was thus rejected as a valid means of determining the subject's last moment of contact. It was not possible to explain the inconsistency which showed the subject leaving the platform anywhere from 0.0225 seconds to 0.08 seconds before the end of the force trace.

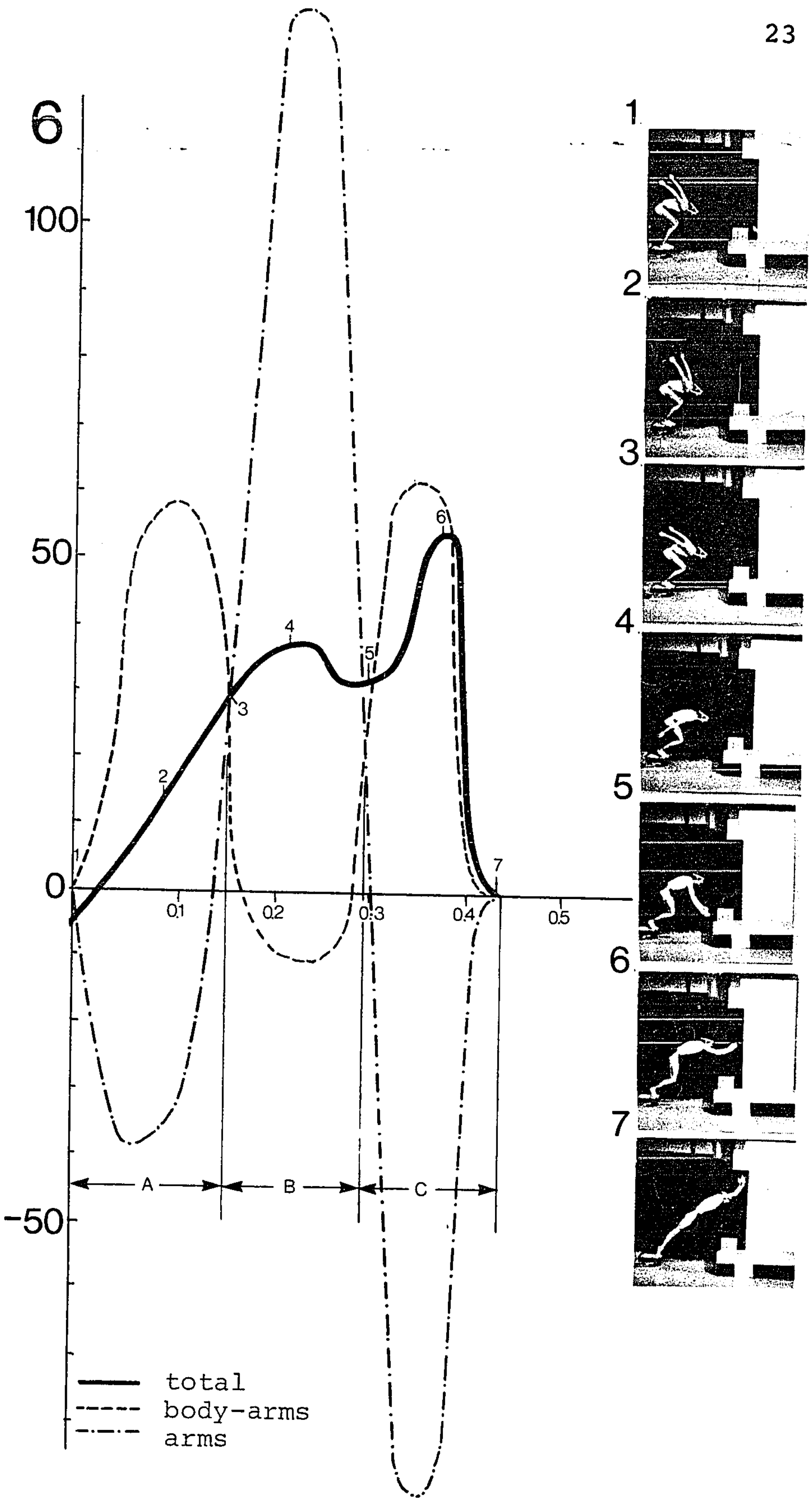


FIG. 6. ACCELERATION-TIME GRAPH OF JUMP SIX

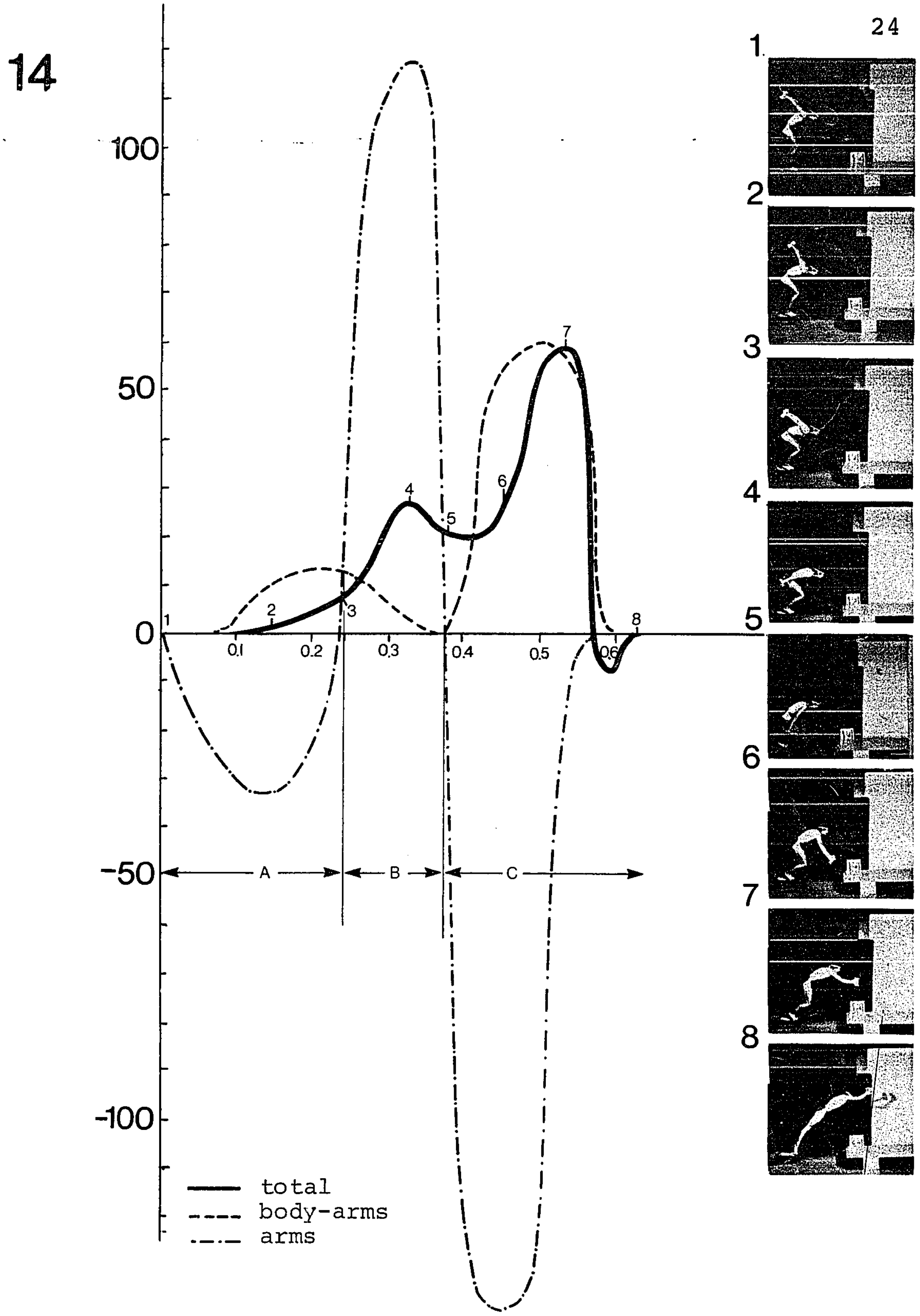


FIG. 7. ACCELERATION-TIME GRAPH OF JUMP FOURTEEN

TABLE 2

Time Comparison of the Two Jumps

	Section	Jump Without Weights	Jump With Weights
Time in each section	A	0.147 sec.	0.242 sec.
	B	0.147 sec.	0.129 sec.
	C	0.130 sec.	0.226 sec.
	Total	0.424 sec.	0.597 sec.
Percentage of time spent in each section	A	35%	41%
	B	35%	22%
	C	30%	38%

TABLE 3

Force and Acceleration Comparison of the Two Jumps

	Section	Jump Without Weights	Jump With Weights
Maximum horizontal acceleration of the center of gravity of the body	A	34 ft/sec^2	12 ft/sec^2
	B	39 ft/sec^2	27 ft/sec^2
	C	56 ft/sec^2	59 ft/sec^2
Maximum horizontal acceleration of the center of gravity of both arms	A	-39 ft/sec^2	-32 ft/sec^2
	B	140 ft/sec^2	117 ft/sec^2
	C	-96 ft/sec^2	-137 ft/sec^2
Maximum horizontal force exerted by the body	A	152 lb.	57 lb.
	B	175 lb.	127 lb.
	C	251 lb.	278 lb.
Maximum horizontal force exerted by both arms	A	-20 lb.	-24 lb.
	B	73 lb.	86 lb.
	C	-50 lb.	-101 lb.

The frame-by frame output from the camera was used to link the film directly to the force recording as is shown in Figure 8. This method had been used successfully by other investigators. The frame-by-frame output of the camera indicated the camera speed to be one hundred thirty-four frames per second in jump six, and the actual speed was 122.8 frames per second (± 1%). The actual speed of the camera in jump fourteen was 124.16 frames per second (± 1%), and the camera output indicated a speed of one hundred thirty frames per second.

Changes in the force trace pattern. Mention should be made of the changes that occurred in the force traces during the nine recorded jumps with weights. The graphs became smoother and have a higher peak force, perhaps indicating that the subject was learning how to more effectively utilize the weights. Reproductions of the force traces seven to fifteen may be found in Appendix D. The inference, although not within the context of this study, is that force traces may be of value in explanation or detection of a learning pattern.

Discussion

The Acceleration Graphs

These graphs (Fig. 6 and 7) are a composite drawing of the horizontal accelerations of the total body, the body minus the arms, and the arms. The numbers on the heavy line, the total body acceleration, refer to the pictures at the side of the graph.

Above the zero line is acceleration, and below this line is deceleration. Acceleration means that a force is being exerted in the positive direction (in this case, to the right), and the deceleration means that a force is being exerted in the negative direction (to the left). For any positive acceleration, the segment referred to was either increasing its velocity if it was moving in a positive direction, or decreasing its velocity if it was moving in a negative direction. In the same sense, a deceleration means that the segment was decreasing its velocity if it was moving in a positive direction, or increasing its velocity if moving in a negative direction.

Acceleration is the rate of change of velocity, and as such, it is possible to have greater and lesser changes of velocity. This means that a segment can still be increasing its velocity even though the graph has a negative slope, if the graph is above the zero acceleration line.

Effect of the Arms

The arms were accelerating faster than the body minus the arms in sections B of the graphs in Figures 6 and 7, in this, therefore, was the area in which the arms were directly contributing to the jump.

The body may be thought of as a hinged link system

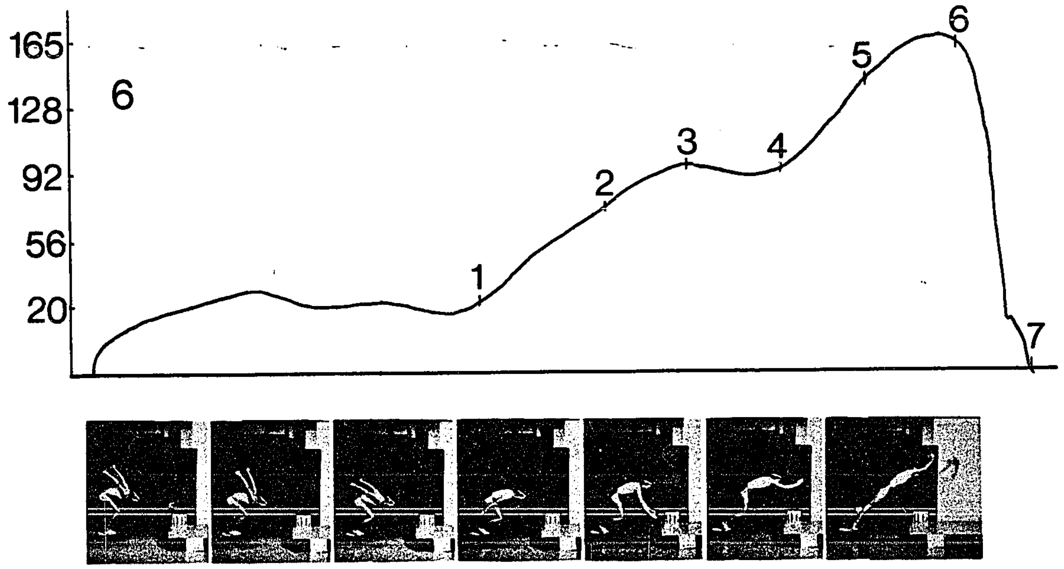


FIG. 8. SYNCHRONIZATION OF BODY POSITIONS WITH THE FORCE TRACE OF JUMP SIX

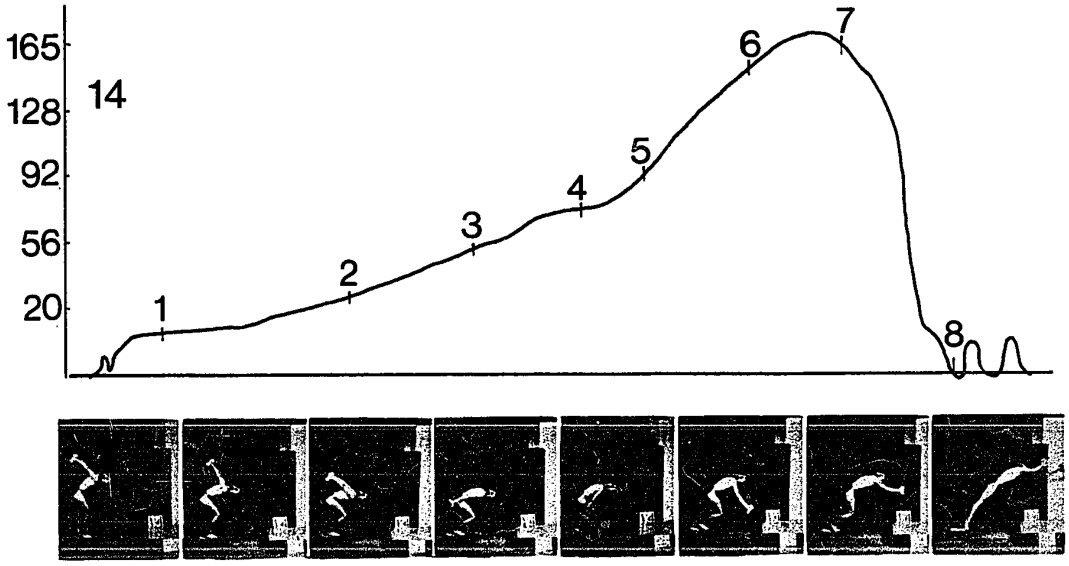


FIG. 9. SYNCHRONIZATION OF BODY POSITIONS WITH THE FORCE TRACE OF JUMP FOURTEEN

which is required to transmit forces in various ways. Any force generated by the arms must be transmitted through the trunk and legs to the ground. In sections A and C, the arms had an impulse in the negative direction and therefore were not, by themselves, increasing the total impulse of the body. It cannot be inferred, however, that the arms are detracting from the jump in A and C, because there are considerations other than the purely mechanical impulse contribution.

Over the entire jump, the arms alone contributed 1.537 lb-sec of impulse (approximately 3% of the total) in jump six. Payne (1968) found an approximate increase of six percent in the vertical impulse due to the arms, when jumping without weights. Thus a three percent contribution in the horizontal impulse of a standing long jump without weights seems reasonable. A negative 7.86 lb-sec of impulse were generated when jumping with the weights.

It should be remembered, however, that the subject was a skilled performer at jumping without weights, but could not be considered to be a skilled performer at jumping with weights.

Comparison of the Two Jumps

In jump six, the three sections are all executed in about the same time, while jump fourteen is split in a 2:1:2 ratio. Using jump six as a standard, this 2:1:2 ratio would imply that the subject not only found the weights hard to accelerate initially, but also that he could not accelerate them for as long a period as he was accustomed to accelerating his arms normally.

The maximum force exerted by the total body was larger for number six in sections A and B, but smaller than jump fourteen in section C. This would suggest that the force developed by the arms was allowing a larger force to be built up in the legs while not allowing them to extend, resulting in a larger than normal impulse for section C. Since a large period of time was also spent in this section, it could be conjectured that the legs also found the extra ten pounds difficult to accelerate.

The total horizontal impulse of jump fourteen was approximately thirteen and one half pound-seconds greater than jump six, and the subject jumped about six inches further in jump fourteen. The time in flight was nearly identical for each jump, and therefore the greater distance achieved was primarily due to a greater horizontal velocity in jump fourteen. The vertical velocity on takeoff for jump six was 7.23 feet per second, and for fourteen was 7.21 feet per second.

An improved landing technique exhibited in jump fourteen also provided an increase of approximately one and one half inches in the distance jumped. This technique was the ability to put a substantial part of his mass behind the path of his center of gravity, thus allowing his feet to reach further ahead than normal.

Nothing can be said about the arms' overall contributions to the jumps, because the effects on the other body segments of the arms accelerating or decelerating were not examined. All that can be stated is whether or not the mass of the arms was contributing to the impulse at any given instant.

Physical Positions of the Performer

As shown in Figures 6 and 7, the subject seems to be in the same relative position at the critical regions in each jump, except that the arms in jump fourteen are slightly slower.

Although it is difficult to connect positions to exact points on the force trace shown by Sinclair (1970), there are similarities in the stance of the subject at the two peaks of the force traces.

Force Exerted Before Deepest Knee Flexion

Eckert (1964) has reported a study based on the assumption that there is no force generated before deepest knee flexion in the standing long jump. The results of this study show that twenty to sixty-five percent of the total impulse had been generated by this time.

Practical Implications

The results of this study show that increasing the effectiveness of the arms results in a greater horizontal velocity at takeoff. This suggests that it would be advisable for coaches to stress acceleration of the arms to obtain an improvement in the distance jumped.

It is interesting to note that if the weights were dropped immediately after they had finished contributing to the total horizontal impulse (position 5 in Figures 6 and 7), the jumper should jump further.

Increasing the effectiveness of the arms also increases the length of time the legs can exert force. This would result in a greater horizontal velocity at takeoff as was exhibited in jump fourteen.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The primary purpose of this study was to determine the percentage contribution of the arms to the total horizontal impulse in the standing long jump. A secondary purpose was to examine the effects of five pound weights held in each hand.

One volunteer subject, a twenty year old male who was an experienced long jumper, was used. On the day of the testing, he performed six jumps for maximal distance without weights, and nine jumps with weights for maximal distance from a force platform.

Force recordings were made of each jump, and all jumps were photographed at approximately one hundred twenty-four frames per second. The accelerations of the centers of gravity of the total body, both arms, and of the body minus both arms were calculated; then the impulses of the total body and of the combined arms were computed for two jumps and used to determine the contributions of the arms.

The effect of jumping with weights was examined and the effect of the increased mass on the motion of the arms was noted.

Conclusions

The following conclusions were drawn from the information gathered:

1. The arms contribute to the horizontal impulse during the middle one-third of a standing long jump for maximal distance, and detract from the total horizontal impulse in the remainder of the jump.

2. In a standing long jump for maximal distance when using weights, the arms contribute to the horizontal impulse during the middle one-fifth of the jump, but detract from the impulse in the remainder.

3. Performing a standing long jump with weights in the hands effectively increases the horizontal impulse, while maintaining approximately the same vertical impulse as a jump without weights.

BIBLIOGRAPHY

BIBLIOGRAPHY

Adamson, G. T. and R. J. Whitney. "The Fallacy of Athletic Power," The Royal Canadian Legion's Coaching Review, 4:1-3, 1969.

Barrow, Harold M. and Rosemary McGee. Measurement in Physical Education. Philadelphia: Lea & Febinger, 1968.

Baumgartner, Ted and Andrew Jackson. "Measurement Schedules for Tests of Motor Performance," Research Quarterly, 41:10-14, 1970.

Bunn, John W. Scientific Principles of Coaching. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1964.

Caskey, Sheila R. "Effects of Motivation on Standing Broad Jump Performance of Children," Research Quarterly, 39:54-59, 1968.

Clarke, H. Harrison. Application of Measurement to Health and Physical Education. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1960.

Clarke, H. Harrison and Ernest W. Degutis. "Relationships Between Standing Broad Jump and Various Maturational, Anthropometric and Strength Tests of Twelve Year Old Boys," Research Quarterly, 35:258-264, 1964.

Considine, William J. "A Validity Analysis of Selected Leg Power Tests Using a Force Platform," Biomechanics, (Proceedings of the C.I.C. Symposium on Biomechanics, Indiana University, October, 1970.), ed. J. M. Cooper. Chicago: The Athletic Institute, 1971.

Cooper, John M. and Ruth B. Glassow. Kinesiology. St. Louis: C. V. Mosby Co., 1972.

Cooper, Leon N. An Introduction to the Meaning and Structure of Physics. New York: Harper & Row, 1968.

Cureton, T. K. "Elementary Principles and Techniques of Cinematographical Analysis as Aids in Athletic Research," Research Quarterly, 10:210-211, 1939.

Dillman, Charles J. "A Kinetic Analysis of the Recovery Leg During Sprint Running," Biomechanics, (Proceedings of the C. I. C. Symposium on Biomechanics, Indiana University, October, 1970.), ed. J. M. Cooper, Chicago: The Athletic Institute, 1971.

Eckert, Helen M. "Linear Relationships of Isometric Strength to Propulsive Force, Velocity and Acceleration in the Standing Broad Jump," Research Quarterly, 35:298-306, 1964.

________. "Takeoff Variations in the Standing Broad Jump," Research Quarterly, 37:143-145, 1966.

________. "Angular Velocity and Range of Motion in the Vertical and Standing Broad Jumps," Research Quarterly, 39:937-942, 1968.

Glencross, D. J. "A Mechanical Analysis of the Standing Broad Jump and Vertical Jump," New Zealand Journal of Physical Education, 3:29-36, 1964.

________. "The Nature of the Vertical Jump Test and the Standing Broad Jump," Research Quarterly, 37:353-359, 1966.

Gombac, R. "Analysis of Movement by Film," Biomechanics I. New York: S. Karger, 1968.

Henry, F. M. "Force-Time Characteristics of the Sprint Start," Research Quarterly, 23:301-318, 1952.

Hopper, B. J. and J. E. Kane. "Analysis of Film--The Segmentation Method," Biomechanics I. New York: S. Karger, 1968.

Ketlinski, Randolph. "Can High Speed Photography Be Used as a Tool in Biomechanics?" Biomechanics, (Proceedings of the C. I. C. Symposium on Biomechanics, Indiana University, October, 1970.), ed. J. M. Cooper. Chicago: The Athletic Institute, 1971.

Lanier, Louis. "A Comparison of Techniques of Determining Velocity in the Track Sprint Start." Unpublished Master's Thesis, University of Alberta, 1968.

Lindeburg, Franklin A, Donald K. Edwards, and William D. Heath. "Effect of Isometric Exercise on Standing Broad Jump Ability," Research Quarterly, 34:478-483, 1963.

Murray, M. P., A. Seireg, and R. C. Scholz. "Center of Gravity, Center of Pressure, and Supportive Forces During Human Activities," Journal of Applied Physiology, 23:831-838, 1967.

Noss, James. "Control of Photographic Perspective in Motion Analysis," Journal of Health, Physical Education, and Recreation, 38:81-84, 1967.

Payne, A. H., W. J. Slater, and T. Telford. "The Use of a Force Platform in the Study of Athletic Activities. A Preliminary Investigation," Ergonomics, 11:123-145, 1968.

Ramey, Melvin R. "Effective Use of Force Plates for Long Jump Studies," Research Quarterly, 43:247-252, 1972.

Rarick, G. Lawrence and Nancy Oyster. "Physical Maturity, Muscular Strength, and Motor Performance of Young School Age Boys," Research Quarterly, 35:523-531, 1964.

Roberts, E. "Cinematography in Biomechanical Investigation," Biomechanics, (Proceedings of the C. I. C. Symposium on Biomechanics, Indiana University, October, 1970.), ed. J. M. Cooper. Chicago: The Athletic Institute, 1971.

Russell, Neil. "Analysis of Force-Time Characteristics of Selected Sprint Starts in Swimming," Unpublished Master's Thesis, University of Alberta, 1967.

Sinclair, Helen. "Influence of the Block Angle on Swim Spring Starts," Unpublished Master's Thesis, University of Alberta, 1970.

Sprigings, Eric. "Cinematography and Force-Time Curves in a Sprint Start," Unpublished Master's Thesis, University of Alberta, 1972.

Taylor, Paul R. "Essentials in Cinematographical Analysis," Biomechanics, (Proceedings of the C. I. C. Symposium on Biomechanics, Indiana University, October, 1970.), ed. J. M. Cooper. Chicago: The Athletic Institute, 1971.

Walton, James S. "A Template for Locating Segmental Centers of Gravity," Research Quarterly, 41:615-618, 1970.

Williams, M. and H. R. Lissner. Biomechanics of Human Motion. Philadelphia: W. B. Saunders Co., 1962.

Zimmerman, Helen M. "Characteristic Likenesses and Differences Between Skilled and Non-Skilled Performers of Standing Broad Jump," Research Quarterly, 27:352-362, 1956.

APPENDIX A

CALIBRATION

CALIBRATION OF THE FORCE BLOCKS

After the core had been centered within the coil, and the output summed by the O. A. Adder and reduced by a factor of 20, the following calibrations were carried out: twenty pounds were applied to each block, and the voltage increase was noted; then forty pounds were applied to each block and again the voltage increase was noted. The average voltage per pound increase was calculated.

From the average voltage per pound, the electrical equivalent of weights from ten to three hundred and twenty pounds were calculated, and input to the recording system to obtain a calibration curve.

CALIBRATION OF THE FORCE BLOCKS

A: Forty pounds

Trial	Voltage Without Load	Voltage With Load	Difference
1	0.44	0.76	0.32
2	0.43	0.76	0.33
3	0.44	0.76	0.32
4	0.43	0.76	0.33
5	0.43	0.76	0.33
6	0.43	0.75	0.32
7	0.43	0.77	0.34
8	0.43	0.76	0.33
9	0.43	0.75	0.32
10	0.43	0.76	0.33
			Σ = 3.27
			$\bar{x}$ = 0.327

Voltage per pound = 0.0082

B: Eighty pounds

Trial	Voltage Without Load	Voltage With Load	Difference
1	0.44	1.13	0.69
2	0.33	1.14	0.71
3	0.33	1.11	0.68
4	0.33	1.14	0.71
5	0.33	1.12	0.69
6	0.33	1.14	0.71
7	0.33	1.12	0.69
8	0.33	1.12	0.69
9	0.33	1.12	0.69
10	0.33	1.12	0.69
			$\Sigma = 6.95$
			$\bar{x} = 0.695$

Voltage per pound = 0.0087

Average voltage per pound = 0.00845

APPENDIX B

CENTER OF GRAVITY COMPUTER PROGRAM

COMPUTER PROGRAM TO CALCULATE CENTER OF GRAVITY

Prepared by Doris Miller*

May, 1969

The output of this program consists of the X and Y coordinates for the center of gravity of each body segment as well as for the total body. The coordinates refer to specific locations on the Vanguard analyzer and are consistent with the coordinates of the end points of the limbs. Dempster's data on relative masses of the segments and segmental center of gravity locations have been employed.

Input

Two data cards are required for each frame analysed, the first containing the X coordinates of the specified limb end points and the second containing the Y coordinates. All data cards must have the following format:

Column	Content
	Event - Devise a code of numbers 1-9 to indicate events of special interest such as take-off, touch-down, etc. This column may be left blank if desired.
	Blank
3, 4, 5	Frame number right justified.
6, 7, 8*	Available for other identification. It is strongly suggested that a "1" be placed in column 7 to indicate the card

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*Professor of Physical Education, University of Saskatchewan.

Column	Content
6, 7, 8*	contains X coordinates and a "2" if it contains Y coordinates. The computer does not read this field but it can be utilized to include information which will facilitate the verification of the raw data. These columns may be left blank if desired.

Columns 9-75 will contain the coordinates of the limb end points obtained from the analyser. Only the first three figures will be recorded. Although no decimals are punched, the computer will interpret the coordination as having one figure to the left of the decimal and two to the right, e.g., 513 will be read as 5.13.

If this is the first card for a particular frame, the following columns will contain the X coordinates; if it is the second card it will contain the Y coordinates.

Column	Content
9, 10, 11	Ear
12	Blank
13, 14, 15	Right shoulder
16	Blank
17, 18, 19	Right elbow
20	Blank
21, 22, 23	Right wrist
24	Blank
25, 26, 27	Right fingertips - may be left blank if this information is not available.
28	Blank
29, 30, 31	Left shoulder.
32	Blank
33, 34, 35	Left elbow
36	Blank
37, 38, 39	Left wrist
40	Blank
41, 42, 43	Left fingertips - may be left blank if this information is not available.
44	Blank
45, 46, 47	Center hip

Column	Content
48	Blank
49, 50, 51	Right knee
52	Blank
53, 54, 55	Right ankle
56	Blank
57, 58, 59	Right toes
60	Blank
61, 62, 63	Left knee
64	Blank
65, 66, 67	Left ankle
68	Blank
69, 70, 71	Left toes
72	Blank
73*	Test number - may be left blank but is useful if several test sessions are to be held, e.g., pilot study, pre-test, post-test, etc.
74, 75	Card number - the first card of each trial must be numbered 01. This is the signal for the computer to print new identification and headings for the output. Subsequent cards are numbered consecutively: 01 Trial 1 X coordinates 1st frame analysed 02 Trial 1 Y coordinates 1st frame analysed 03 Trial 1 X coordinates 2nd frame analysed 04 Trial 1 Y coordinates 2nd frame analysed 05 Trial 1 X coordinates 3rd frame analysed 06 Trial 1 Y coordinates 3rd frame analysed etc. 01 Trial 2 X coordinates 1st frame analysed etc.
76*	Speed
77*	Variable
78*	Trial
79, 80	Subject number - right justify

*It is not absolutely necessary to use these spaces but they will provide further information about the trial. Suitable single digit codes should be devised. Examples are as follows:

Speed
1 = 5 ft/sec
2 = 10 ft/ sec

Variable
1 = uphill
2 = level
3 = downhill

7

The trial number is useful where a subject performs more than once under the same experimental conditions.

General Instructions

1. Only numbers can appear on the data cards (no alphabetic characters are permitted).

2. All the spaces must be filled unless indicated otherwise in the above description of the card format.

3. If the fingertip coordinates are not available, this program will estimate the center of gravity location for the forearm and arm combined. If this is the case, leave columns 25, 26, 27, and 41, 42, 43 blank. Appropriate calculations will then be performed and titles printed. Be consistent within a trial: either include the fingertip coordinates for all the frames in a trial or do not include any.

Verifying the Output

1. Identification and titles should be printed for each trial. If these are missing at the beginning of a trial, probably a data card is missing. Check to see that there are two cards for each frame.

2. The X and Y coordinates for the center of gravity of the head and neck should be identical to the ear coordinates of the raw data.

3. Hand calculate two or three frames at random.

Comments

This program is written so that those unfamiliar with computer programming will be able to follow the logic of the calculations. The accompanying diagram and comments within the program itself should make this possible. The program requires less than one minute of computer time.

APPENDIX C

COMPUTER PROGRAM MODIFICATIONS

COMPUTER PROGRAM MODIFICATIONS

One modification was necessary to obtain the desired data on jump six. The segment weights as a percentage of the total weight were modified so the program would print out the center of gravity of the arms and the center of gravity of the body minus the arms (modification #1).

Two changes were developed for jump fourteen. The addition of five pound dumbells in each hand necessitated a change in the segment weight percentages in the calculation of the total body's center of gravity (modification #2). To obtain the centers of gravity of the combined arms and the body minus the arms, a similar change to modification #1 was necessary, bearing in mind the changed segment weight percentages (modification #3).

SEGMENT WEIGHTS AS A PERCENTAGE OF TOTAL WEIGHT

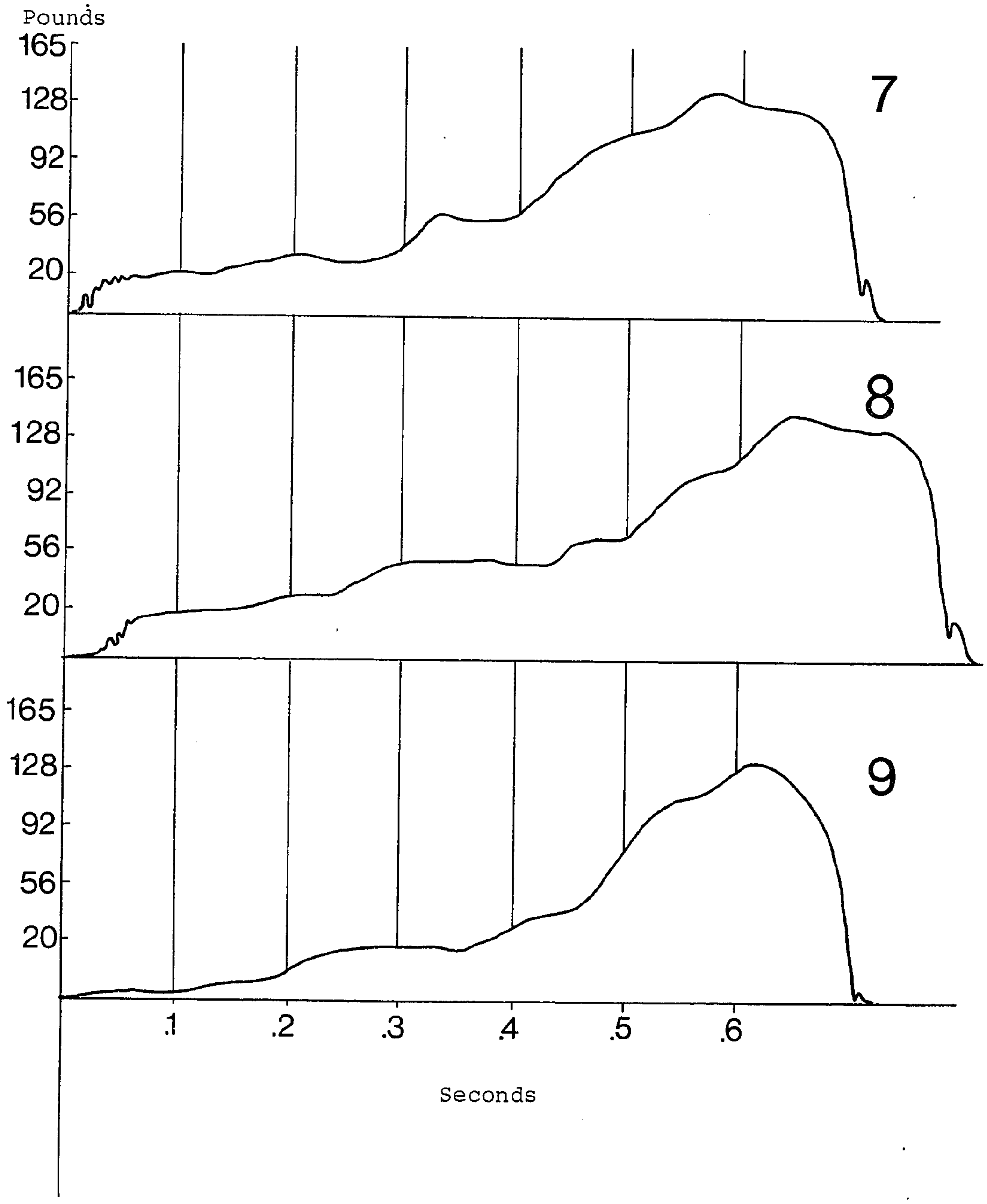
Segment	Standard Program*	Modification #1	Modification #2	Modification #3
Head and neck	7.90%	8.48%	7.38%	8.48%
Trunk	51.40%	56.80%	48.06%	56.80%
Right thigh	9.65%	10.71%	9.02%	10.71%
Right calf	4.50%	5.04%	4.20%	5.04%
Right foot	1.40%	1.59%	1.30%	1.59%
Left thigh	9.65%	10.71%	9.02%	10.71%
Left calf	4.50%	5.04%	4.20%	5.04%
Left foot	1.40%	1.59%	1.30%	1.59%
		/100%		/100%
Right upper arm	2.65%	27.20%	2.47%	15.21%
Right forearm	1.55%	16.16%	1.44%	9.03%
Right hand	0.60%	6.62%	3.80%	25.74%
Left upper arm	2.65%	27.20%	2.47%	15.21%
Left forearm	1.55%	16.16%	1.44%	9.03%
Left hand	0.60%	6.62%	3.80%	25.74%
	/100%	/100%	/100%	/100%

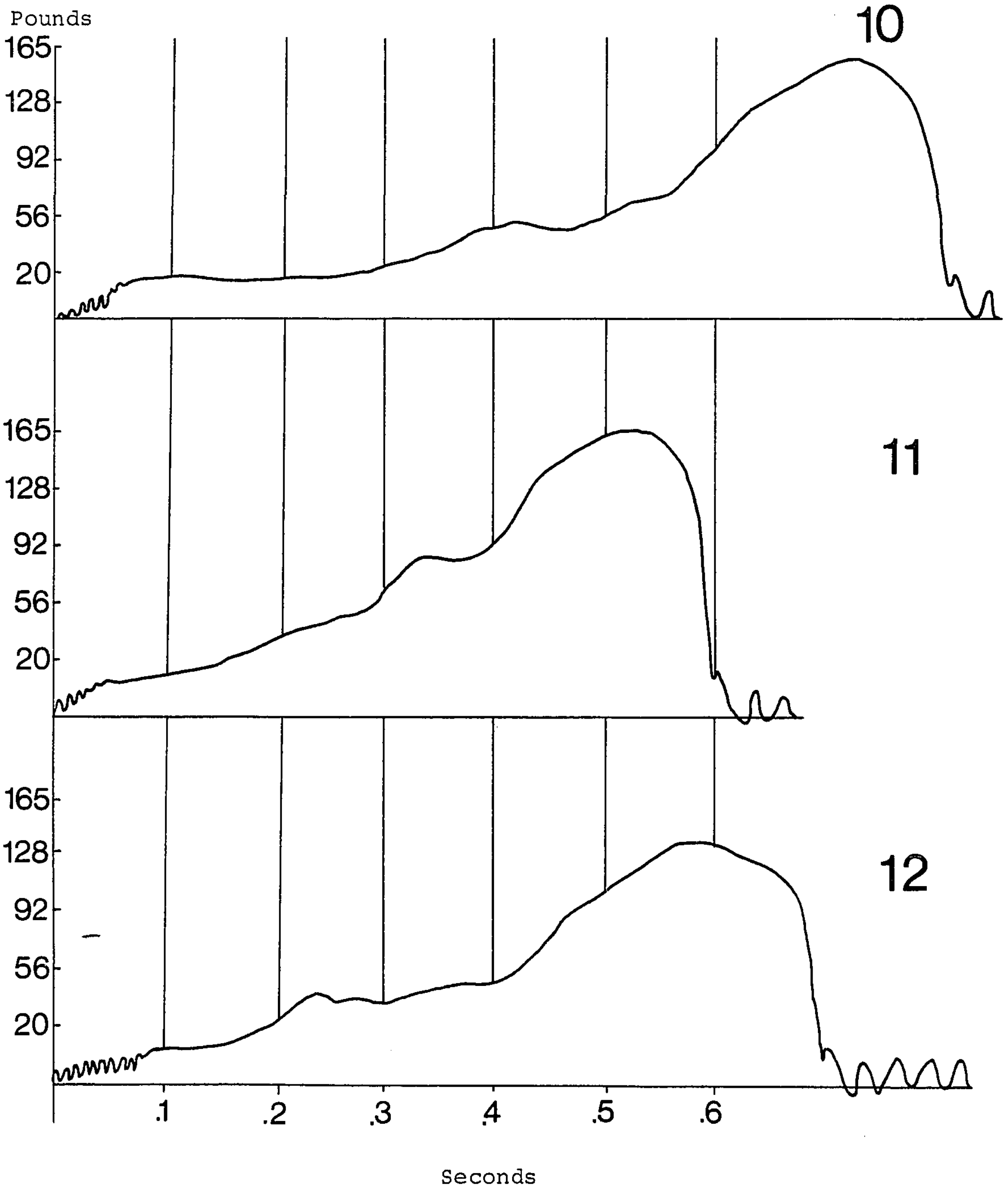
* based on a 131.5 pound man

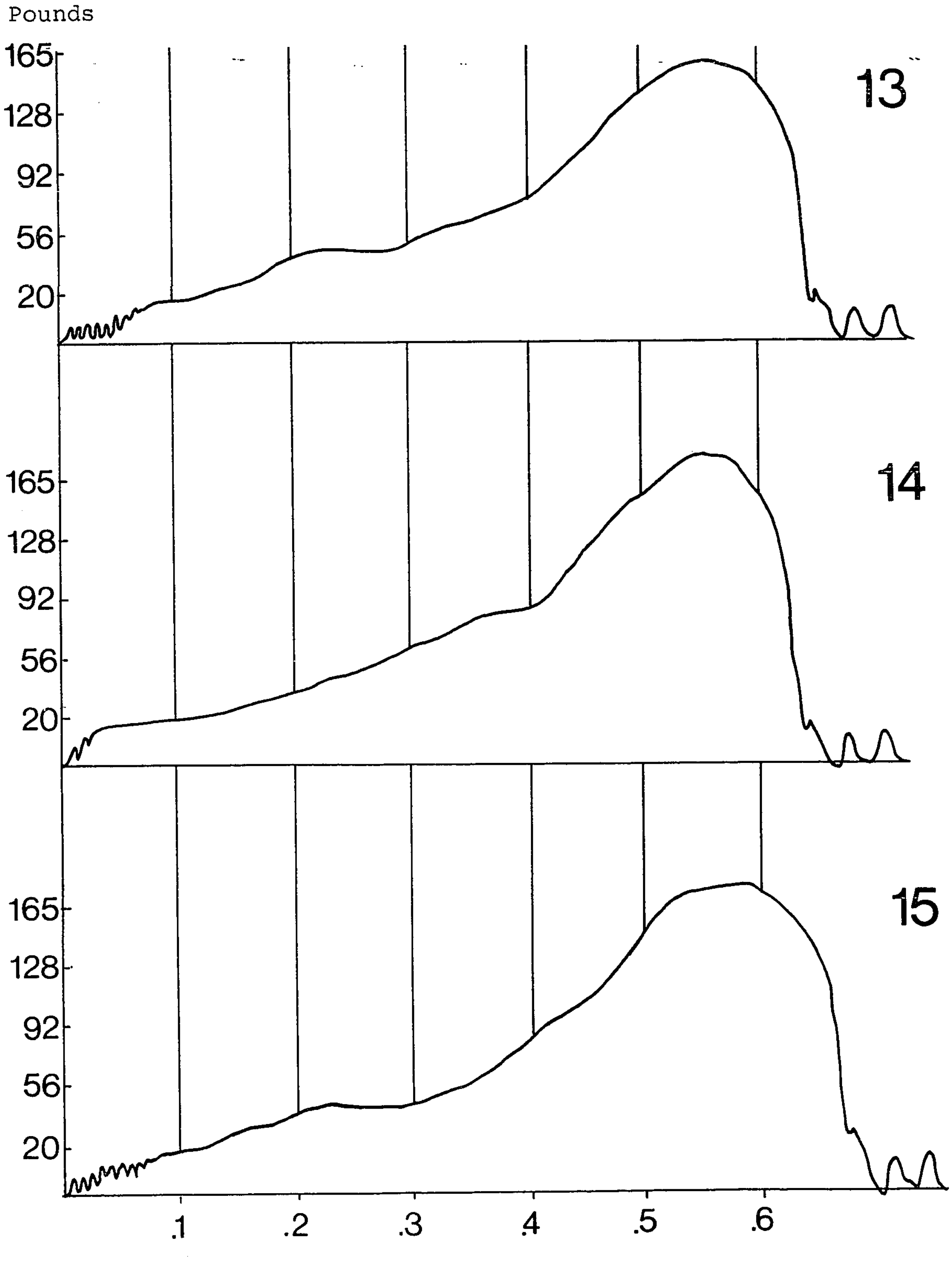
** based on a 131.5 + 10 = 141.5 pound man

APPENDIX D

PROGRESSION OF FORCE TRACES


Pounds
165
128
92
56
20
7
165
128
92
56
20
8
165
128
92
56
20
9
.1
.2
.3
.4
.5
.6
Seconds


Pounds
165
128
92
56
20
10
165
128
92
56
20
11
165
128
92
56
20
12
.1
.2
.3
.4
.5
.6
Seconds


Pounds
165
128
92
56
20
13
165
128
92
56
20
14
165
128
92
56
20
15
.1
.2
.3
.4
.5
.6
Seconds