TECHNICAL REPORT
70-65-CE

DESIGN, DEVELOPMENT AND FABRICATION OF A PERSONNEL ARMOR LOAD PROFILE ANALYZER

by

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Chicago, Illinois

and

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U.S. Army Natick Laboratories
Natick, Massachusetts

Contract No. DAAG17-69-C-0008

April 1970

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing and Personal Life Support Equipment Laboratory
C&PLSEL-75

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FOREWORD

Many varieties of armor suspension systems have been designed in the past to carry and position protective armor on the human body. Evaluation of these systems has been purely subjective with sparse or nonexistent analytical data available to determine the efficacy of the various systems related to load distribution, comfort and wearer endurance, and resistance to fatigue. An instrument which can evaluate and compare armor suspensions, or other military load-carrying equipment would have great value in optimizing the various designs. To this end, the IIT Research Institute undertook the development of such an instrument.

This is the final report for IIT Research Institute Project J6162, "Personnel Armor Load Profile Analyzer." The program was conducted for the U. S. Army Natick Laboratories by the IIT Engineering Mechanics Division under Project 1F164204D154, Development of Aircrew and Aircraft Protection.

The cooperation of Dr. Ronald Singer, anthropologist and Director of the Anatomy Department of the University of Chicago, in supplying physiological background information related to human tolerances to load and torso sensitivity greatly supplemented program efforts.

The project officer for the U. S. Army Natick Laboratories, Mr. Edward R. Barron, Mr. Stanley Tanenholtz, instrument advisor, and Mr. Robert M. White, physical anthropologist, provided guidance which substantially enhanced the results of the program.

In addition to the authors, participating IIT Research Institute staff members who contributed to the program were C. Ogden, C. Hall, K. Mayerhofer, R. Rodzen, R. Joyce and J. MacDonald.

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ABSTRACT

The purpose of this program was to design, develop, and fabricate an instrument which could locate and sense loads induced on the body of a person wearing protective armor, and to compare suspensions and suggest improvements which could be incorporated in current or future load-carrying systems.

The development of a "Personnel Armor Load Profile Analyzer" saw the attainment of a method of sensing loads, the integration and positioning of sensors in a suitable garment, a method of displaying information, and the correlation of output data to torso sensitivity.

It was found that armor suspension systems could effectively be evaluated using this instrument. Static and dynamic load patterns were displayed and the shift in these patterns with articulation could be observed. The data obtained from the display could provide guidelines for improving suspension system design by determining whether a particular suspension was effective in distributing loads on the optimum load-bearing areas of the torso. The progressive electrical contact sensor approach provided a direct reading system with maximum reliability, ruggedness, and versatility. In addition, the system did not require special signal conditioning equipment. The variable inductance sensor approach produced an analog sensor output converted to a digital display.

A review of the load-sensing and display techniques developed during the program and the supplementary work related to the selection of the final systems is provided. The results of an evaluation study of different suspension systems are presented and data presentation and interpretation are discussed.

DESIGN, DEVELOPMENT AND FABRICATION OF A PERSONNEL ARMOR LOAD PROFILE ANALYZER

Introduction

The broad variety of personnel armor suspension systems and military load-carrying devices currently in existence makes the selection or comparison of systems extremely difficult. The purpose of this program was to design and develop an instrument which could evaluate various suspension and load-carrying approaches based on their effectiveness in distributing loads to optimum load-bearing areas of the torso.

An analytical approach to the establishment of a sensitivity profile of the human torso was evolved to study pain thresholds and torso sensitivity in humans. Physiologically, certain areas of the torso are capable of carrying substantial loads, while other areas are more sensitive. Physiological and psychological differences in the makeup of individuals also account for a wide variance in their abilities to endure loads or to tolerate discomfort induced by protective or load-carrying equipment.

Knowledge of torso sensitivity was necessary in establishing design parameters for the development of a load-sensing device. This information provided a reference for determining suspension system efficacy for distributing loads on the optimum load-bearing areas of the torso.

This report includes a review of the load-sensing and display techniques developed during the course of the program and the supplementary work related to the selection of the final systems. It presents the results of an evaluation study of different suspension systems and discusses data presentation and interpretation.

PART I. SYSTEM ANALYSIS AND DESIGN

A. Load-Sensing Garment Display, Prototype #1

1. Sensor Garment and Display

A sensor garment and light display console comprise the deliverable items of Prototype #1. The complete system can be used to analyze and compare various armor suspension systems or load-carrying equipment by describing load distribution and magnitudes induced on the torso.

The sensor garment was worn on the torso and acted as an intermediate garment between armor and the body (Figure 1a). A basic fabric garment was sewn using nylon oxford cloth. The garment was overhead donned with size adjustment straps provided at each side. Chest sizes from 32 to 44 in. could be accommodated and garment length covered the 99th percentile man for torso length. The sensor garment contained a matrix of 116 progressive electrical contact sensors covering the right side of the torso, anterior and posterior. A vertical row of sensors was placed on the torso centerline, and a horizontal row of sensors was placed on the iliac crest line. The remaining sensors were positioned on 1-1/4 in. horizontal centers and 2 in. vertical centers resulting in the matrix shown in Figure 1a. The sensors were bonded to the nylon vest with Room Temperature Vulcanizer (RTV).

The output of the sensors was fed into a console which is capable of displaying 30 sensors at a time (Figure 1b). Sensor leads (a total of 464) were joined into a 6 ft long cable harness leading from the vest and terminating in a 100-pin connector. An outer cover of nylon completed the vest, covering and protecting the sensor wiring from snags and abrasion.

The sensor garment was divided into four zones with a selector switch on the display console to permit interrogation of each of the zones. A reference display manikin defines each of the zones (Figure 2). Zone 1 represents the upper front; zone 2, the upper back; zone 3, the lower front, and zone 4, the lower back. Each zone contained 30 sensors except for zone 1, which contained 26. Four sensors were eliminated for the neck cutout.

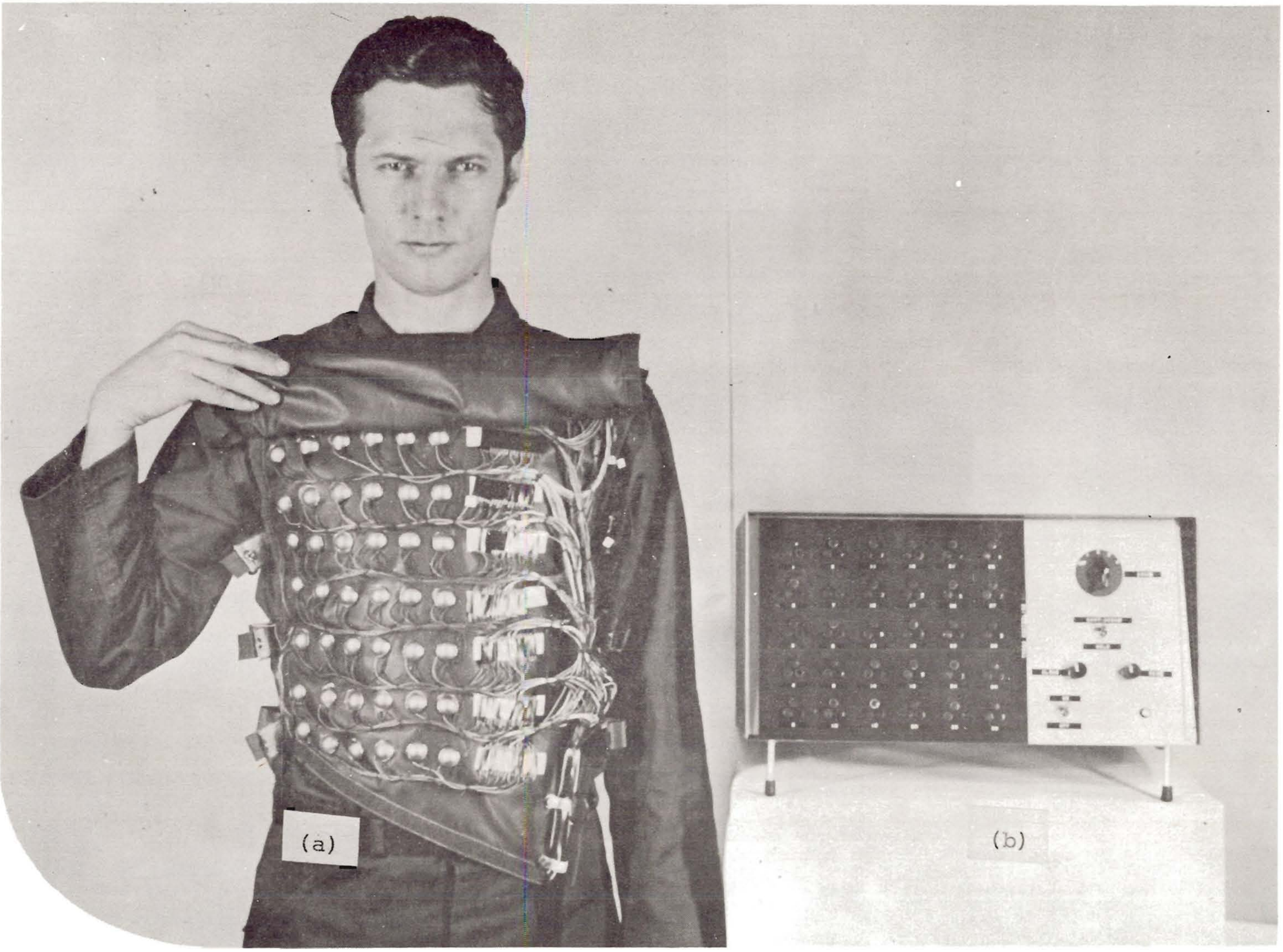
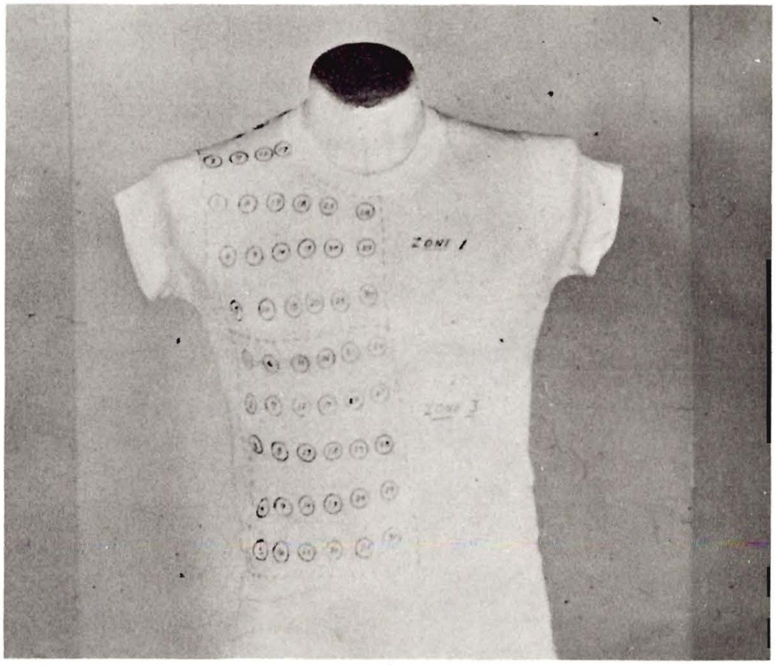
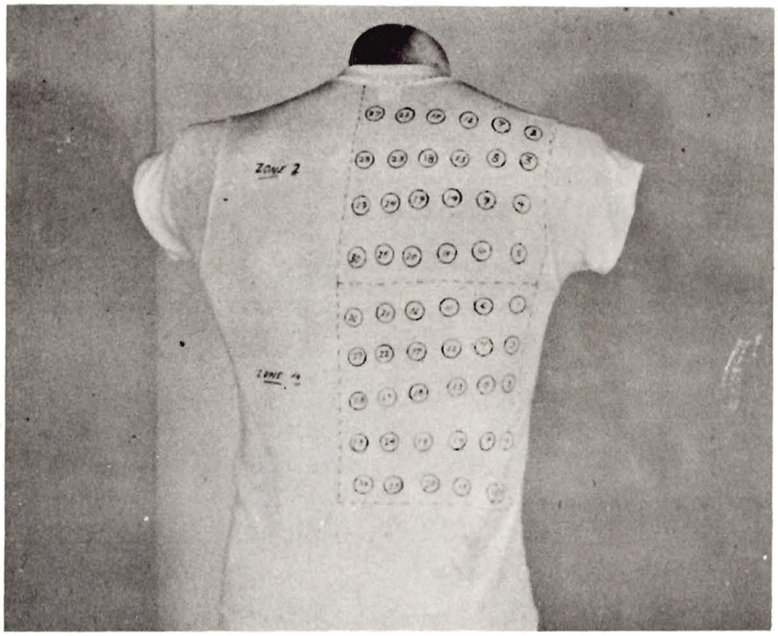


Figure 1. Load-Sensing Garment and Display Prototype #1



(a)



(b)

Figure 2. Sensor Locations On Torso Quadrants

Each sensor could discriminate between three load levels, and sensor output was depicted using a colored light cluster on the front of the display console. Green indicated loads over 1/2 lb; yellow, loads over 1 lb; and red, loads over 1-1/2 lb. The display panel contained 30 groups of three colored light clusters.

All sensor outputs for a particular zone were displayed simultaneously enabling an investigator to see loading patterns similar to isobars and to immediately identify high load areas. The display could be viewed in two operating modes, 1) a continuous mode where dynamic changes in load patterns could be observed, and, 2) a hold or memory mode where a particular load pattern could be stored in the display for recording and analysis.

The display operating controls consisted of an on-off switch, zone selector switch, mode of operation switch, read, and clear buttons, used when operating the hold mold. A schematic diagram for the light display console and load-sensing garment combination for Prototype #1 is provided in Appendix D.

2. Sensor

A progressive electrical contact sensor was designed as the load-sensing element for Prototype #1 with the sensor components and assembly depicted in Figures 3 and 4. An insulated phenolic base, 1/16 in. thick (Figures 3a and 4), supports three leaf spring contacts, with each contact representing a specific load range. A calibration screw for each leaf spring permits accurate adjustment for each sensor range.

Loads are applied to the contact switch through a spherical cap (Figure 3b). A flanged retaining ring (Figures 3c and 4) assembles the phenolic base to the spherical cap by crimping the edges over after assembly. The sensors are 11/16 in. diam and 1/4-in. thick. Four leads emanate from each sensor. Three leads connect with the three colored light cluster on the front of the display console (Figure 1b).

The progressive electrical contact sensor had the following desirable characteristics:

- Rugged, simple and dependable.
- Relatively small size.

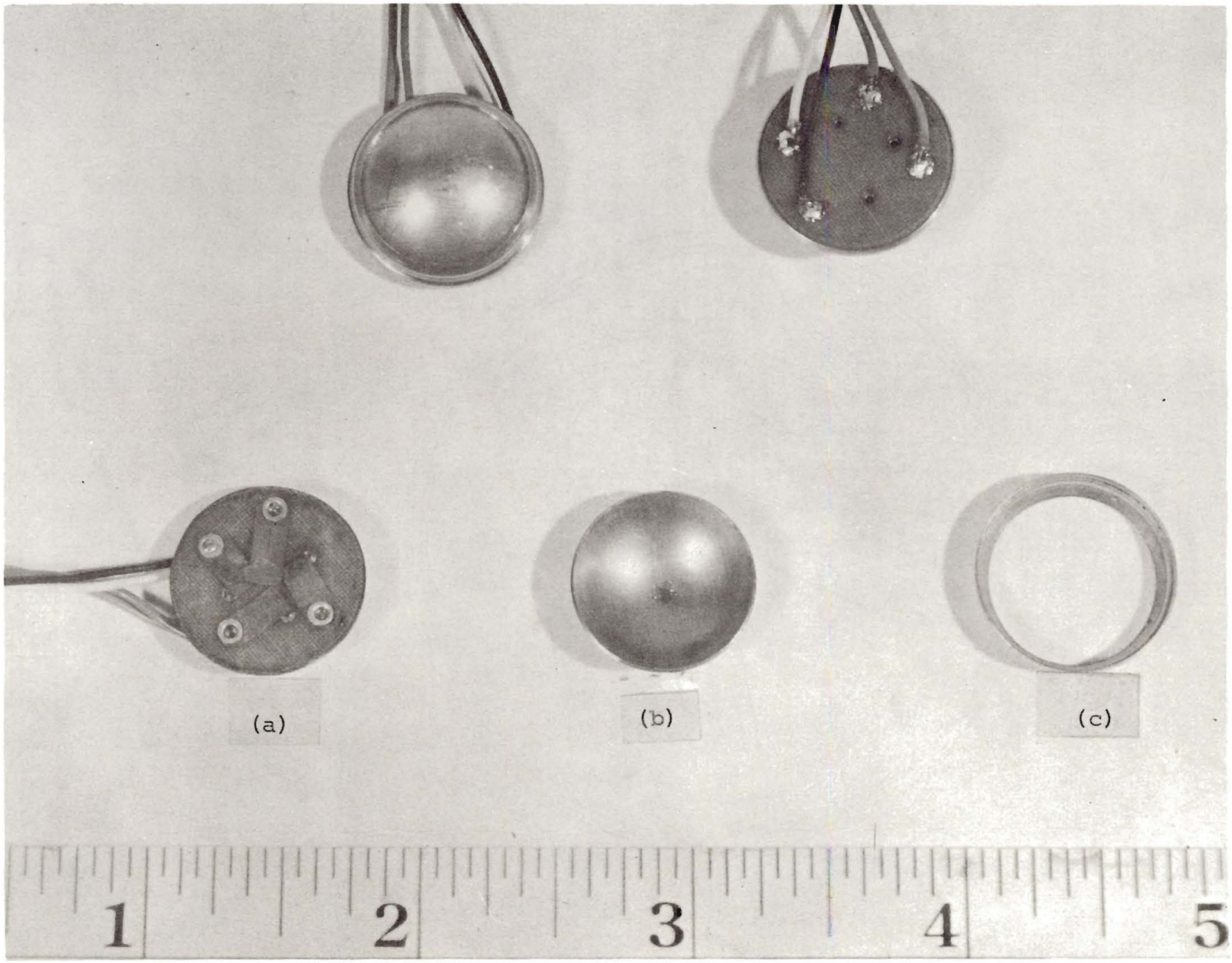


Figure 3. Progressive Electrical Contact Sensor - Prototype #1
(Components and Assembly)

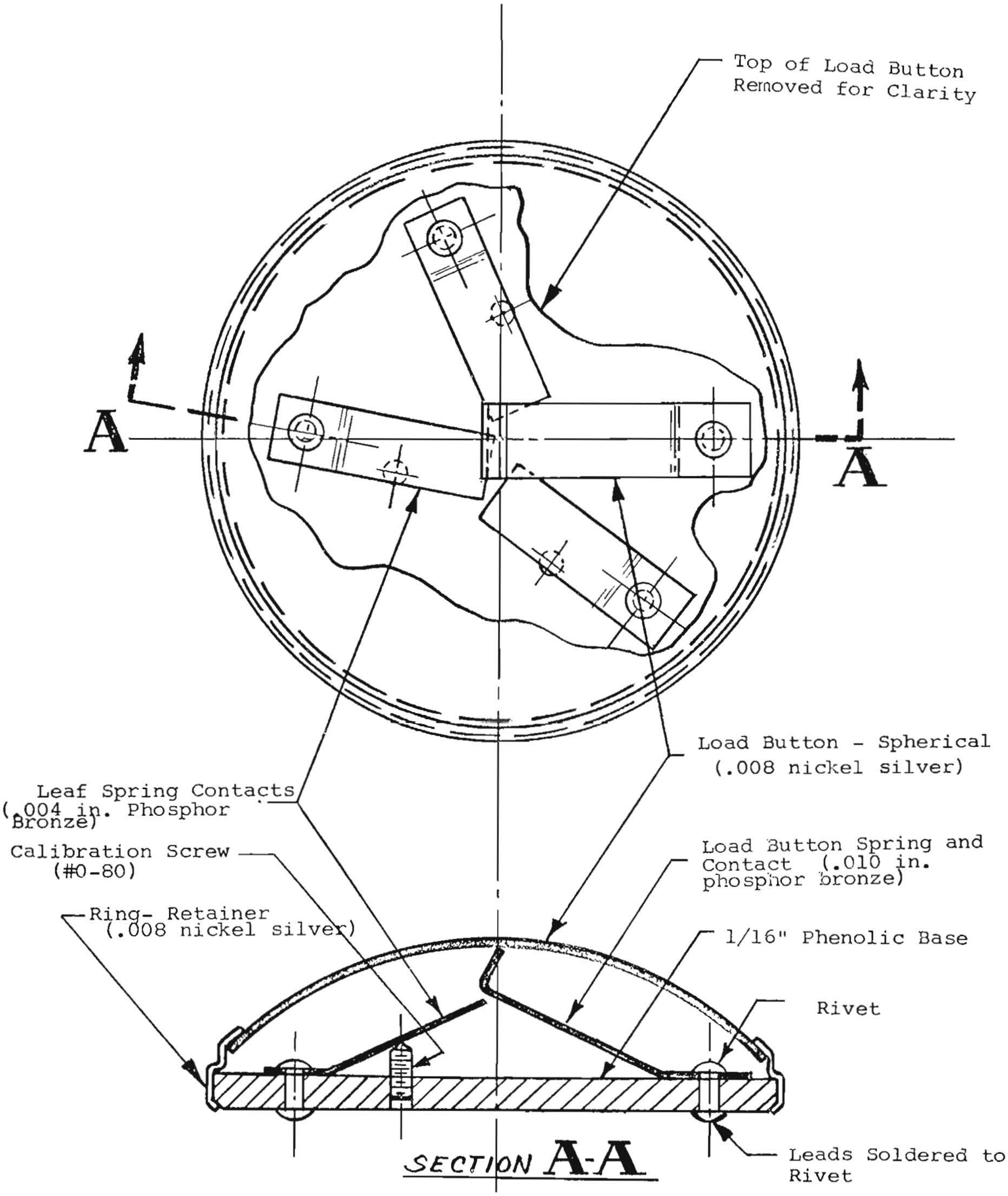


Figure 4. Progressive Electrical Contact Sensor Assembly

- Output signal did not require amplification or special conditioning equipment.
- Can be calibrated.

The disadvantages were that occasionally the contact switches stuck because of mechanical friction between the parts, and calibration was time-consuming.

B. Load-Sensing Pad Display, Prototype #2

1. Sensor Pad and Display

A variable inductance technique was used in the sensor design of Prototype #2. The total system consisted of a sensor pad, a basic fabric vest, signal conditioning equipment, display, and signal generator (Figure 5).

A total of 25 variable inductance sensors were mounted on a nylon fabric pad fringed with nylon pile that could be positioned and retained anywhere on a basic nylon vest fringed with nylon hook and worn by a test subject. The pad was positioned beneath the section of the suspension or load-carrying system of interest to the investigator.

The output of the variable inductance sensors was conducted by cable to signal conditioning equipment contained in a display console. A single light per sensor indicated when a load applied to the sensor exceeded a preselected level. A level selector switch on the console front panel permitted the investigator to select load levels of 1/2, 1, 1-1/2, 2, 4 and 6 lb.

Sensor outputs were displayed by depressing a sensor selector switch and pressing the read button located on the console front panel. Loads exceeding the preselected load level would light up the switch for the sensor being interrogated. The display would hold the information until the clear button was pressed. Any one of the 25 sensors could be interrogated individually and sensors could also be interrogated sequentially in ascending order.

2. Sensor

The variable inductance sensor consisted of a coil, armature, spring, spherical cap and case (Figure 6).

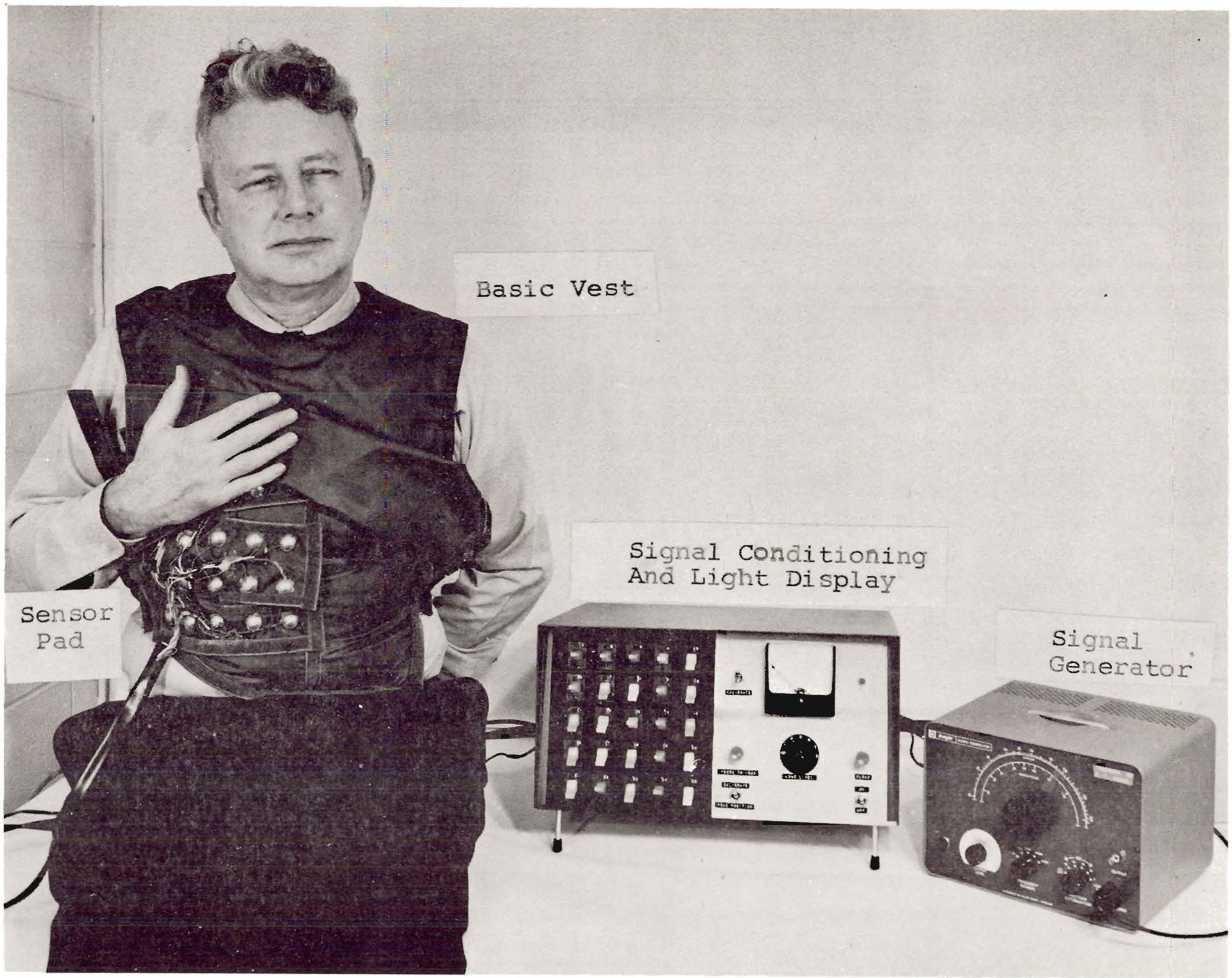


Figure 5. Load Sensing Pad and Display - Prototype #2

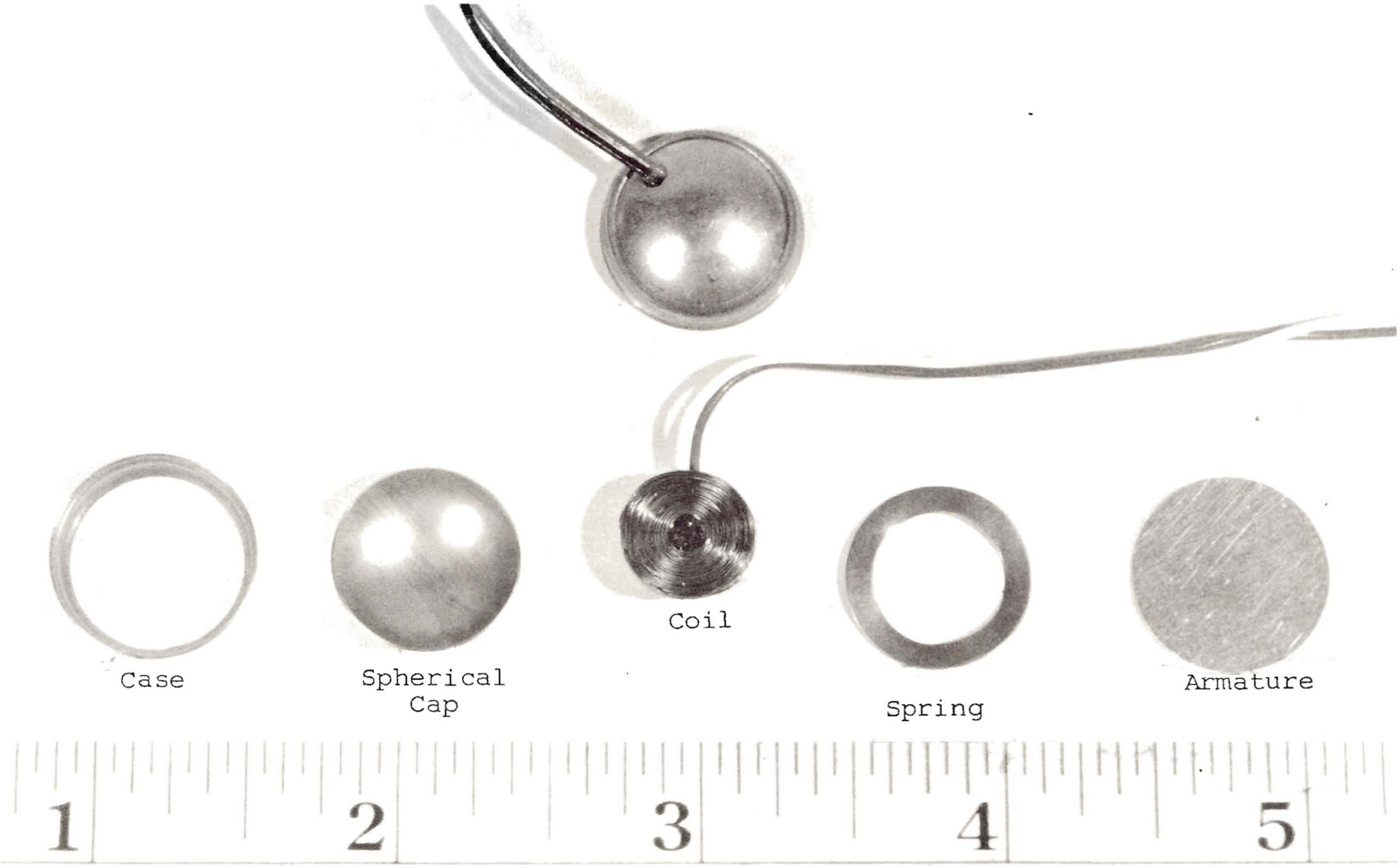


Figure 6. Variable Inductance Sensor - Prototype #2
(Components and Assembly)

As a force was applied to the sensor the distance between the armature and coil decreased, changing the inductance of the coil. Varying the inductance caused a change in voltage across the coil. This voltage change was balanced against a reference voltage, and was calibrated to read in pounds of force applied to the sensor.

The sensors were 11/16 in. diam, 1/4-in. thick and had two leads which connected to the inductance coil. A signal generator supplied the coil with AC voltage.

PART II. INVESTIGATION OF TORSO SENSITIVITY

A. Naturally Sensitive Torso Areas

The physiological makeup of the human body involves certain naturally sensitive areas. The ability to endure discomfort and the tolerance threshold to pain for short durations or extended periods varies considerably from one individual to another. This is a complex interaction of physiological and psychological effects.

From a physiological standpoint, there are certain veins, arteries, nerves and portions of the skeletal structure common to all individuals which appear near the surface of the skin (Figures 7 and 8). These areas may be extremely sensitive to load, depending on how the load is distributed. In general, fleshy areas can tolerate greater loads than bony areas. (Ref. 1).

The arteries which supply blood to the brain run along the rear of the shoulder, up either side of the neck to the head. Even light pressure on these arteries can reduce the blood supply to the brain resulting in varying degrees of blackout, nausea, and/or loss of coordination. Pressure applied to nerves lying beneath the skin and above the skeletal structure can produce pain, reduce endurance, and produce fatigue rapidly. (Ref. 1).

Load sensor locations should permit observation of these naturally sensitive areas of the torso. A well-designed suspension system will avoid armor load distribution on these areas, particularly the bony structure of the torso which can result in severe pain or discomfort.

B. Data Collection Technique

A torso sensitivity study was conducted using 10 subjects described in Figure 9. The test subjects ranged in bodily structure from muscular to fleshy. The data collected provided a general picture of torso sensitivity and the relative load-carrying capabilities of various areas of the torso.

The technique for data collection was to use a 2 in. grid pattern, such as shown in Figure 10, marked on a white T-shirt (front and back), sizes small, medium and large. Sized T-shirts were used to permit scanning of the same relative areas on various-sized test subjects.

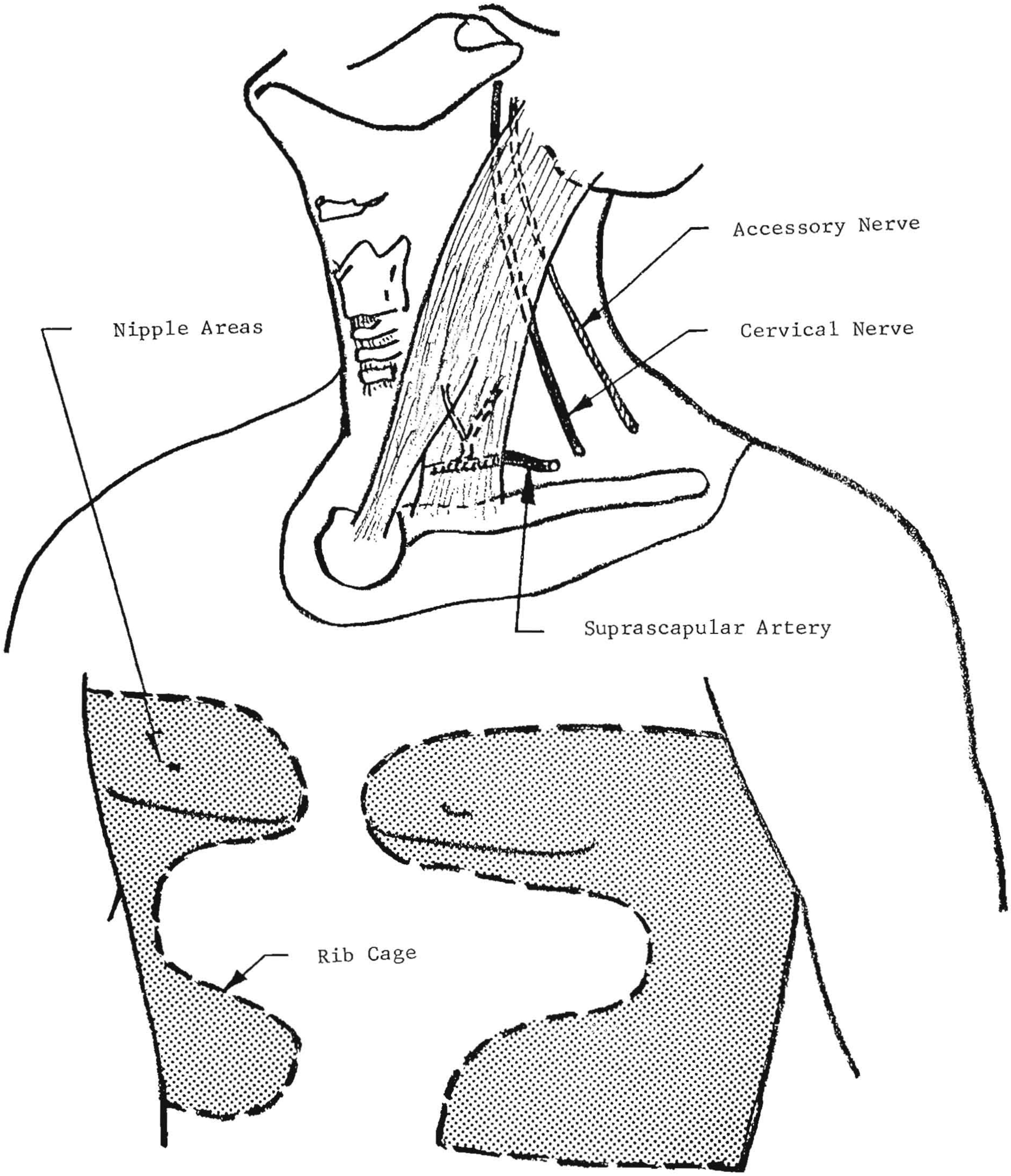


Figure 7. Naturally Sensitive Areas of the Torso Anterior View

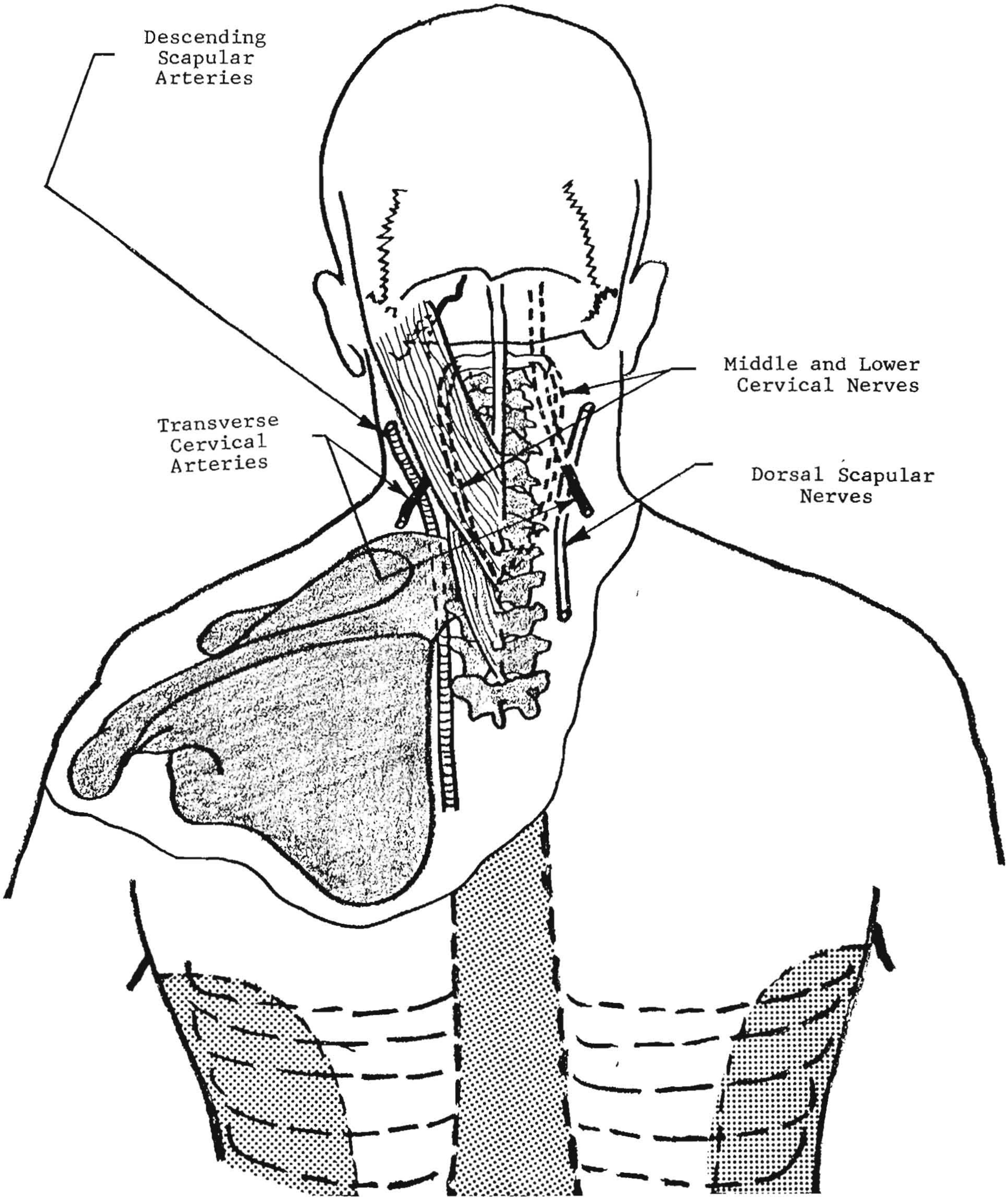


Figure 8. Naturally Sensitive Areas of the Neck

Posterior View

Test Subject	Name	Height	Weight	Age	Size	Physical Condition	Build
1.	Clarence Lamber	5'-11"	180	38	Med.	Good	Normal
2.	Kenneth Mayerhofer	5'-8"	155	25	Small	Good	Normal
3.	Edward Hahn	5'-11"	180	35	Med.	Excellent	Muscular
4	Frank Scribano	5'-11"	185	44	Large	Good	Fleshy
5	Richard Rodzen	5'-10"	140	29	Small	Good	Slender
6	William Kiscellus	6'-0"	195	28	Large	Excellent	Muscular
7	Jozef Slowik	5'-6"	150	46	Small	Good	Normal
8	Romas Kasparas	6'-1"	173	35	Large	Excellent	Muscular
9	Frank Bartos	5'-8"	145	31	Small	Good	Slender
10	Kiyo Norikane	5'-7"	162	41	Small	Good	Slender

Figure 9. Test Subjects Torso Sensitivity Study

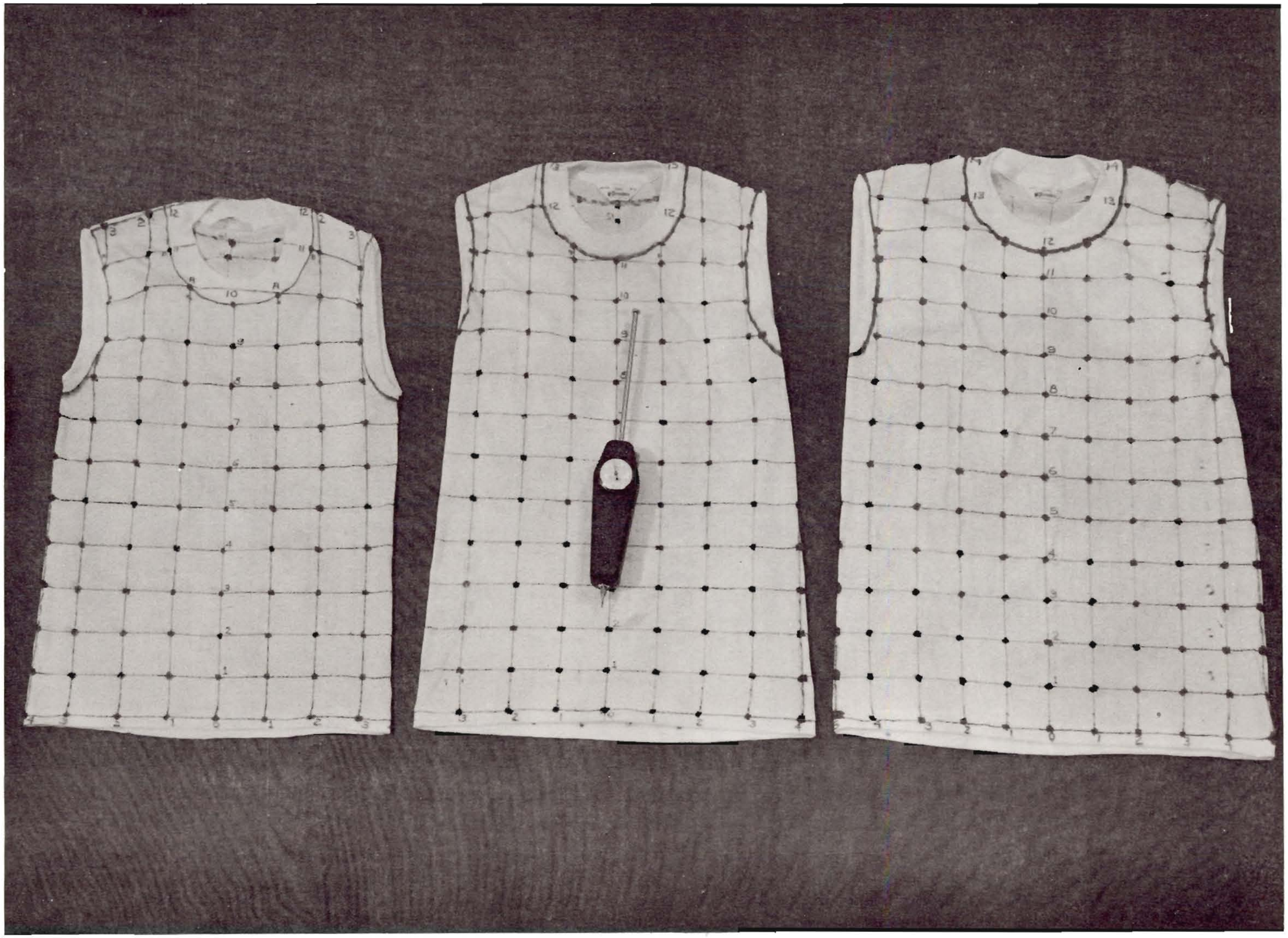


Figure 10. T-Shirts With 2-inch Grid Pattern
For Torso Sensitivity Data Collection

A Hunter force gage with a 3/16-in. diam blunt tip (0 to 20 lb range) was used to apply loads at the intersection points of the 2-in. grid patterns. The Hunter gage and its application are shown in Figure 11. The gage tip was pressed into the test subject until the resultant force produced discomfort. This force was then read on the gage and recorded on a typical torso sensitivity data plot (Figure 12). Each circle represented an intersection point on the 2-in. grid system, and the number in the circle was the force, in pounds, applied at that point which resulted in discomfort. The same procedure was followed on the rear of the torso (Figure 13) with a similar torso sensitivity data plot for the posterior torso. (See Appendix A for torso sensitivity data plots for the 10 test subjects).

Maximum tolerable loads on the torso, using a 3/16-in. diam probe tip, proved to be 20 lb. Other loads applied to the body ranged from 1 to 20 lb. Load sensitivity for most individuals was not completely symmetrical about the vertical torso centerline.

The first step in the development of a statistical torso sensitivity chart was to average the sensitivity loads between the left and right sides of the torso (anterior and posterior). Load charts showing the "averaged" load about the torso centerline for the 10 test subjects are shown in Appendix B. The tolerable force (in pounds) applied to the torso is dependent on probe diam. A probe was selected which would not exceed the 20 lb range of the Hunter gage.

As probe diameter diminishes, the pounds of force, the torso can tolerate at any single point also diminishes. Conversely, as probe diameter increases, the tolerable force increases because of force distribution over a greater area. The Hunter gage was therefore the limiting factor in the selection of an optimum probe diameter. Five load ranges were selected and coded as follows:

	Range (lb)	Degree of Sensitivity
1.	1 to 4	Extremely Sensitive
2.	5 to 8	Sensitive
3.	9 to 12	Moderately Sensitive
4.	13 to 16	Moderately Insensitive
5.	17 to 20	Insensitive

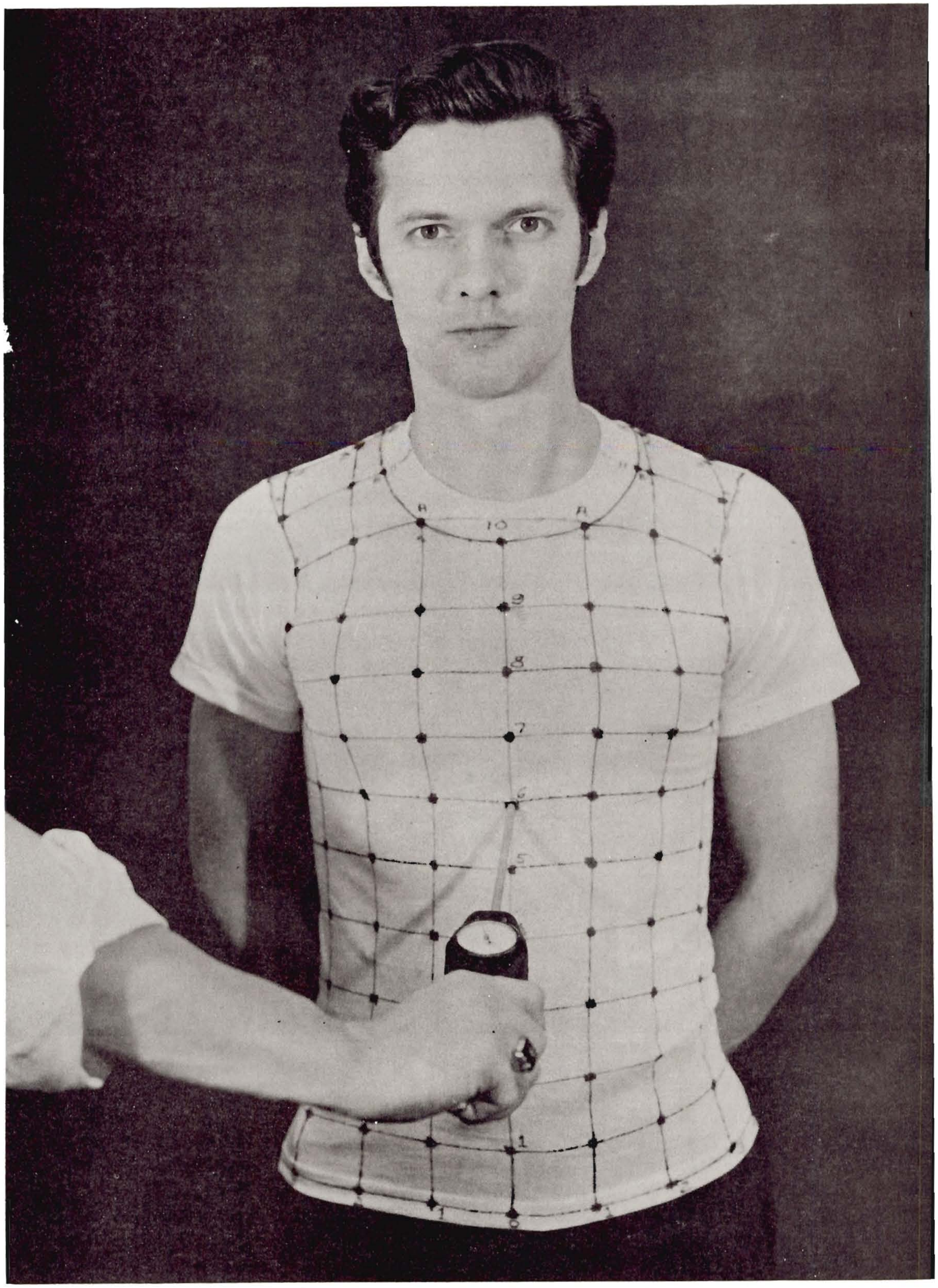


Figure 11. Torso Sensitivity Data Collection Technique - Anterior View

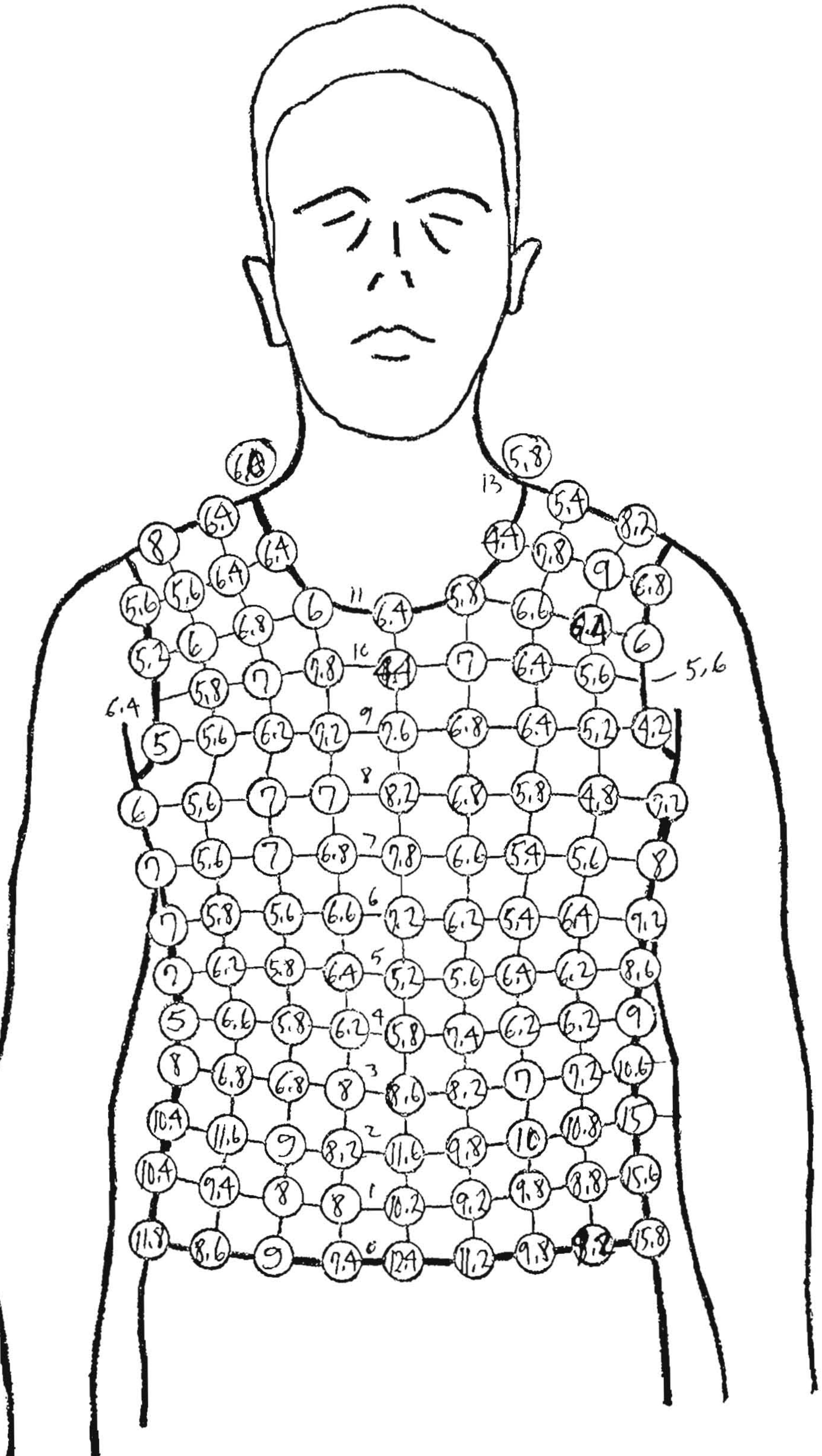


Figure 12. Torso Sensitivity Data Plot - Test Subject No. 1 (Anterior View)

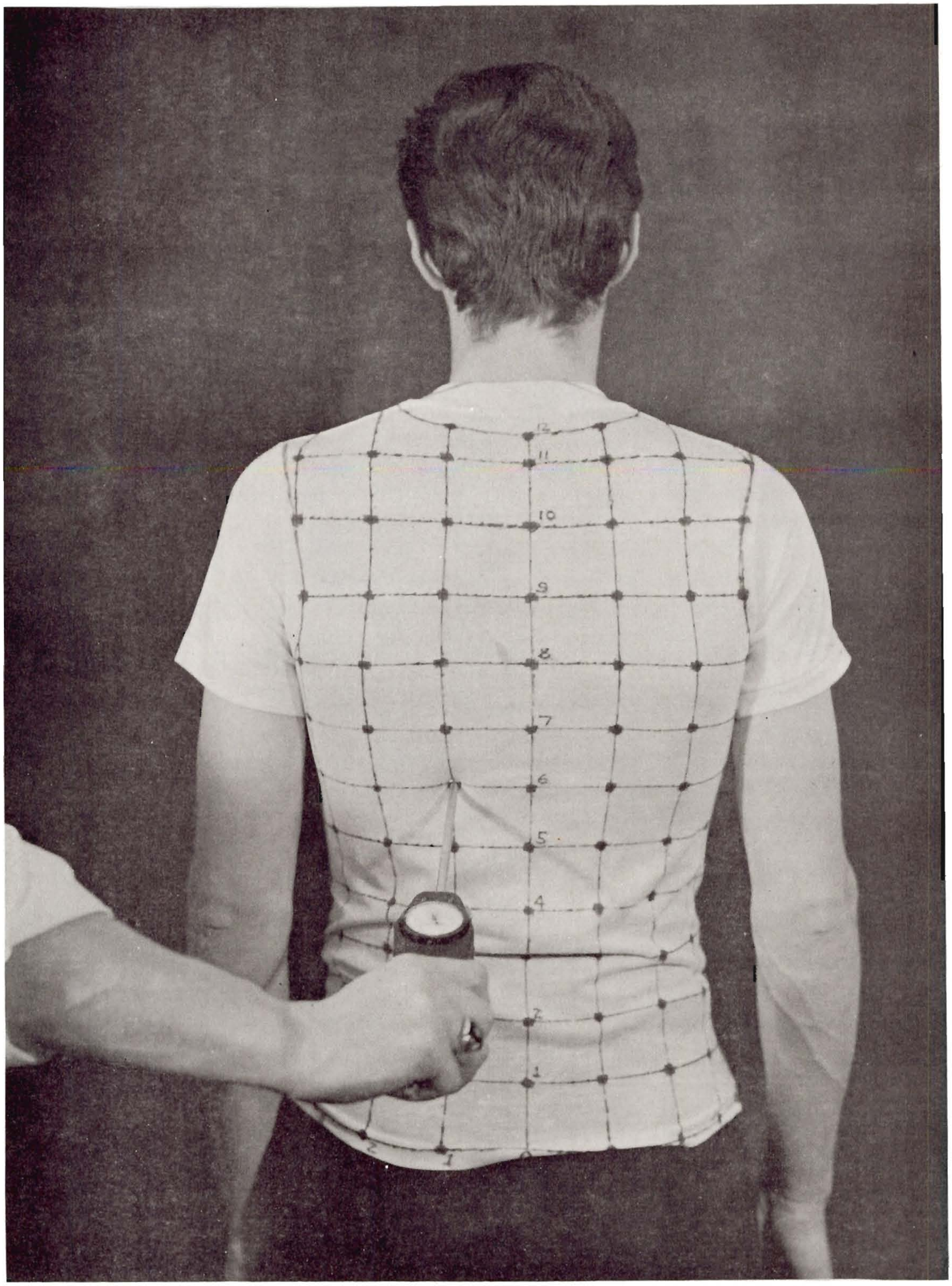


Figure 13. Torso Sensitivity Data Collection
Technique Posterior View

A typical isobar plot of equal load ranges was constructed, and coded for all 10 test subjects. Isobar plots for each of the test subjects were made, illustrating individual torso sensitivity. Typical data for the 10 test subjects are shown in Appendix C. The isobar plots of the torso show load tolerance ranges and indicate torso sensitivity, from extremely sensitive to insensitive.

C. Data Interpretation

Averaging the torso sensitivity data (Appendix B) for the 10 test subjects (Figures 14 and 15) was the final step in preparing the Isobar Torso Sensitivity Charts shown in Figures 16 and 17. The data shown on the charts indicates the degree of sensitivity of various areas of the torso, and denotes areas of extreme sensitivity, moderate sensitivity and insensitivity.

The loads indicated are relative numbers, and were derived by utilizing a Hunter force gage with a 3/16-in. diam flat probe to apply loads to the torso. The figures do not indicate maximum loads that the body can tolerate, but the data may be used to establish a "sensitivity ratio" between specific areas of the torso. For example, using the hips as a base or the least sensitive point, the shoulders are 25 to 31 percent more sensitive than the hips, while the chest is 50 to 62 percent more sensitive than the hips.

$$\text{Percent Sensitivity (with respect to hips)} = \frac{\text{Hip Load (lb)} - \text{Torso Reference Load (lb)}}{\text{Hip Load (lb)}} \times 100$$

The purpose of the torso sensitivity study was to determine the relative significance of load values indicated by the load determination and magnitude measuring instrument when evaluating armor suspensions. The Isobar Load Sensitivity Charts have value for the following reasons.

- They permit sensitivity comparisons between various areas of the torso.
- They identify preferable load-bearing areas of the torso.
- The charts can be used as an aid in designing suspension systems or in analyzing data collected from the load-sensing devices developed in this program by establishing whether a suspension system is distributing loads properly.

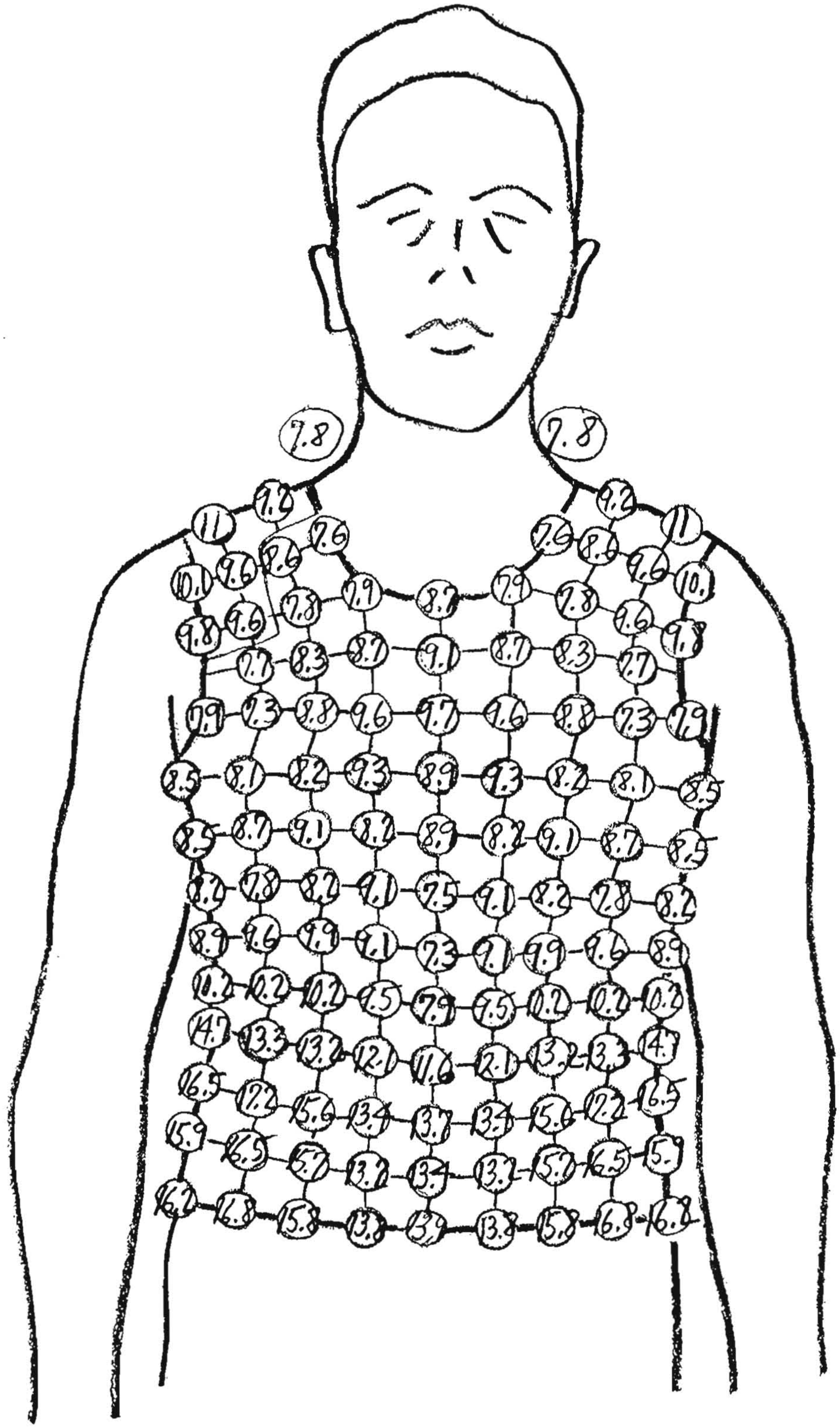


Figure 14. "Averaged" Torso Sensitivity Data
Anterior View
(10 Test Subjects)

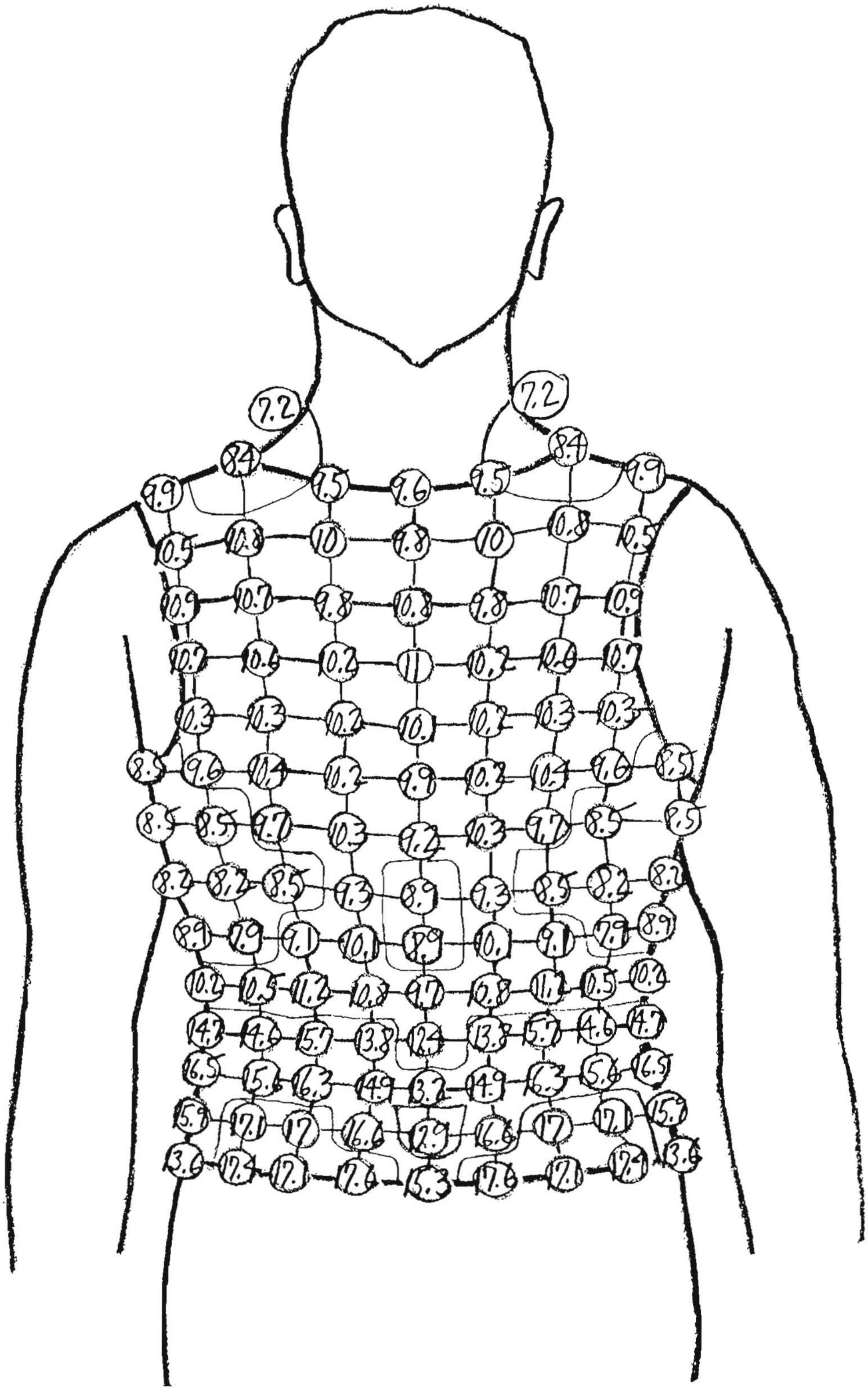


Figure 15. "Averaged" Torso Sensitivity Data
Posterior View
(10 Test Subjects)

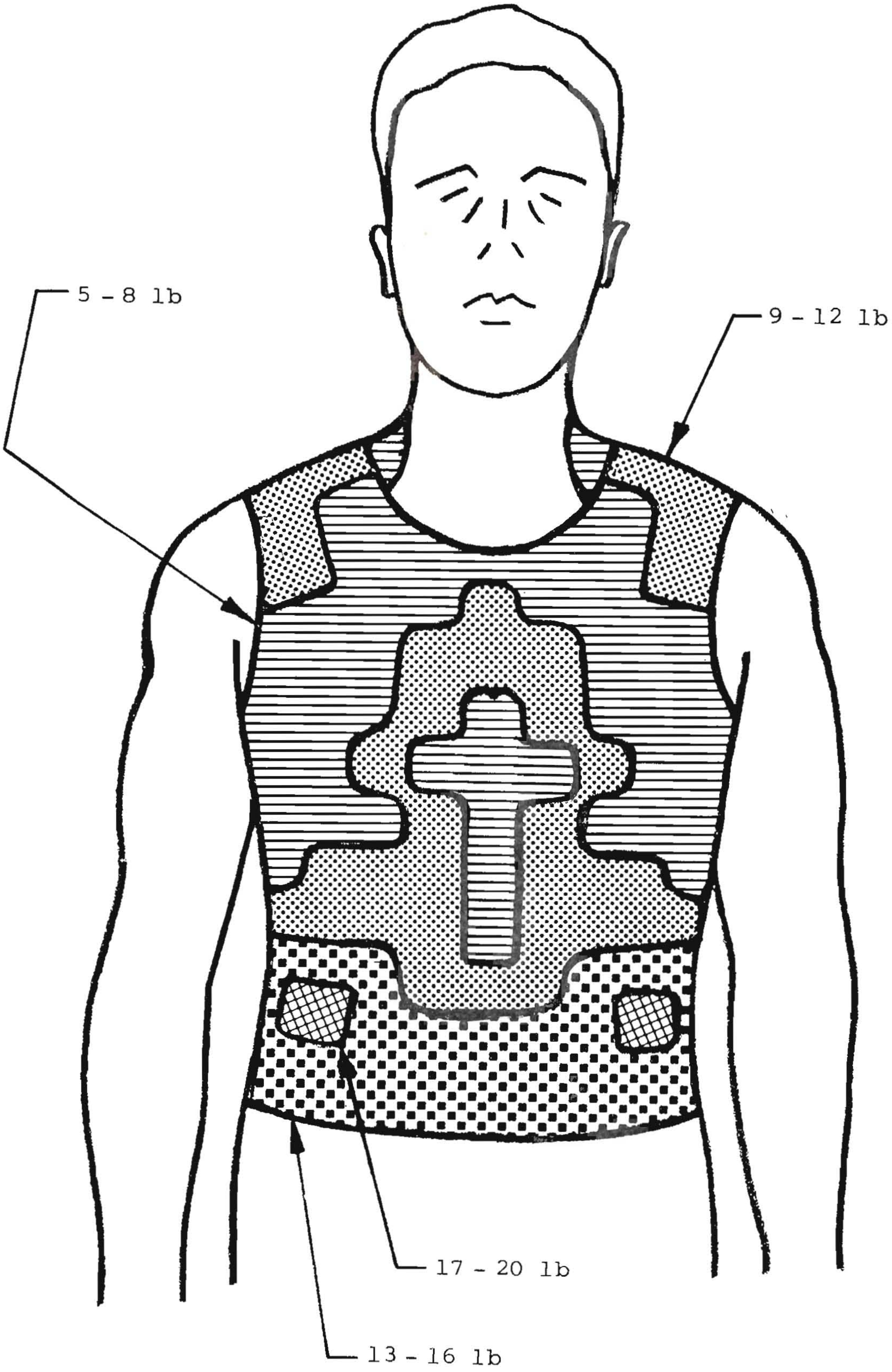


Figure 16. Isobar Load Sensitivity Chart
Anterior View - Averaged Data

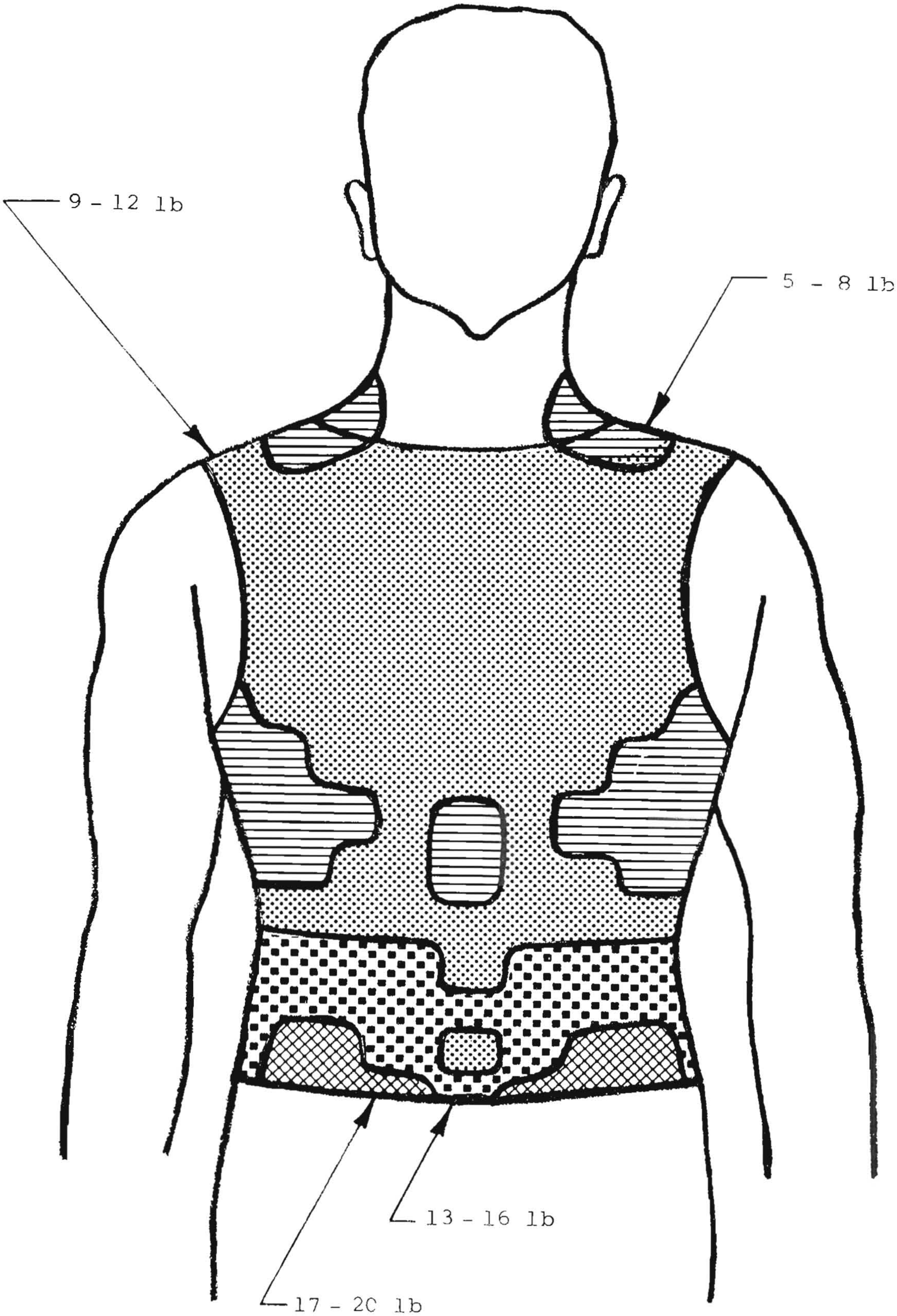


Figure 17. Isobar Load Sensitivity Chart
Posterior View - Averaged Data

The isobar charts further indicated areas where little or no loads could be tolerated (for example, around the neck-shoulder junction). They also revealed optimum load-bearing areas where higher loads may be endured. The degree of fleshiness or muscular development was not directly related to sensitivity or load-bearing capability, and in general, the subjects reacted consistently with respect to load sensitivity of the various regions of the torso. This result increased confidence in the "averaged" values and permitted effective application of the data in the subsequent design phases of the program.

The results of the torso sensitivity studies may be summarized as follows:

- The hips are the least sensitive torso areas and can tolerate the greatest loads.
- The abdomen below the rib cage can carry moderately high loads and is relatively insensitive.
- The rib cage, anterior and posterior, is sensitive and can carry moderate loads only if properly distributed. It is best to avoid these areas for load carrying.
- The shoulders can endure moderate loads and are good load-bearing areas.
- The neck, where it joins the shoulder, is the most sensitive area of the torso and is a poor load-bearing area.
- The upper back on either side of the spine is an excellent load-bearing area.
- The spine is a poor load-bearing area.
- The chest is a poor load-bearing area, particularly about the nipples, which are very sensitive.

D. Physiological/Psychological Considerations

The sensitivity data collected are only one indication of human tolerance to load. Physical and mental condition of a test subject can produce variations superimposed on the nominal values.

The psychological makeup of our subjects made the collection of sensitivity data extremely interesting. Individuals built up a tolerance to pain as the test progressed, and developed a psychological immunity to being prodded with the test probe. Others expressed discomfort at the thought of having a probe impinge on their torso, despite the fact that the probe was not producing pain.

It may be safely assumed that the reaction to wearing armor also varies between individuals, depending on mental or psychological reaction to having loads bearing on the torso. For this reason, weight distribution and awareness of load are extremely important to psychological acceptance of any armor suspension system.

The sensitivity data collected, when used to develop a load-sensing garment, can establish whether a suspension system is accomplishing the desired goals of proper load distribution on the optimum load-bearing areas of the body.

PART III. LABORATORY TEST AND SUSPENSION SYSTEMS EVALUATION

A. Test Procedure

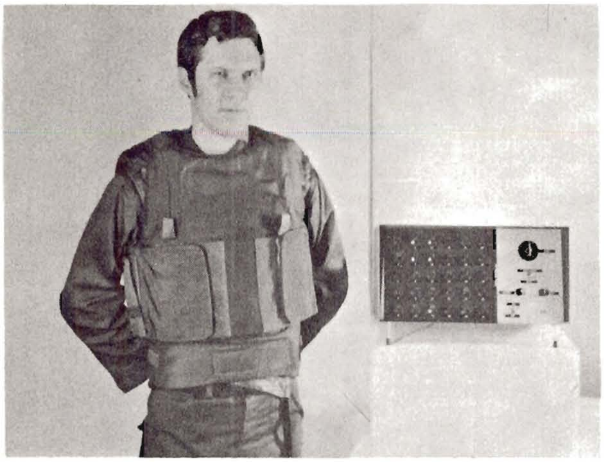
A laboratory test was conducted using the Progressive Electrical Contact Sensor Garment and Light Display Device for analyzing loads imposed on the body by armor. Three armor suspension systems were evaluated:

- Standard Army Aircrew (Modified) Carrier (Total System Weight = 34-3/8 lb) (Ref. 2)
- Experimental Raschel Net Suspension (total system weight = 34-7/8 lb) (Ref. 2)
- Experimental Raschel Net Suspension with Waist Augmentation (total system weight = 36-3/8 lb) (Ref. 2).

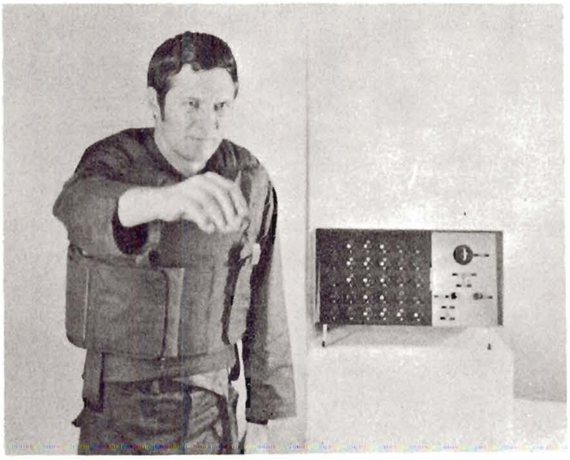
Three test subjects separately donned the load-sensing garment and adjusted it to their particular size. The armor suspension was then donned over the load-sensing garment (Figure 18) and the test subject exercised through the following series of movements:

1. Standing - arms at side
2. Sitting - arms at side
3. Sitting and reaching forward
4. Sitting and leaning forward
5. Sitting and reaching right to left

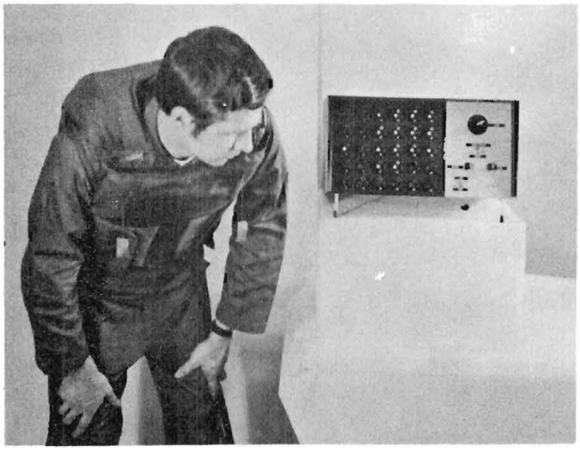
The light display was set for the continuous mode and each of the four zones was interrogated during the above movements. If a zone indicated high load levels, the display was set to hold and the read button pressed, locking the sensor inputs into the light display and giving an overall picture of the load distribution and magnitude. Once the read button was released, the subject could change positions without disturbing the display. By comparing the display to the zone maps (Figure 2), the sensor locations on the torso could be quickly determined and load ranges recorded on specially prepared data sheets.



Raschel Net/Waist Augmentation Suspension Worn Over Sensor Garment (Display Scanning Zone 2 - See Figure 2b)



Reaching Forward (Waist Aug. Belt Disconnected) Zone 2 Being Interrogated



Bending Forward Zone 3 Being Interrogated (Ref. Fig. 2a)

Figure 18. Evaluation of Suspension System Using Light Display

The test subjects used to evaluate the various suspensions moved through the various test positions and the resultant load patterns were observed for shifts in pressure points or changes in load distribution with articulation. Composite loading patterns were also observed by keeping the mode switch in the hold position and depressing the read button while the subject went through the prescribed test movements.

B. Data Presentation and Analysis

1. Data Collection

The information presented on the light display can be treated in several fashions.

a. The investigator can visually analyze load patterns and the shifts in pressure points, or load distribution with articulation. Visual comparisons can then be made between various suspension systems.

b. The load pattern of particular interest for any position can be locked into the light display and analyzed at greater length. The data can also be recorded on a data sheet by transcribing the light patterns appearing on the display.

c. Colored Polaroid pictures of the load patterns can be taken for a permanent record.

d. Movies of the light display can be made with the display set in the continuous read mode, and the test subject articulating through a series of movements.

2. Data Analysis

The light patterns which appear on the light display console locate loads and indicate the magnitude of forces imposed on the torso. The display scans four zones and the investigator must interpolate between the display presentation and the zone and/or sensor on the torso (Figures 2a and 2b).

A data sheet was prepared for the laboratory test, with a typical completed sheet shown in Figure 19. Evaluation data sheets for the various suspensions are contained in Appendix E.

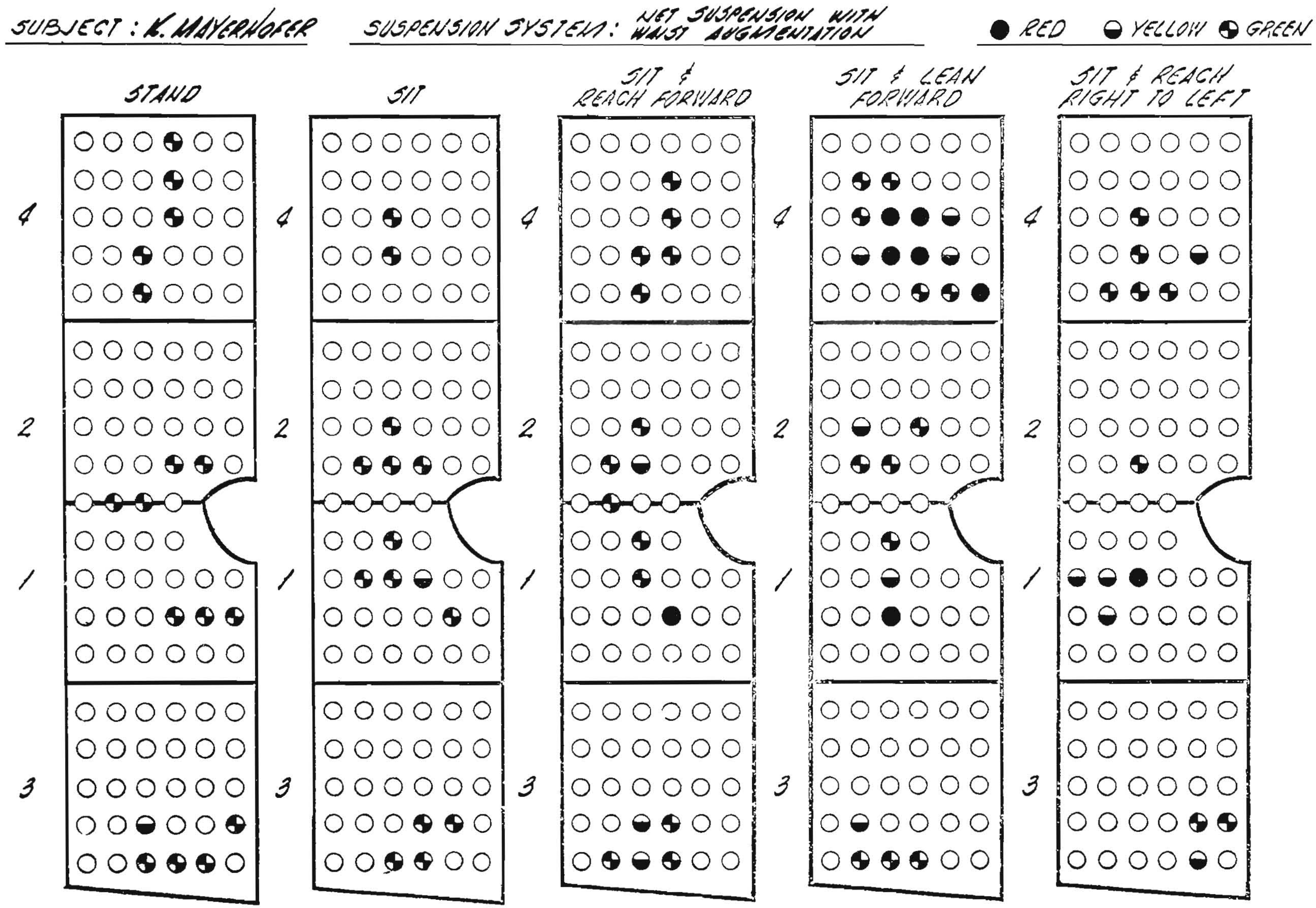


Figure 19. Evaluation Data Sneet

The data sheet shows the four zones of the torso scanned by the sensor garment. Each zone on the data sheet includes the 30 groups of 3 colored lights of the light display. Four zones are shown for each of the test positions described earlier. With the test subject in a selected test position, the colored light patterns were observed and marked on the data sheet.

Reviewing the evaluation data sheets, the following conclusions can be drawn for the suspensions evaluated.

Army Standard Aircrewmen Armor Carrier

- The carrier distributes high armor loads on the shoulders in the standing, sitting and sitting plus reaching forward positions.
- Moderate armor loads are distributed on the lower back and practically no armor loads are carried on the torso front.
- High armor loads are concentrated on the spine and back when leaning or reaching forward.

Raschel Knit Suspension

The following comments indicate the relative characteristics of the prototype suspensions systems (Ref. 2) compared with the Standard Army Aircrew Carrier (used as the control item).

- Armor load concentrations on the shoulders appear to have been reduced as indicated by a preponderance of green lights in these areas. (Reference data sheet, Figure 19 and Appendix E).
- The raschel knit acting in tension across the chord line of the armor elements aids in distributing armor loads on the chest and back and minimizes armor loads on the spine. However, for certain individuals high load concentrations still appeared on the spine, indicated by the load-sensing device. This suggests that the tension web approach, though functioning in most cases, could still be improved.
- The raschel knit over the shoulder can form lines of high stress concentration if not properly sewn into the carrier. Additional effort is necessary to eliminate this possibility.

Raschel Knit Suspension Waist Augmentation

- The waist augmentation belt (Ref. 2) effectively reduced armor loads on the shoulders by transferring the load to the hips.

- High load concentrations on the back, in articulated positions, were indicated by the load-sensing device (bending and reaching forward). The device dramatically portrays that the suspension/waist augmentation approach has improved load distribution. However, additional design effort is required to optimize the approach.

- The waist augmentation belt tends to slip down on the hips during articulation or during extended periods of use as indicated by the increasing number of lights in the shoulder, chest and back areas. One can therefore deduce from the data that the waist augmentation belt, in its present form, would require readjustments by the wearer during extended periods to properly perform its load-transferring function. Further design efforts should be applied to improve this condition.

PART IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The development of a "Personnel Armor Load Profile Analyzer" involved many unique accomplishments including (1) method of sensing loads, (2) integration and positioning of sensors in a suitable garment, (3) method of displaying information, and (4) correlation of output data to torso sensitivity. The following conclusions are based on the work performed during the program:

- Armor suspension systems can effectively be evaluated using the Personnel Armor Load Profile Analyzer. Static and dynamic load patterns are displayed and the shift in these patterns with articulation can be observed.

- The data obtained from the display can provide guidelines for improving suspension system design by determining whether a particular suspension is effective in distributing loads on the optimum load-bearing areas of the torso.

- The progressive electrical contact sensor approach provides a direct reading system with maximum reliability, ruggedness and versality. In addition, the system does not require special signal conditioning equipment.

- The variable inductance sensor approach produces an analog sensor output converted to a digital display. The shortcomings of this system are:

  (1) signal generator drifting which requires recalibration of sensors periodically.

  (2) limited capability to interrogate multiple sensors simultaneously without introducing a complex mechanical or electronic scanning system. However, this sensor offers certain benefits with respect to ease of calibration, and flexibility in the number of load ranges which can be accommodated.

B. Recommendations

- The requirement for switching through different zones to view a particular group of sensors is not desirable. A display which would permit simultaneous sensing and immediate viewing of all load points would be preferable.

- A full-size anatomical display would eliminate the need for an observer to interpolate sensor location on the torso.

- A memory capability should be incorporated to provide the researcher with extended viewing time for studying display data without continuous input from the test subject.

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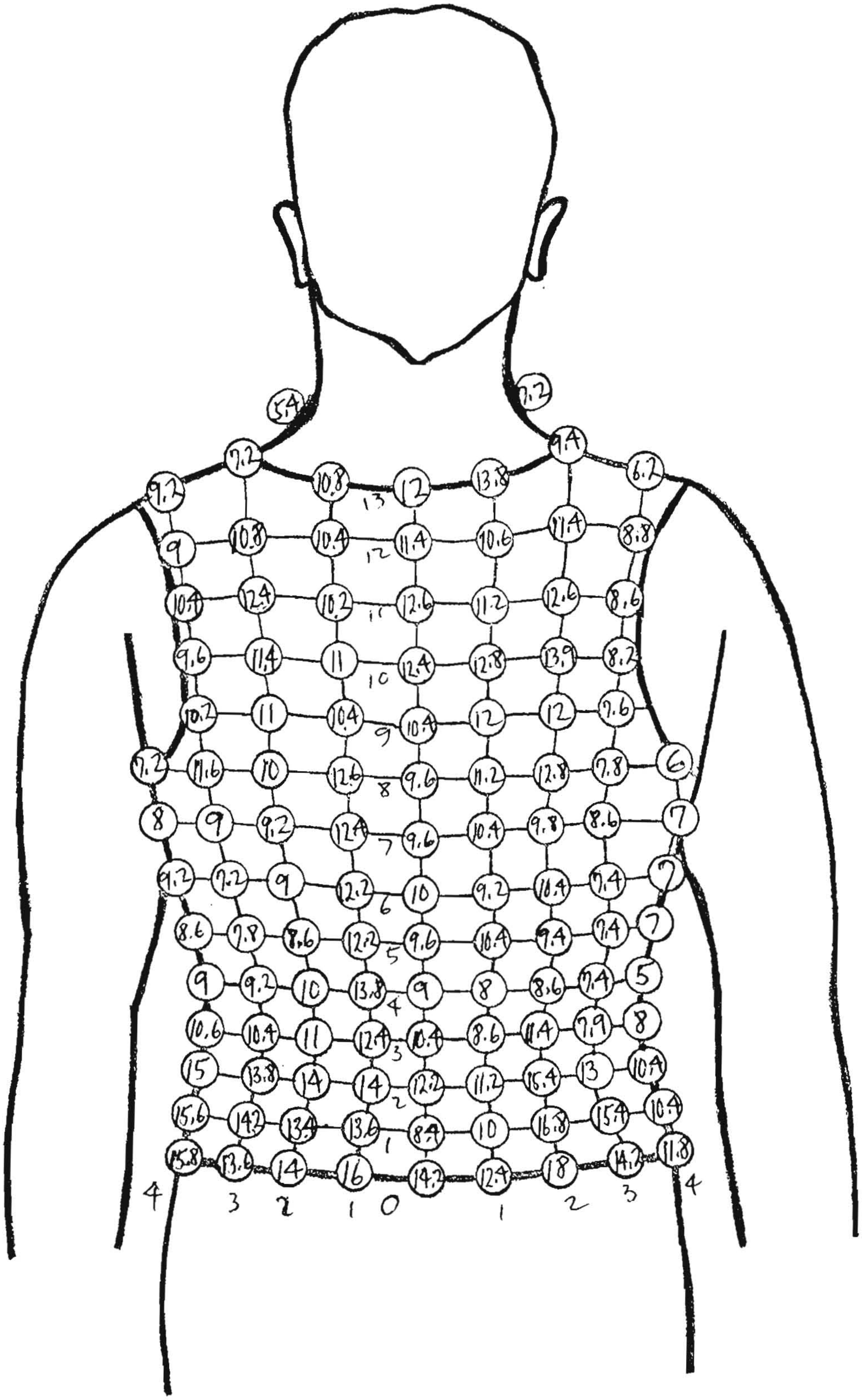
APPENDIX A

TORSO SENSITIVITY DATA AS COLLECTED

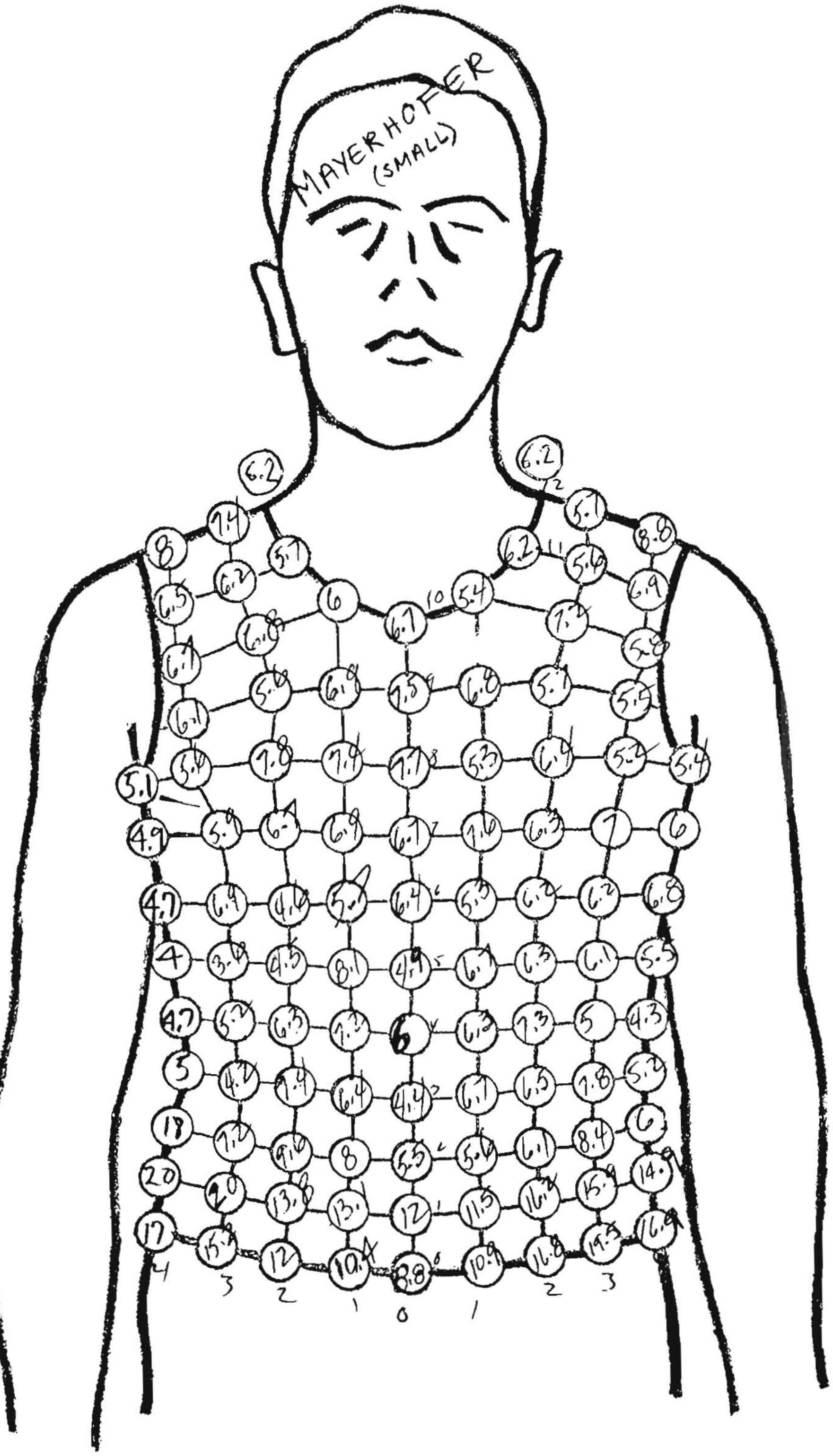
(Test Subjects 1 through 10)



Torso Sensitivity Data Plot

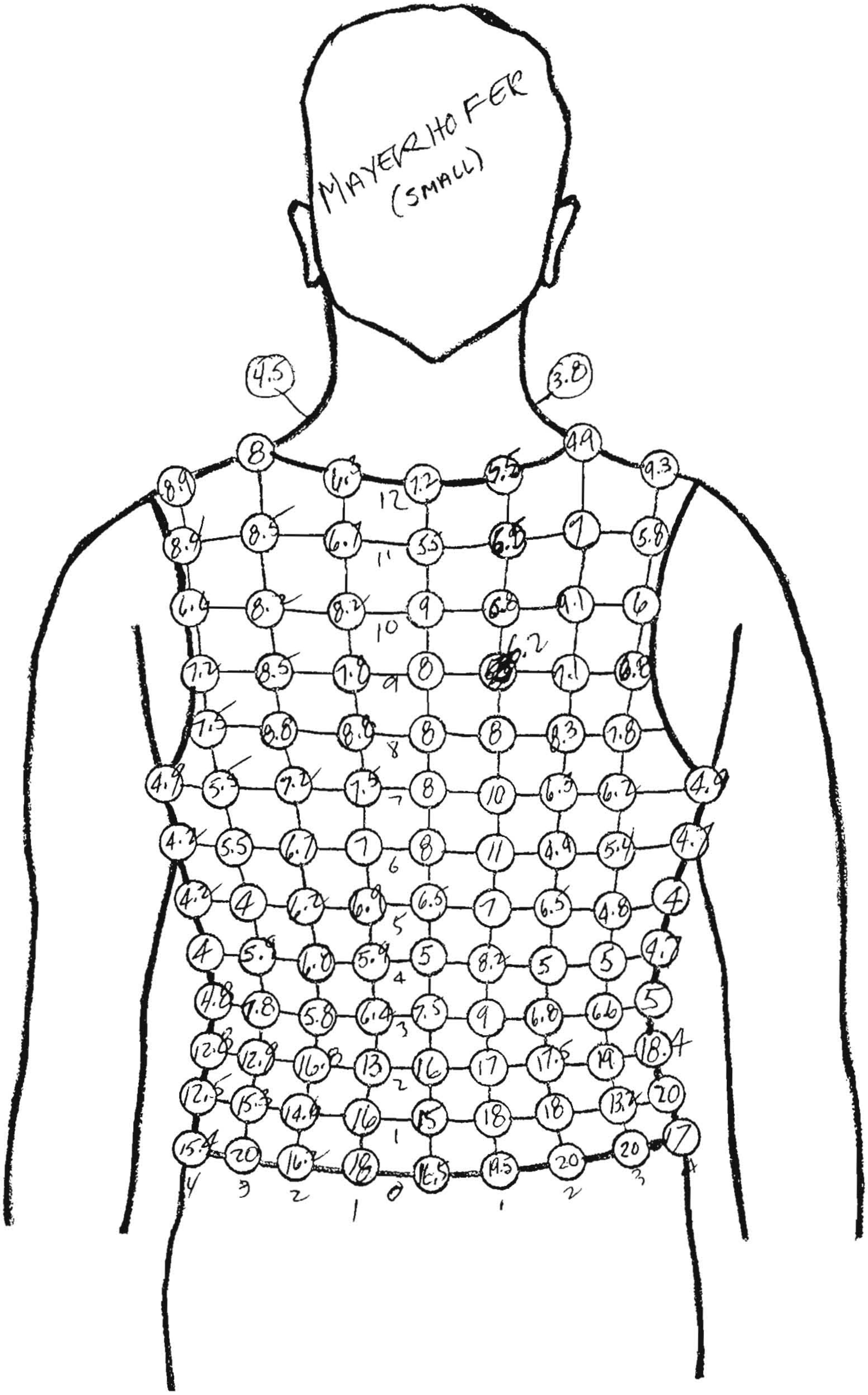
Test Subject No. 1

(Posterior View)



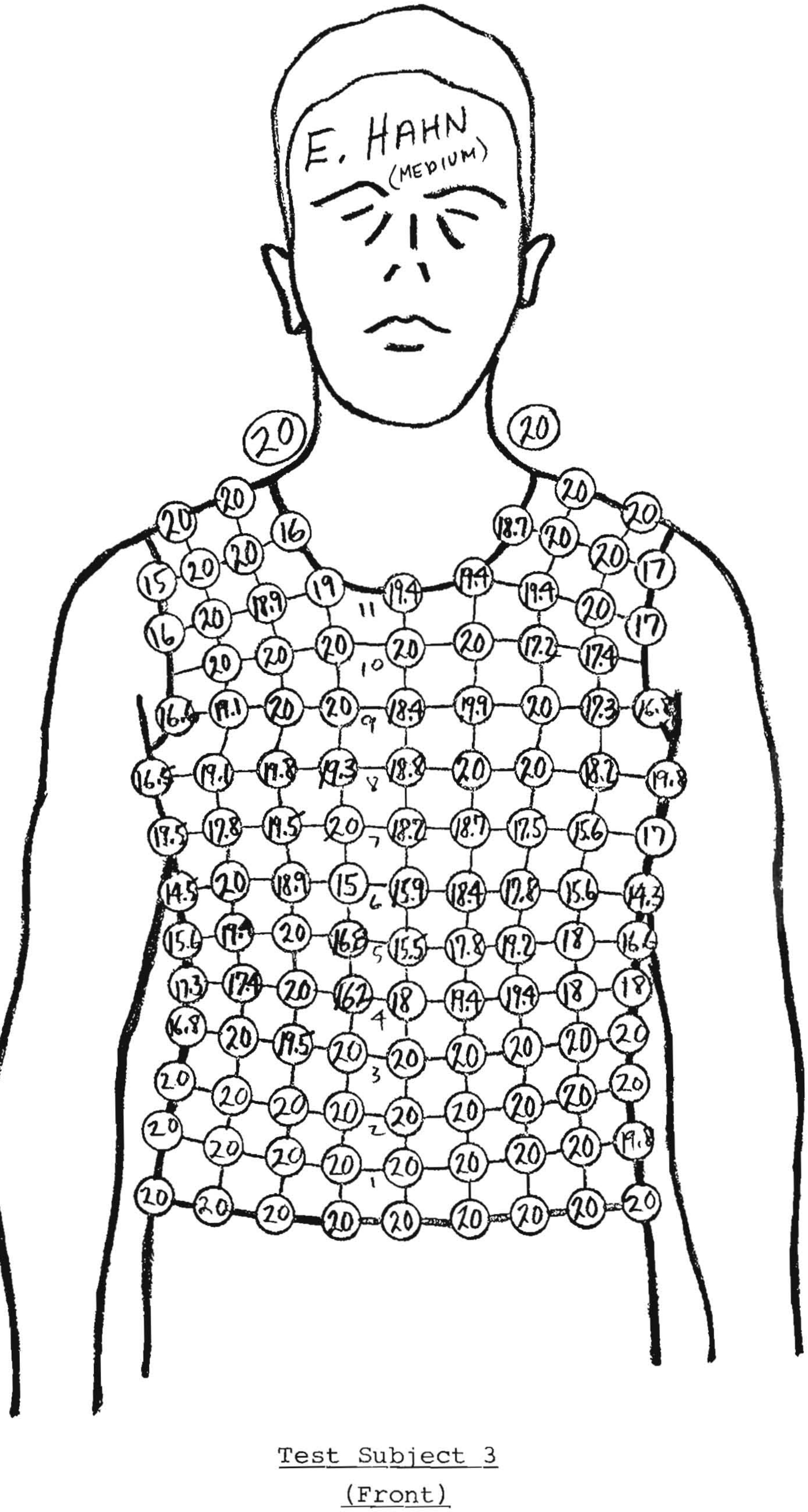
Test Subject 2

(Front)



Test Subject 2

(Rear)



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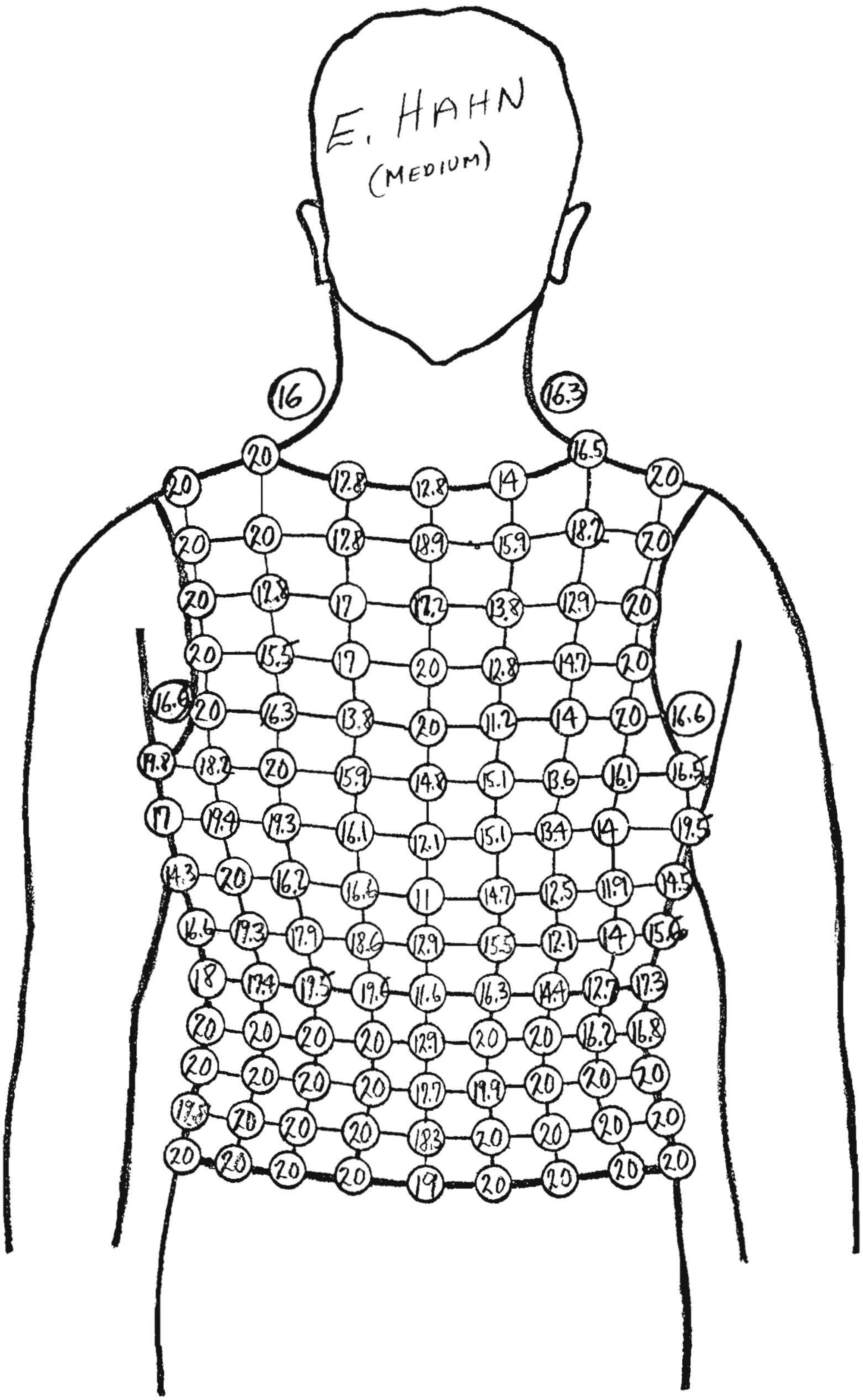
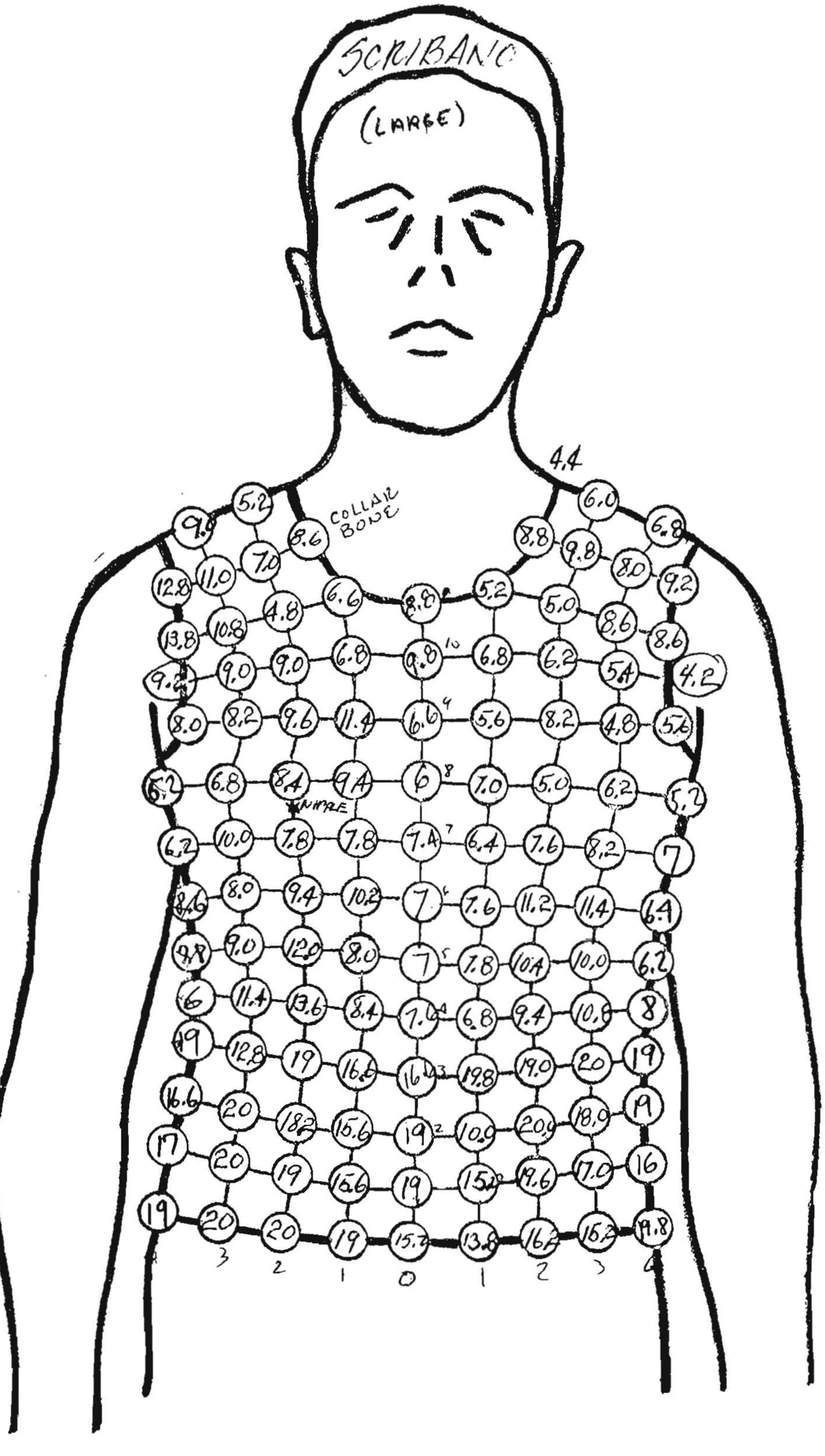
(Front)



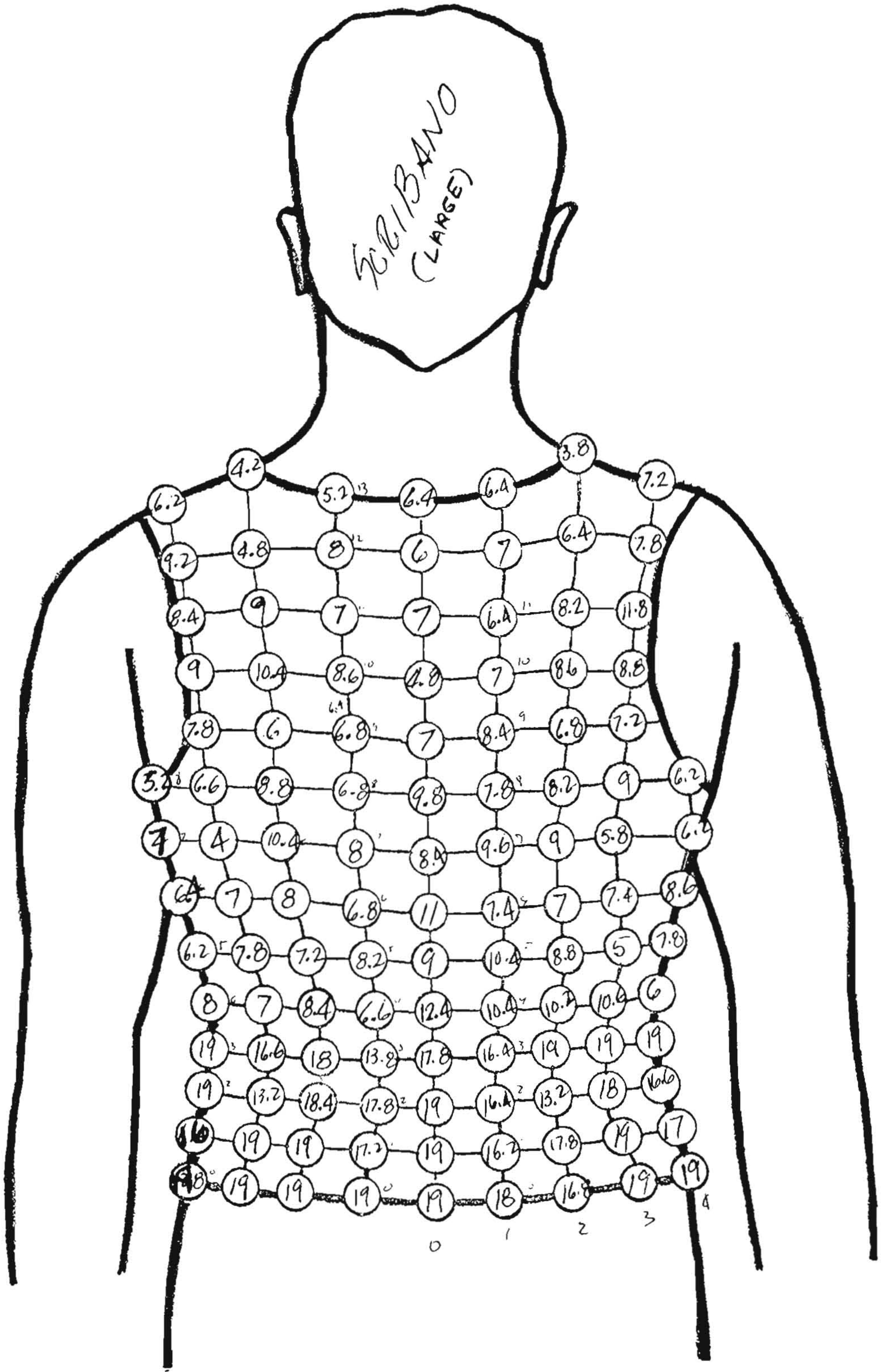
Test Subject 3

(Rear)



Test Subject 4

(Front)



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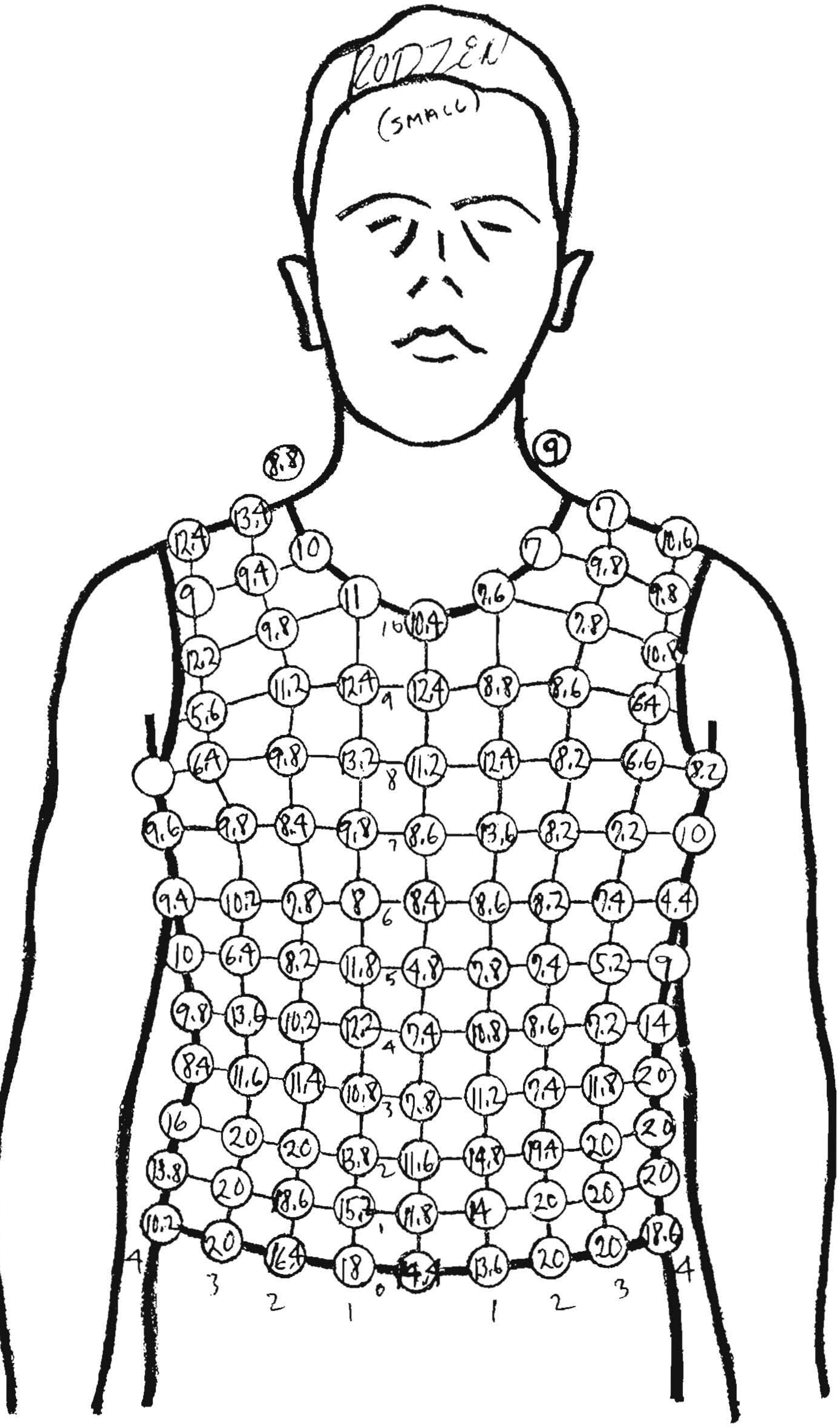
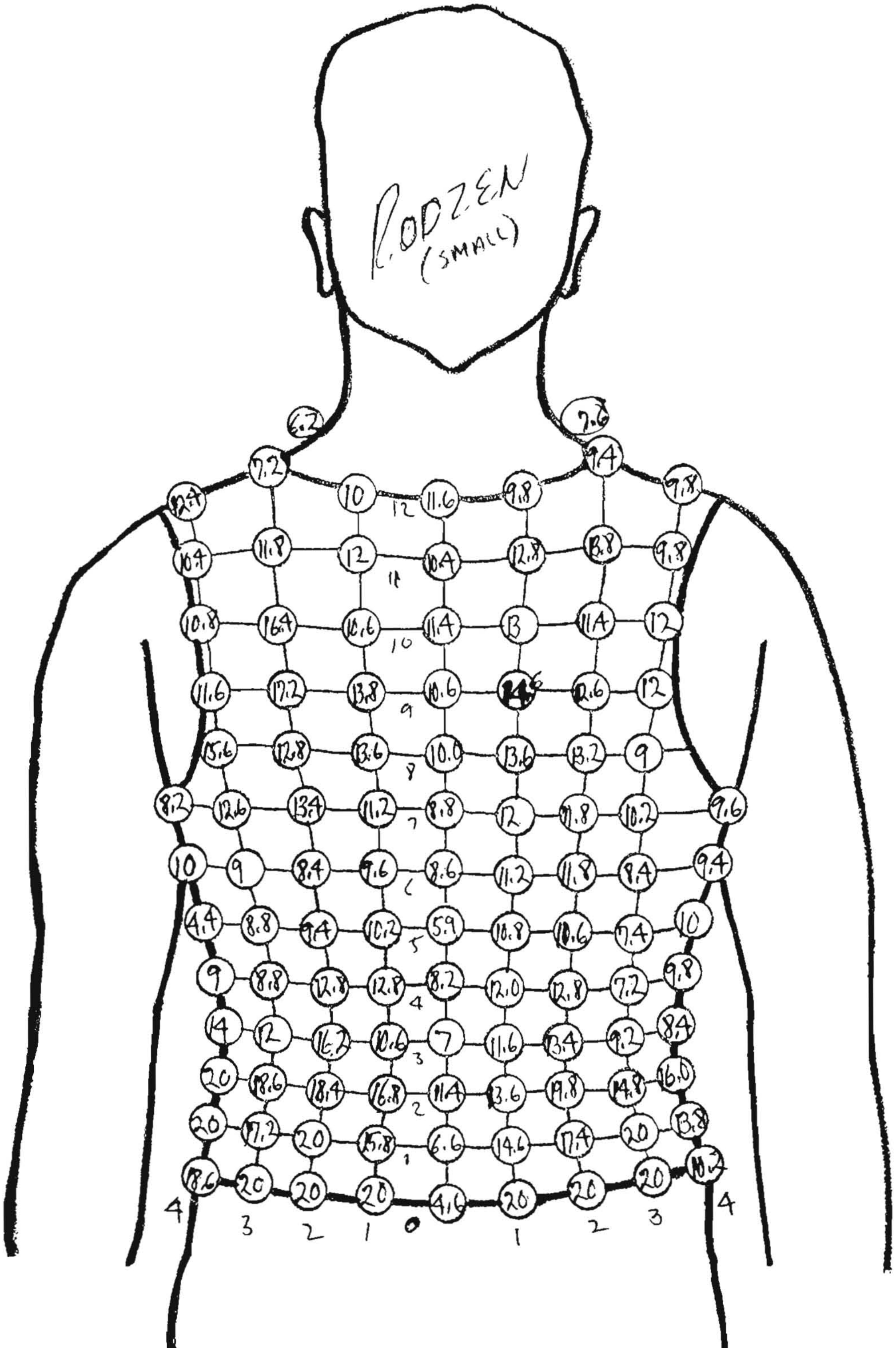
(Rear)



Test Subject 5

(Front)



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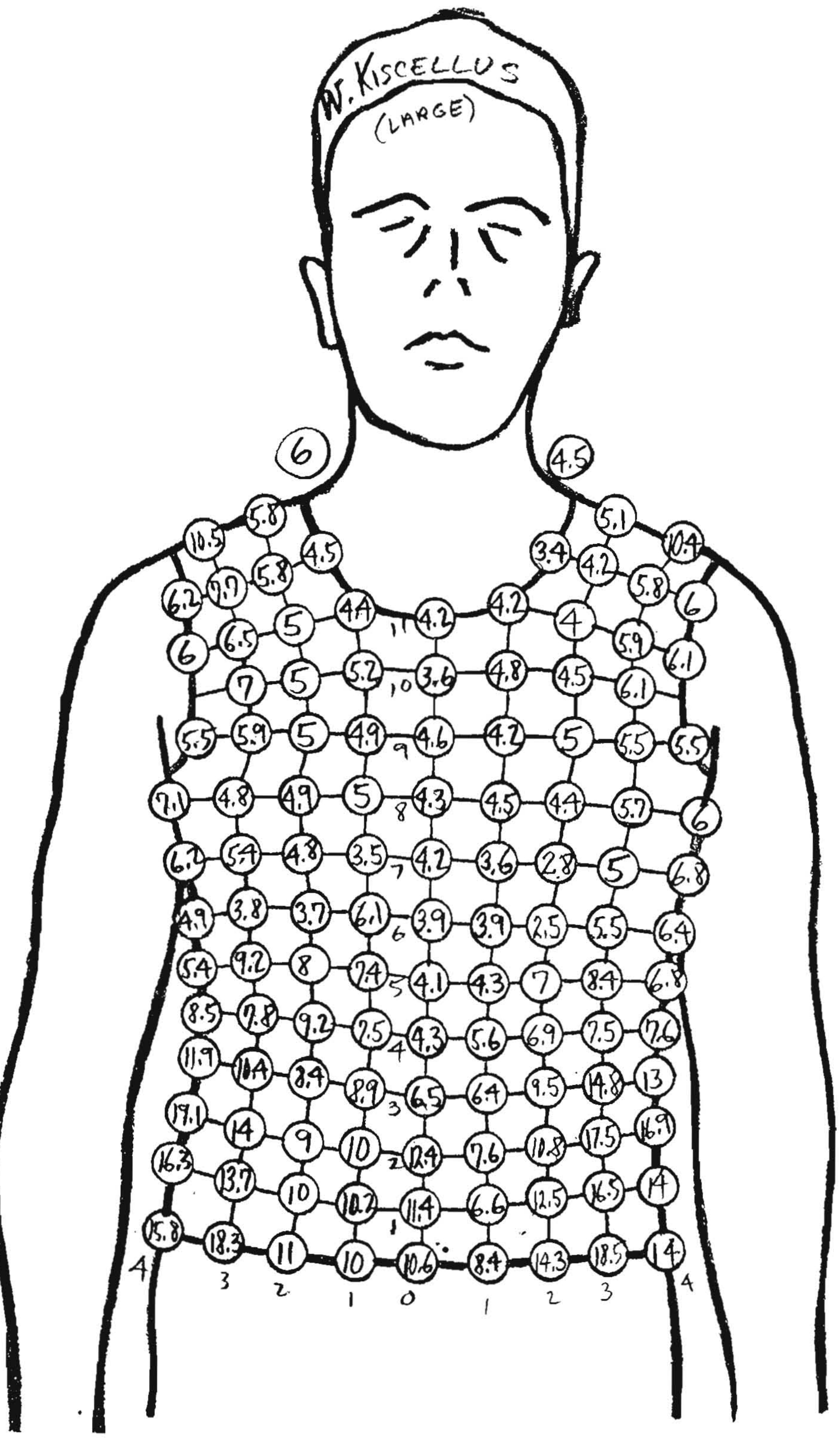
(Rear)



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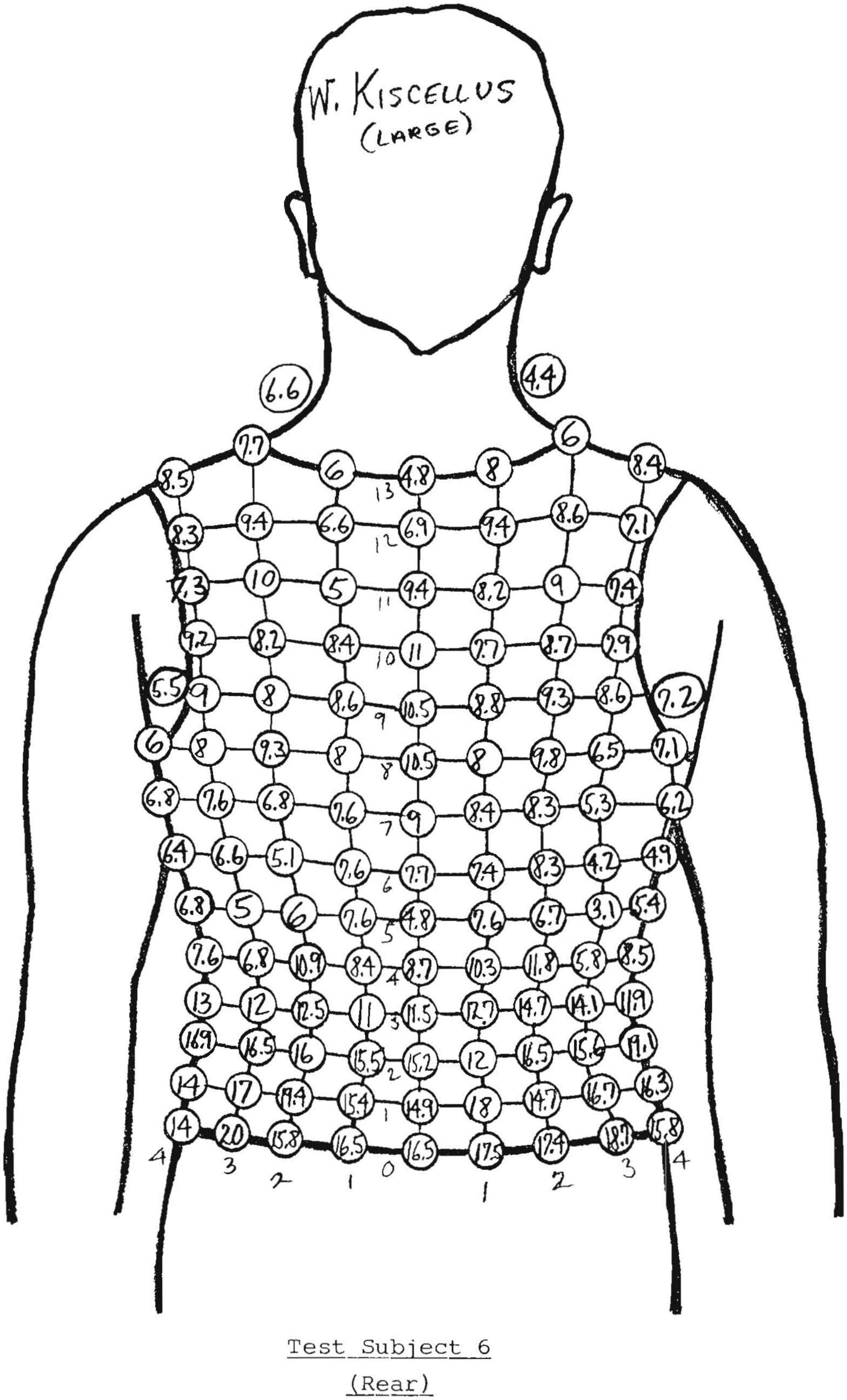
(Front)



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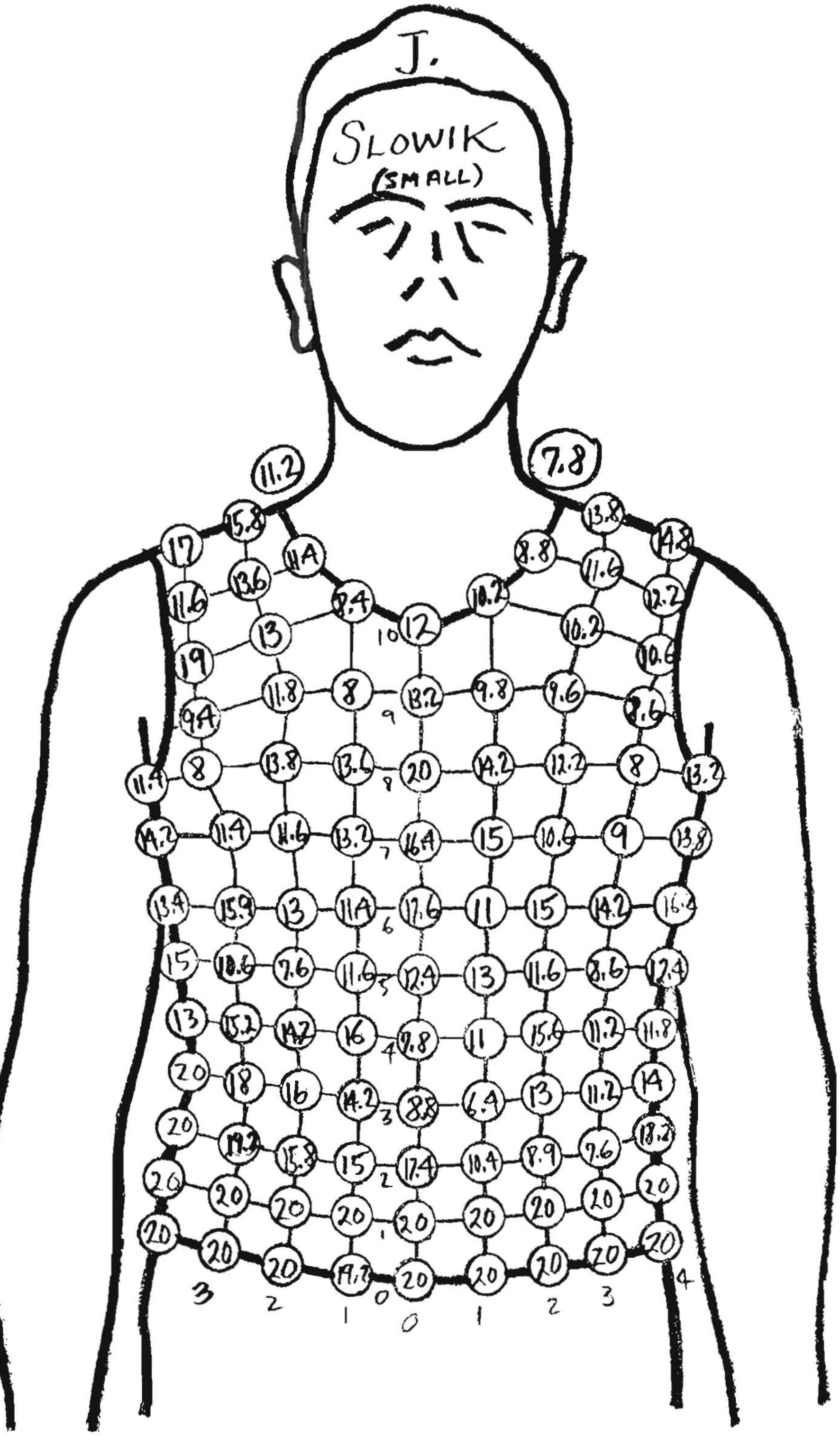

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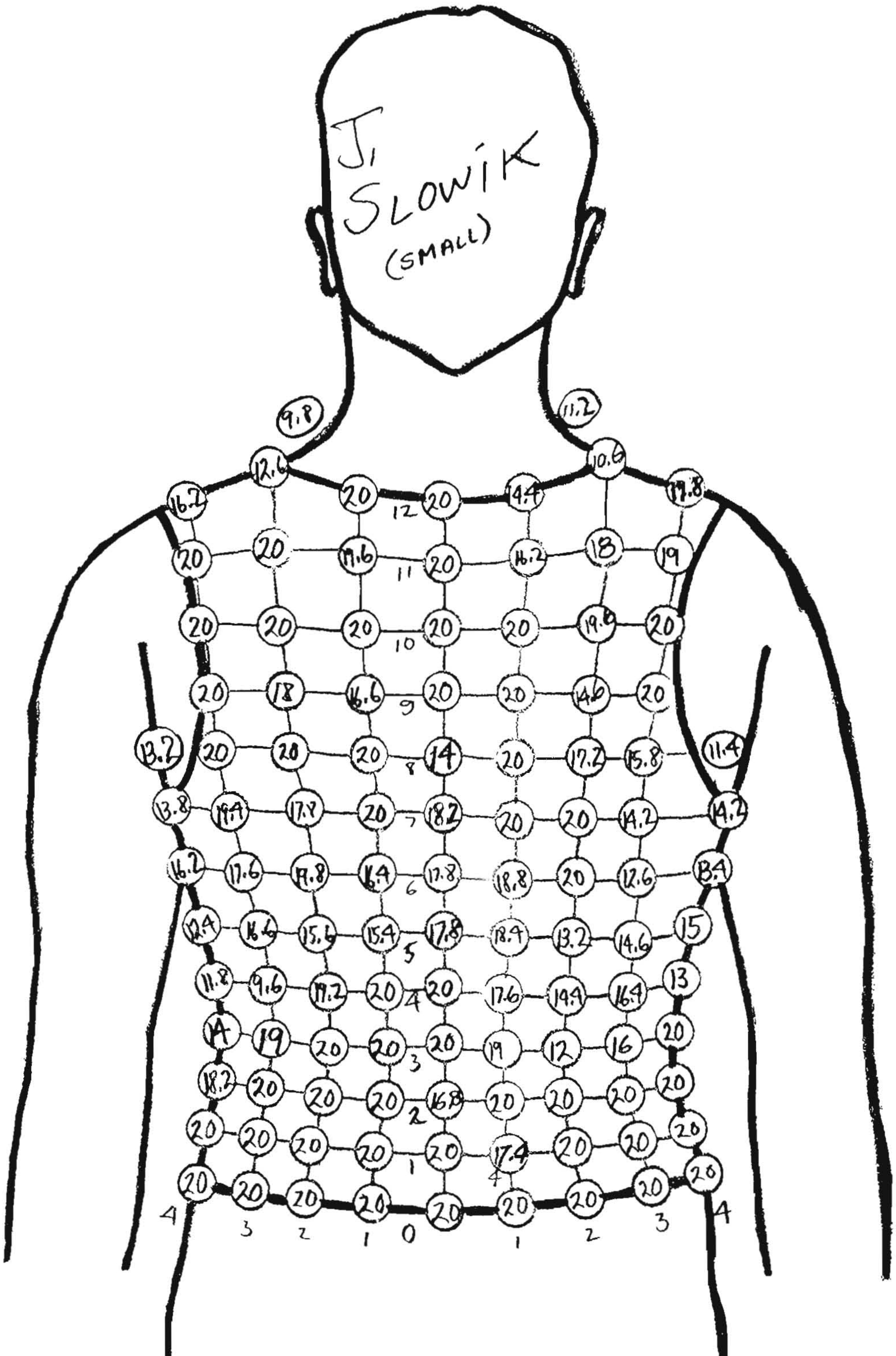

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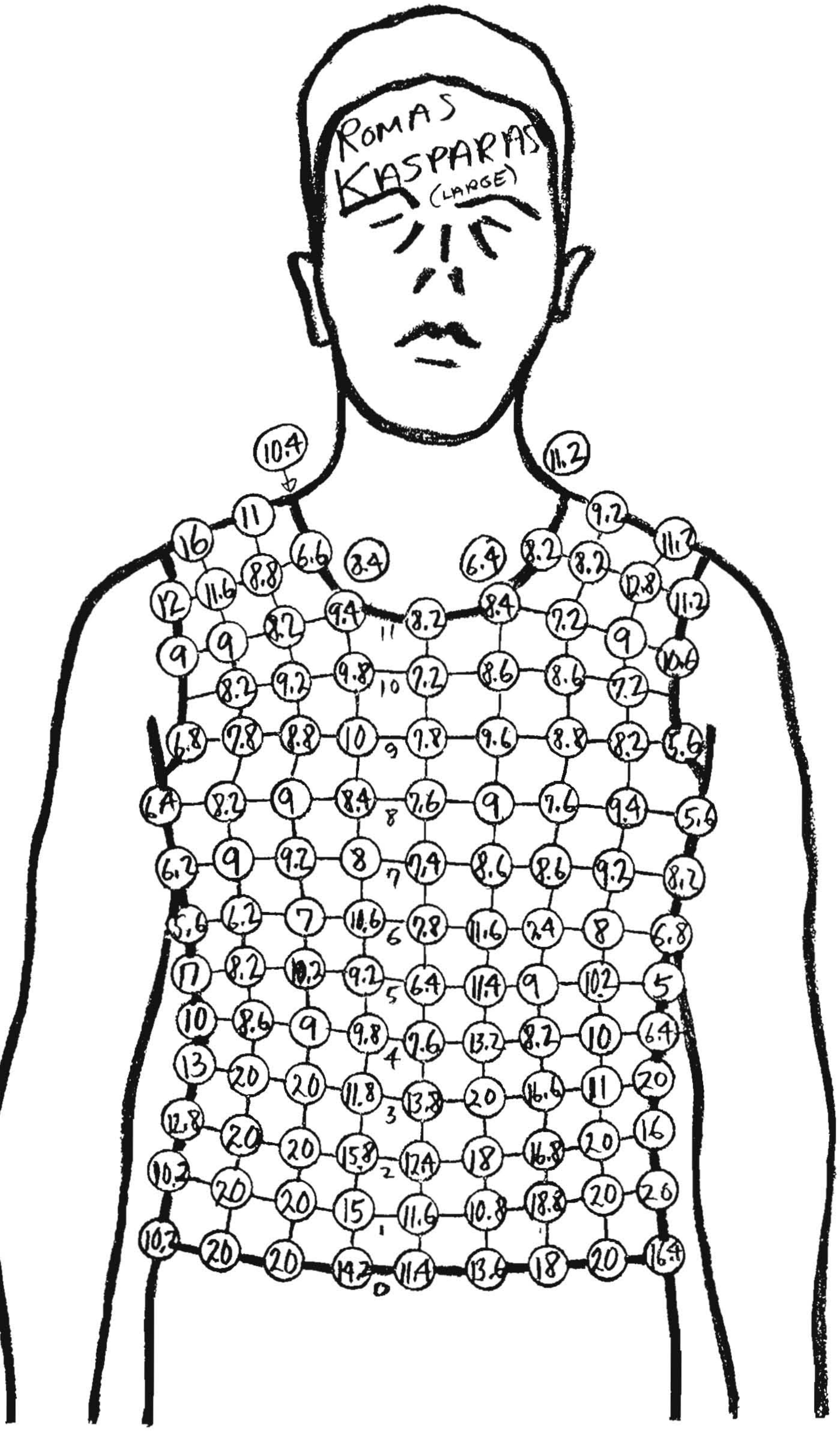
(Rear)



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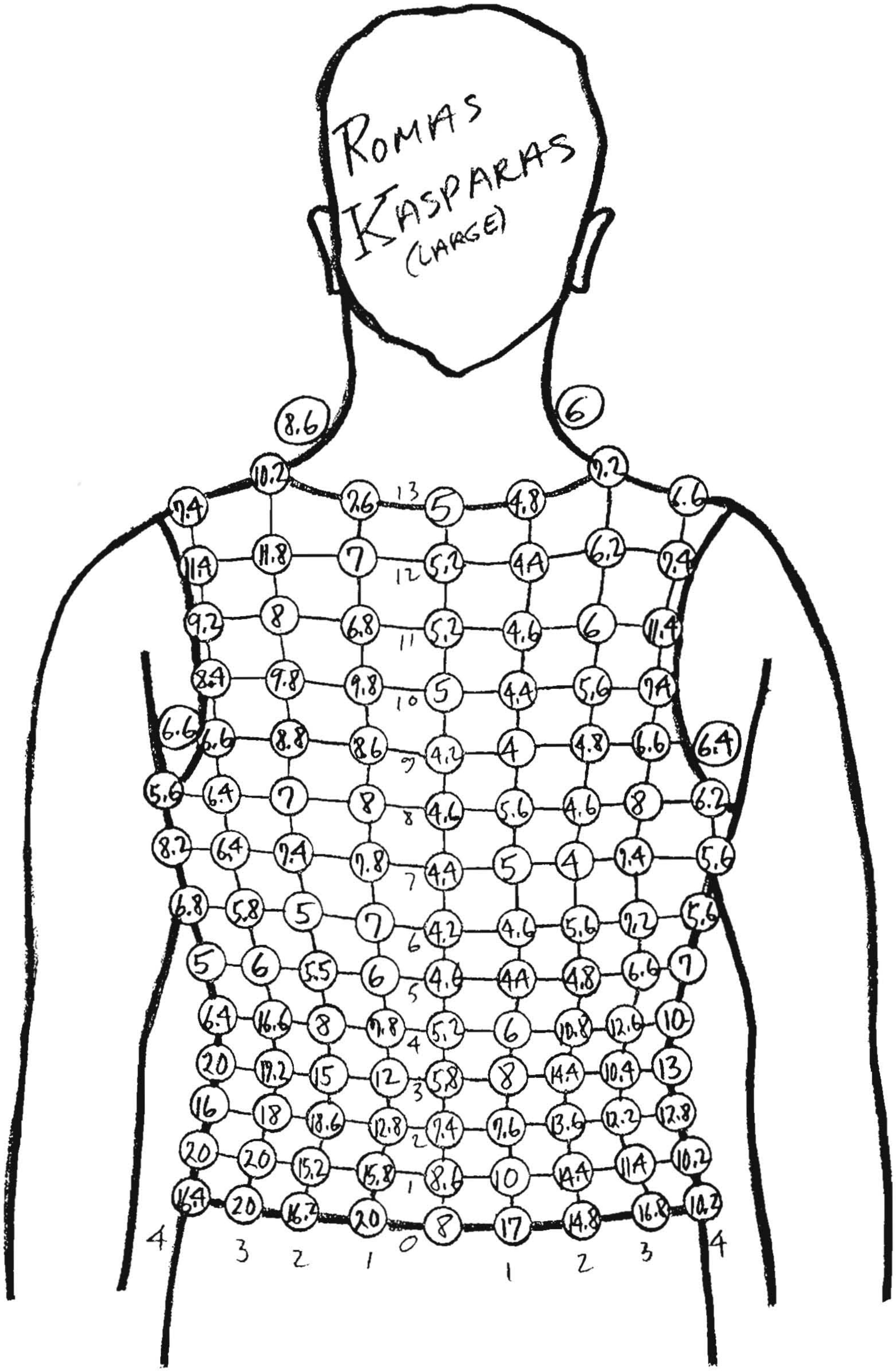
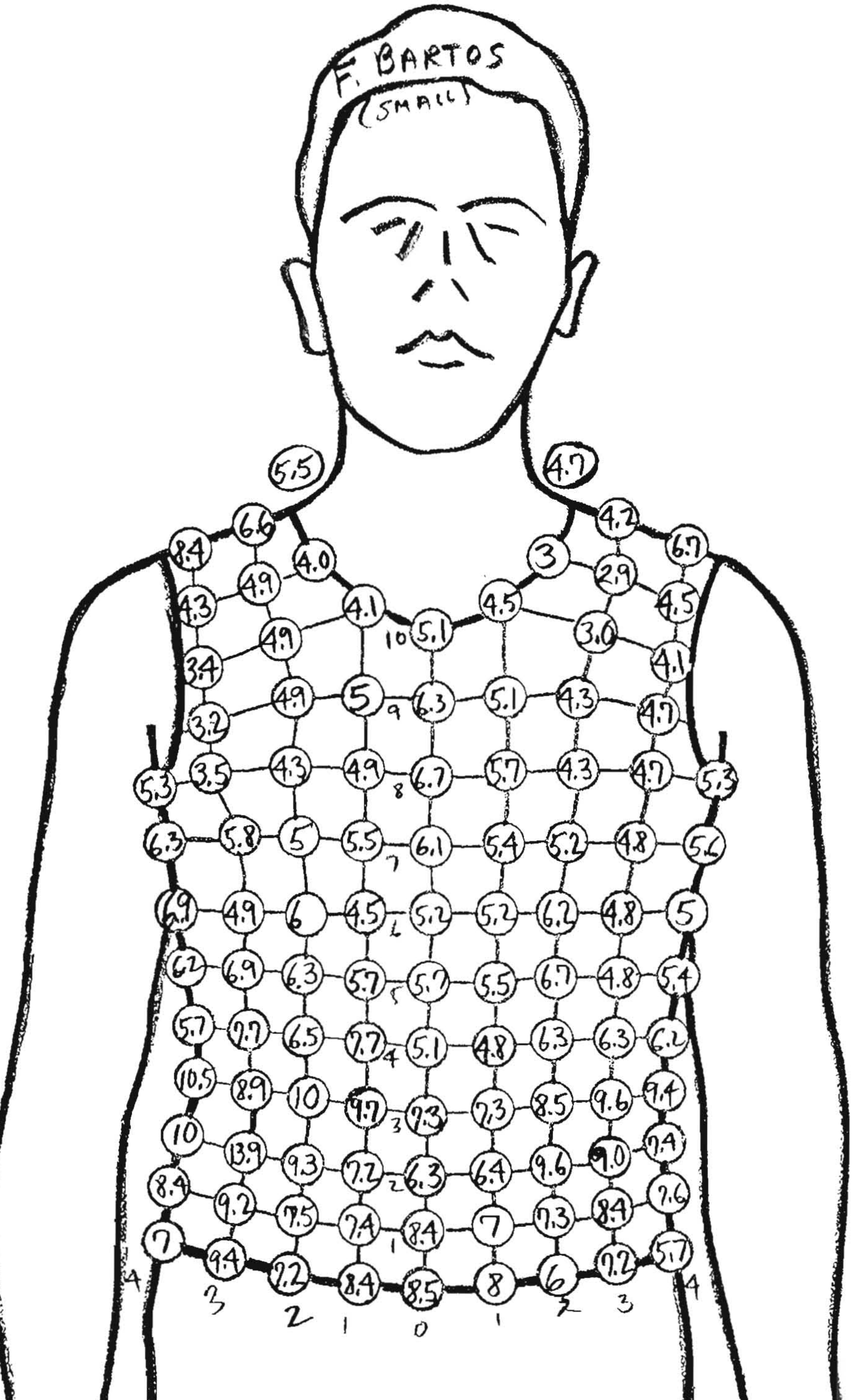
(Front)



Test Subject 8

(Rear)



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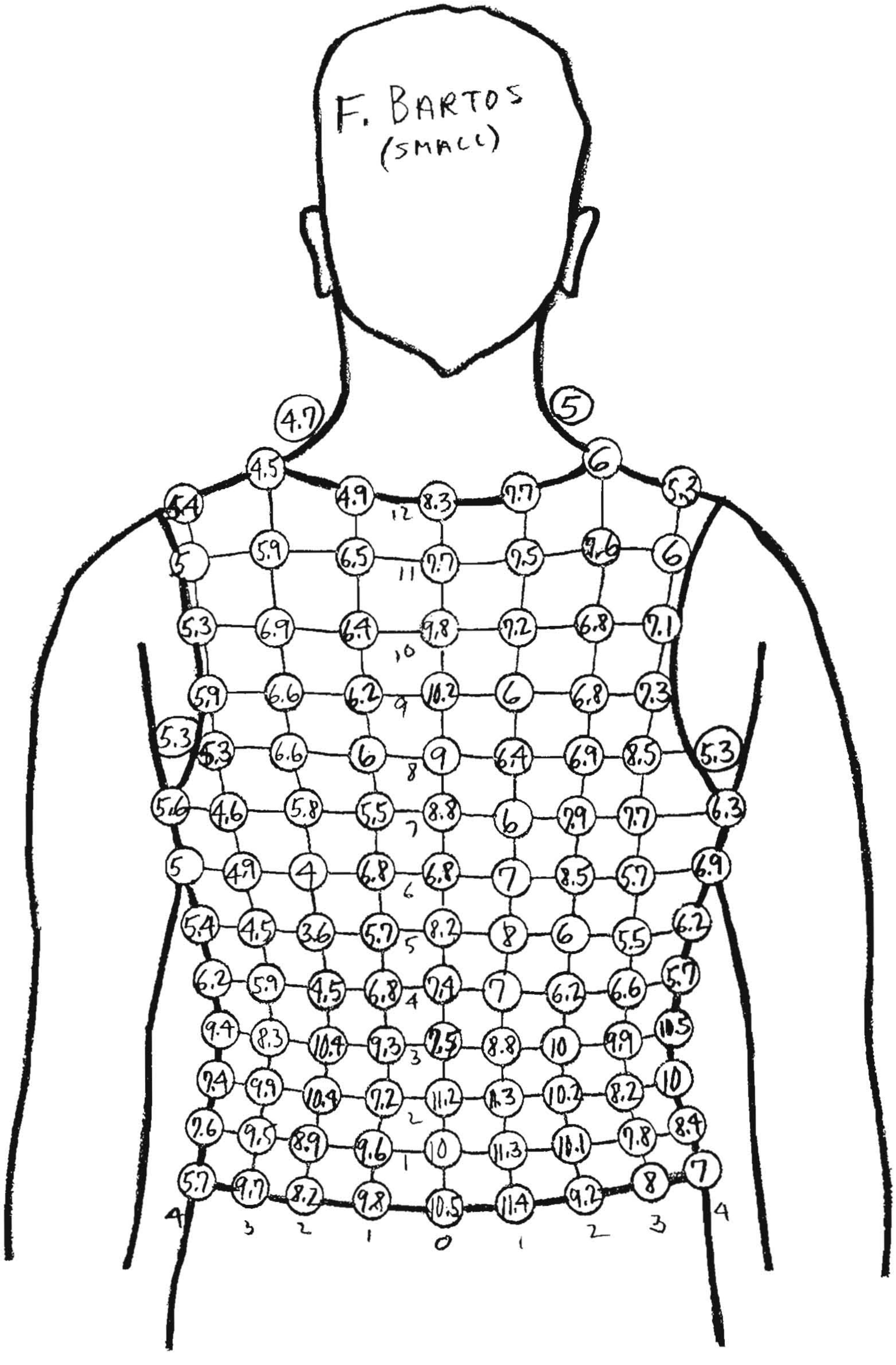
(Front)



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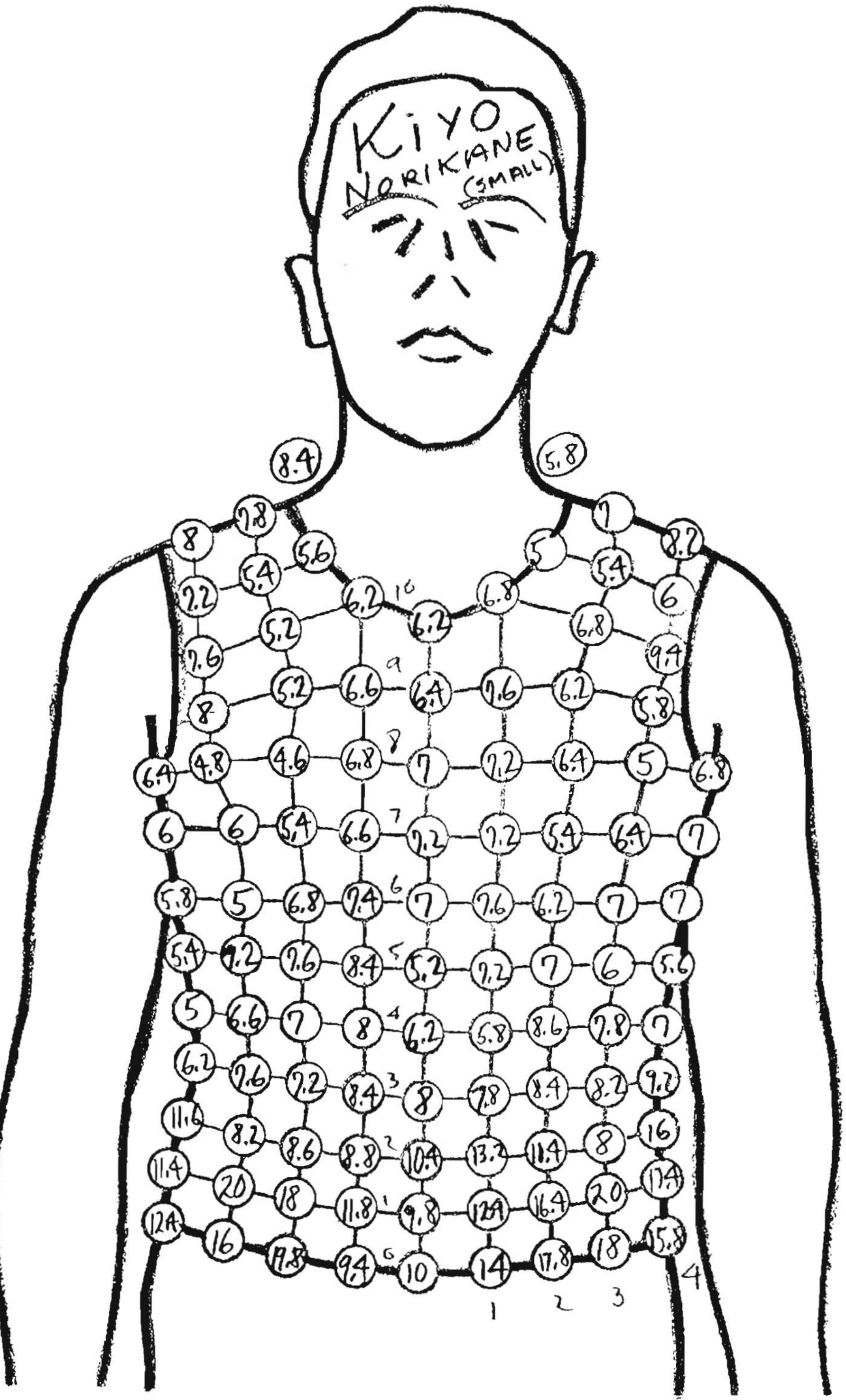
(Rear)



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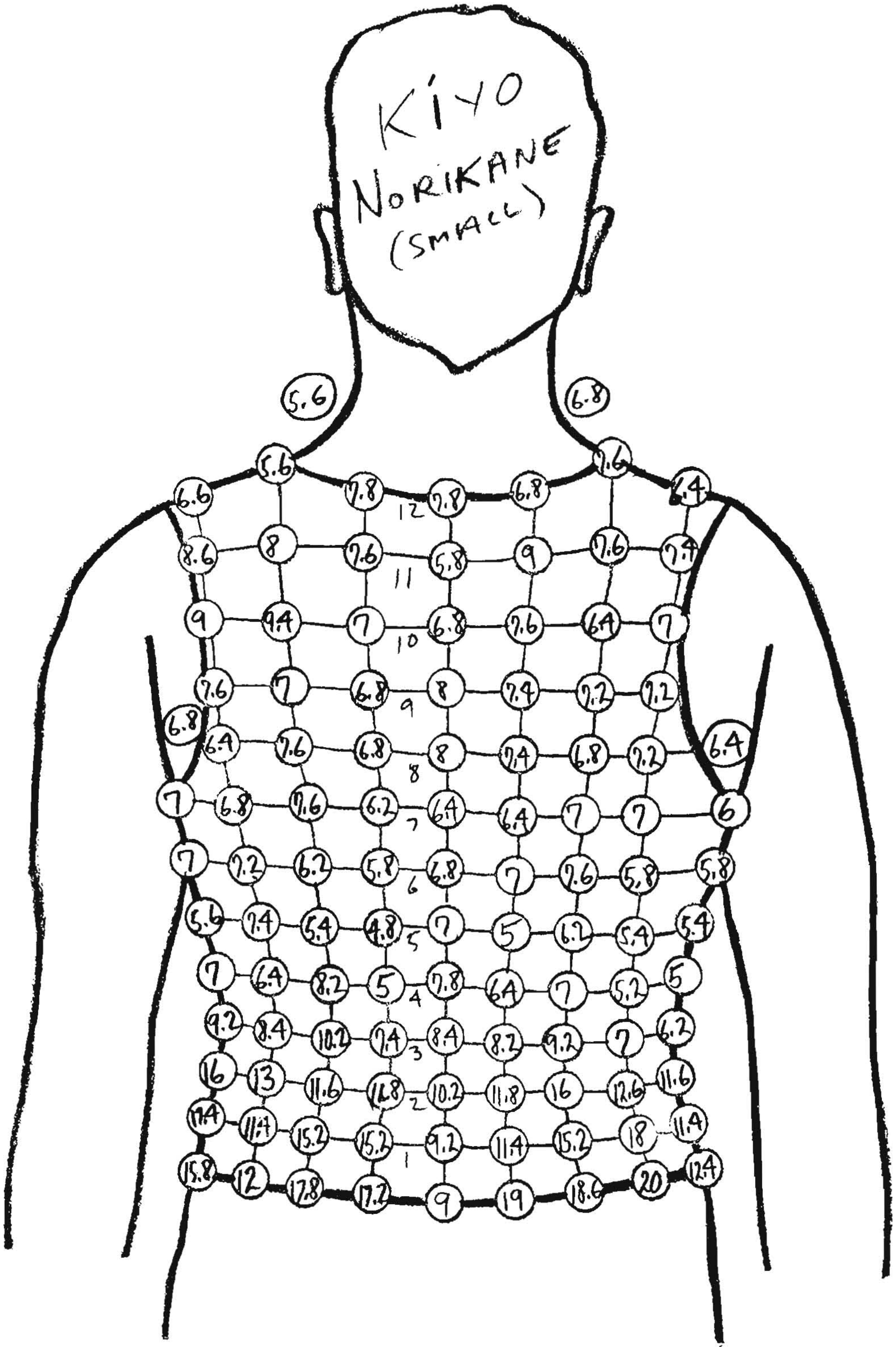
(Front)



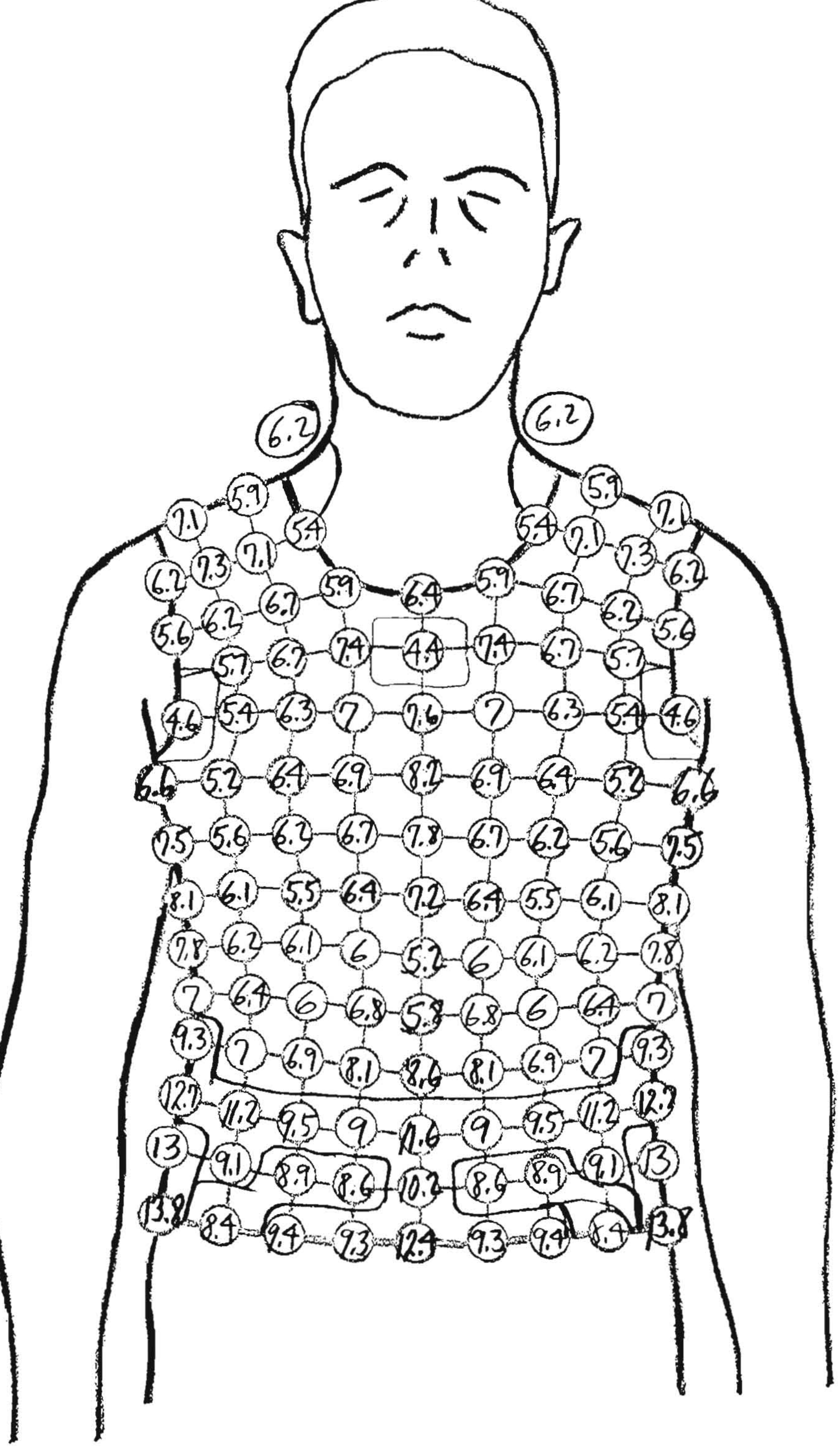
Test Subject 10

(Rear)

APPENDIX B

TORSO SENSITIVITY DATA

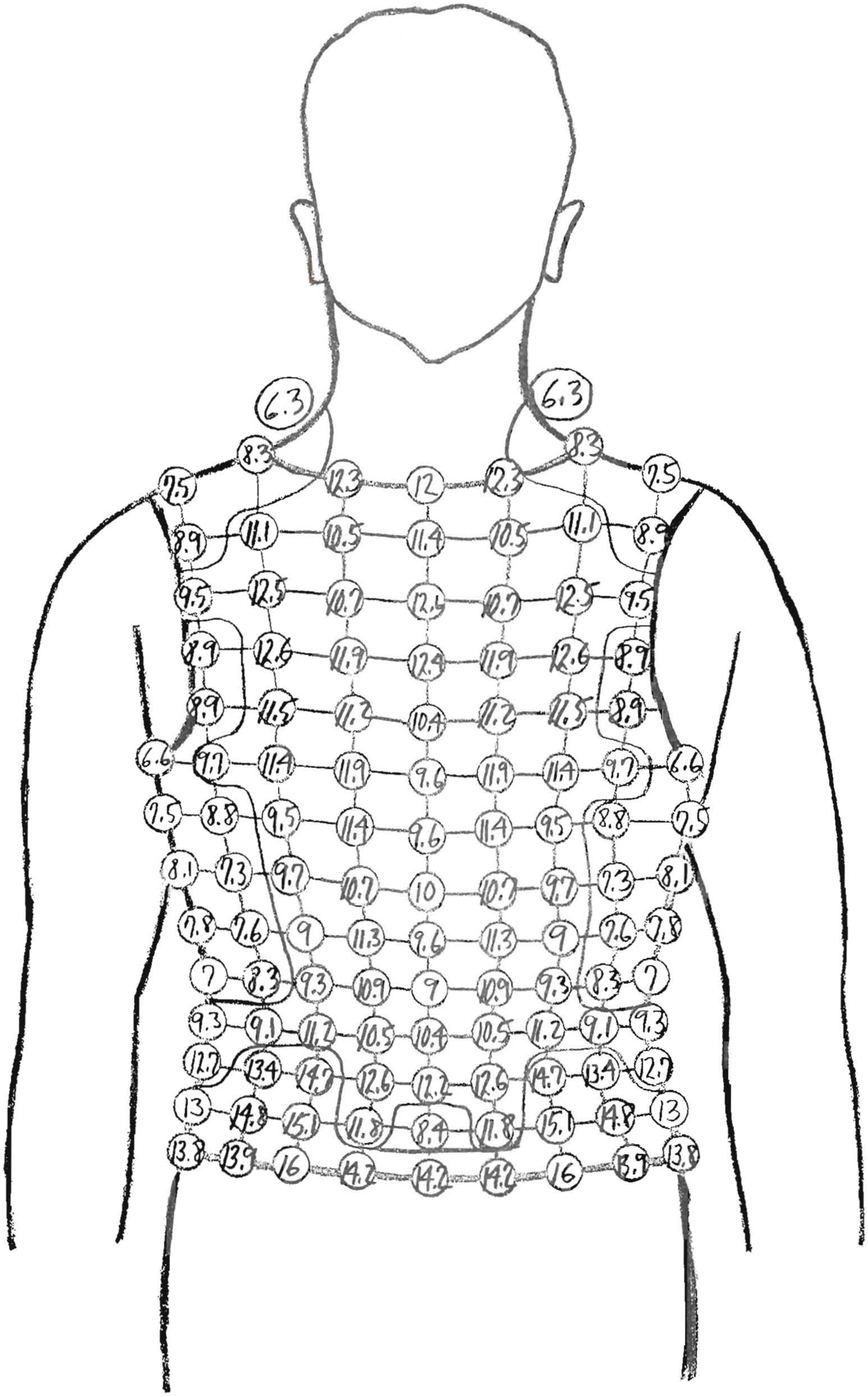
(Torso Left-Hand and Right-Hand Data Averaged,
Test Subjects 2 through 10)



"Averaged" Torso Sensitivity

Data For Test Subject No. 1

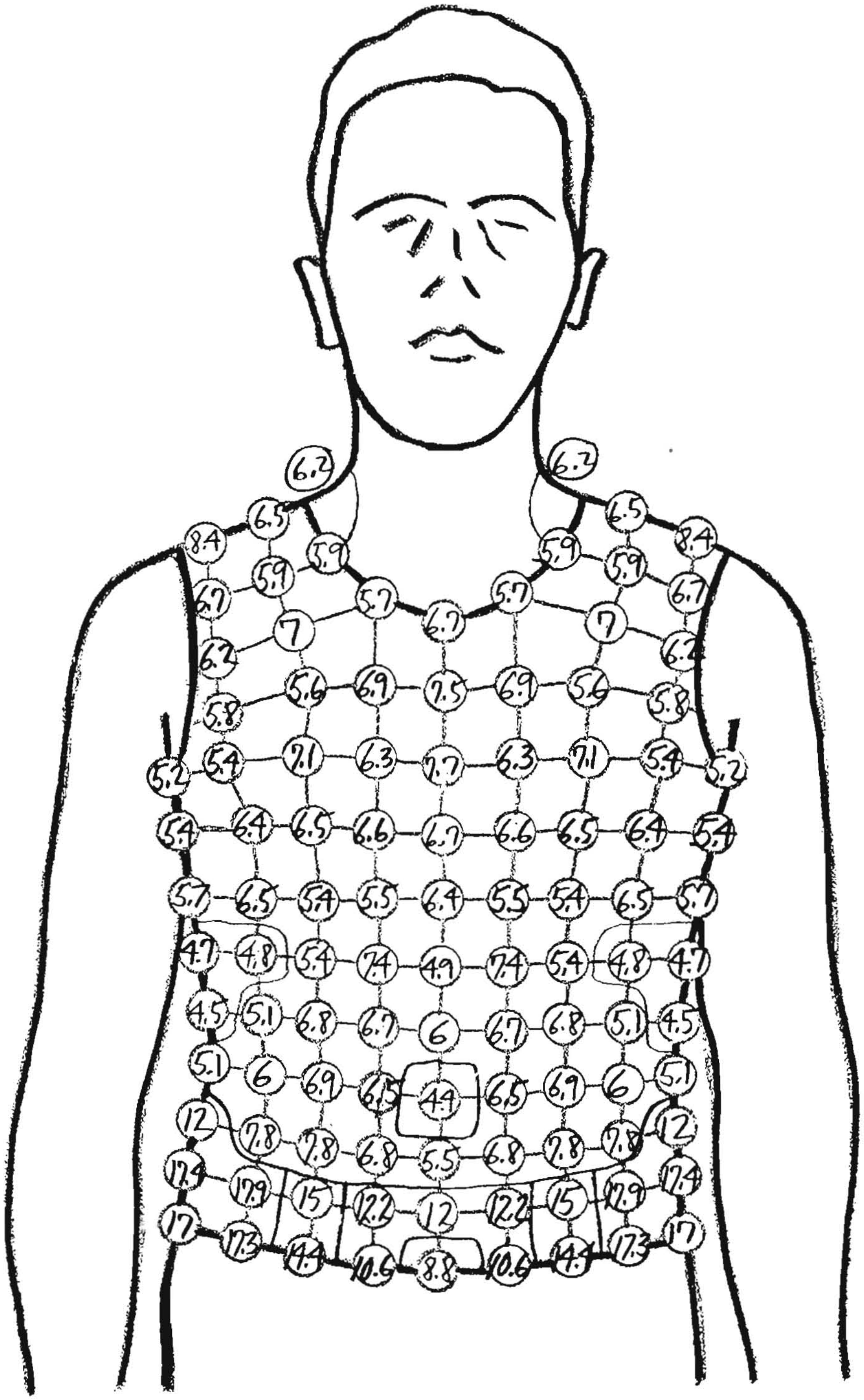
(Anterior View)



"Averaged" Torso Sensitivity

Data For Test Subject No. 1

(Posterior View)



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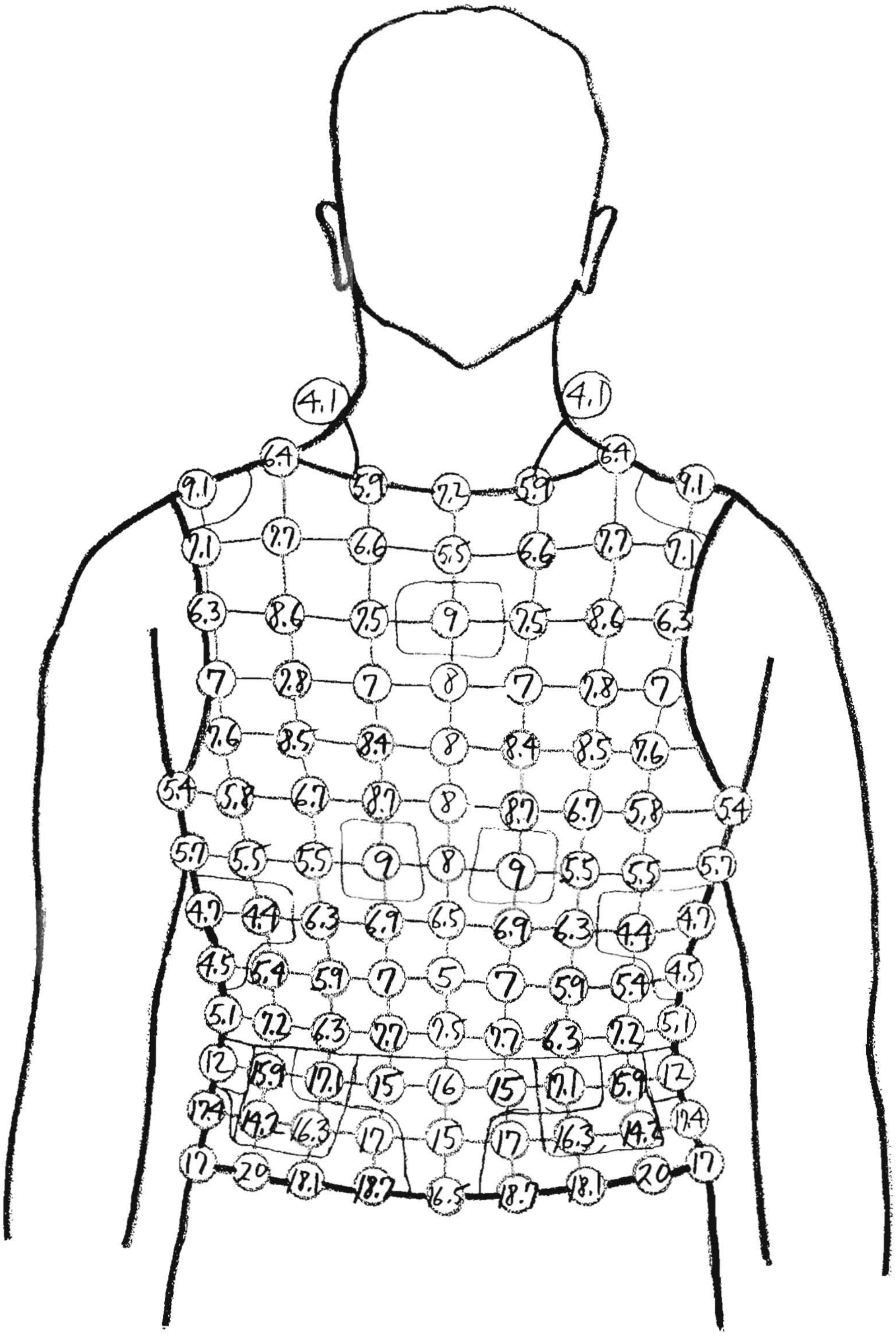
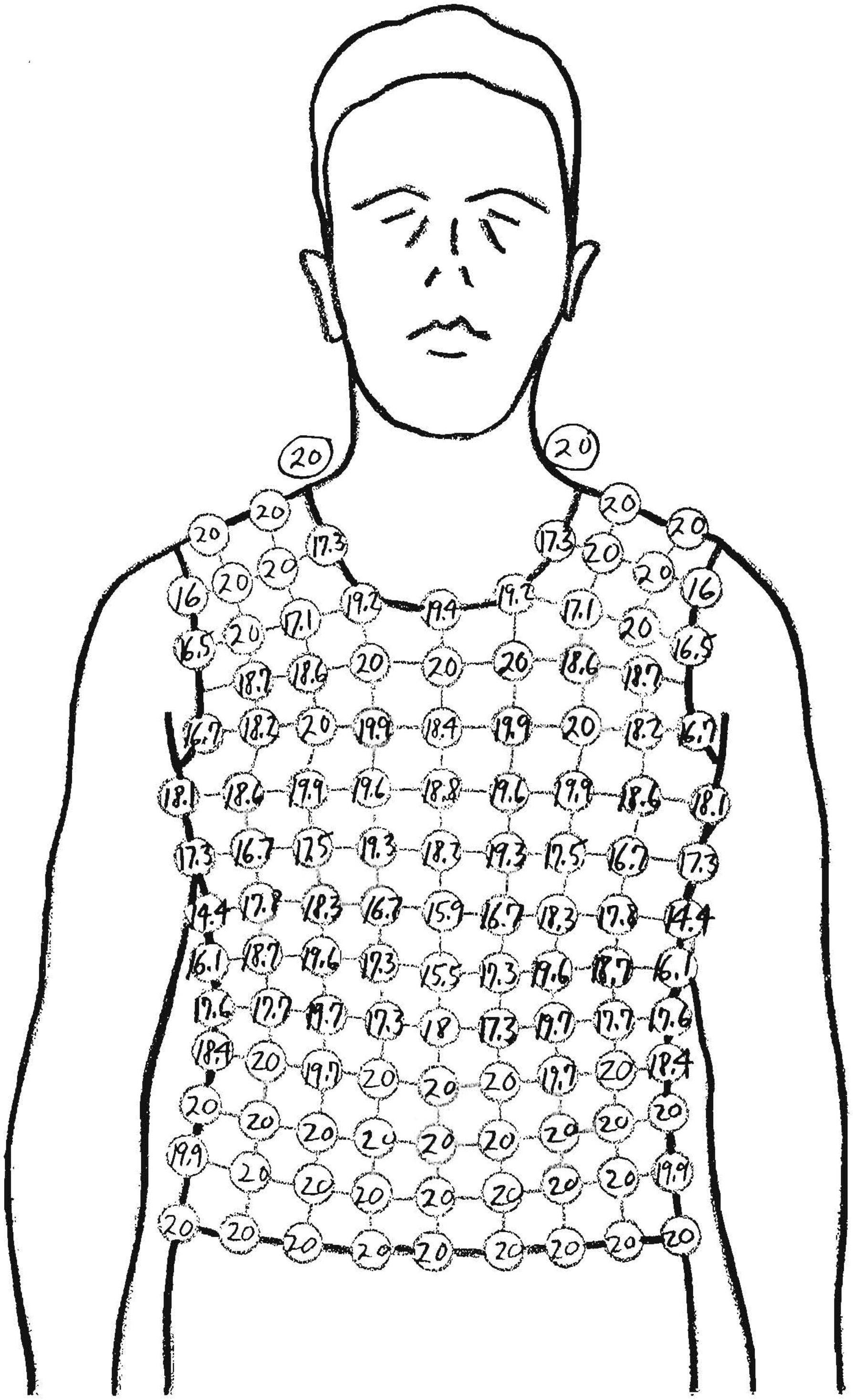


Test Subject 2

(Rear Averaged)



Test Subject 3

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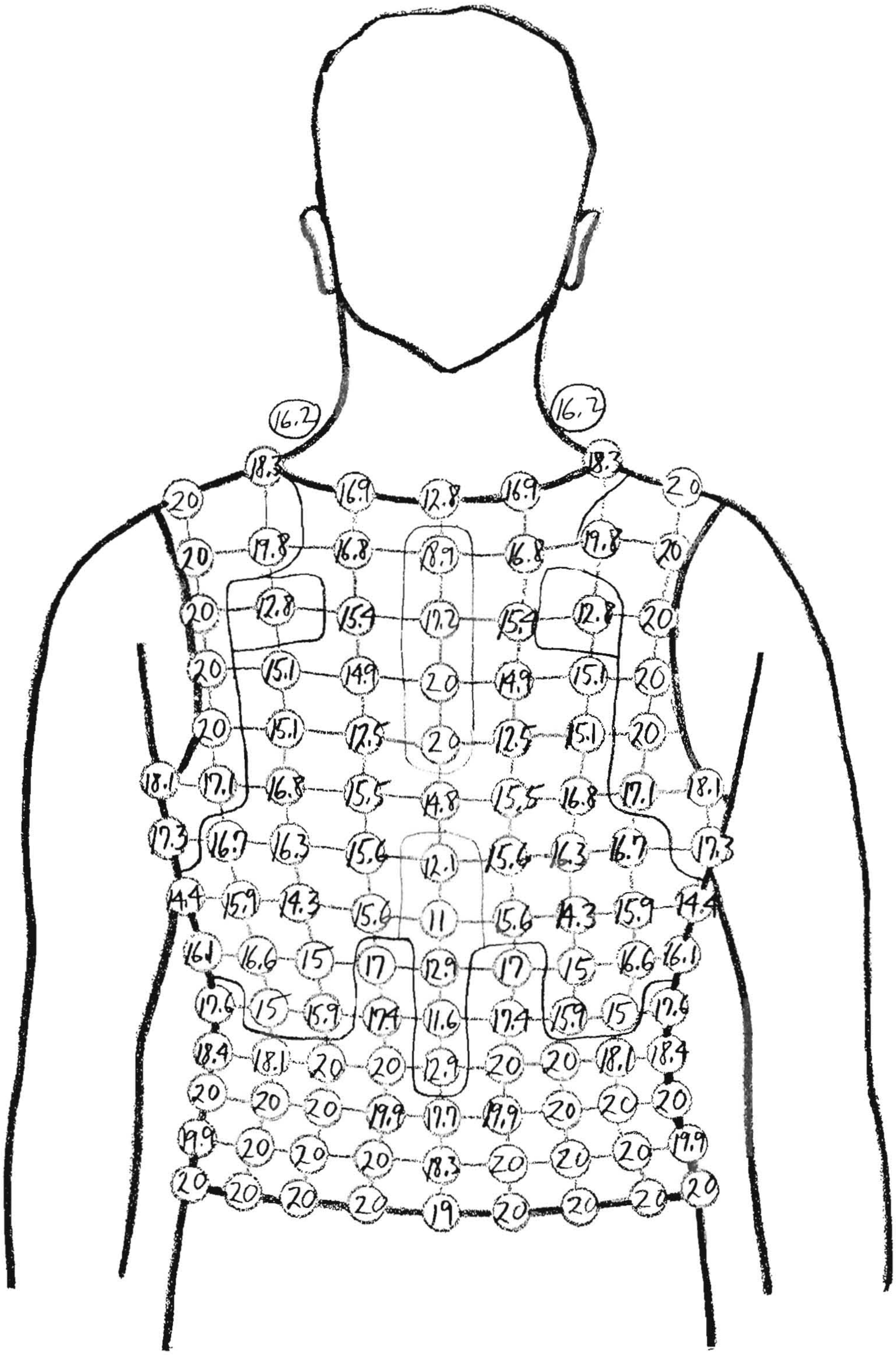

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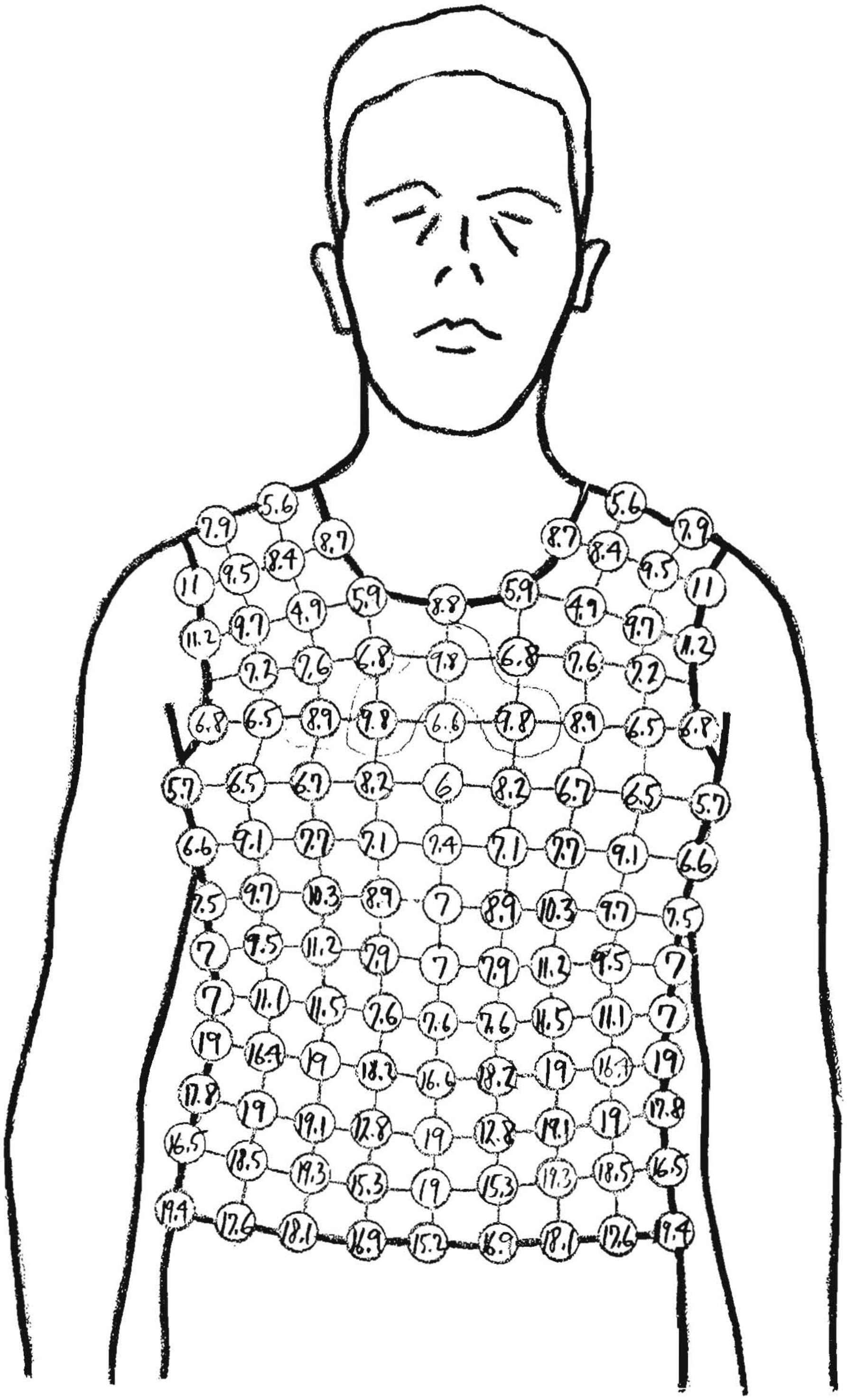

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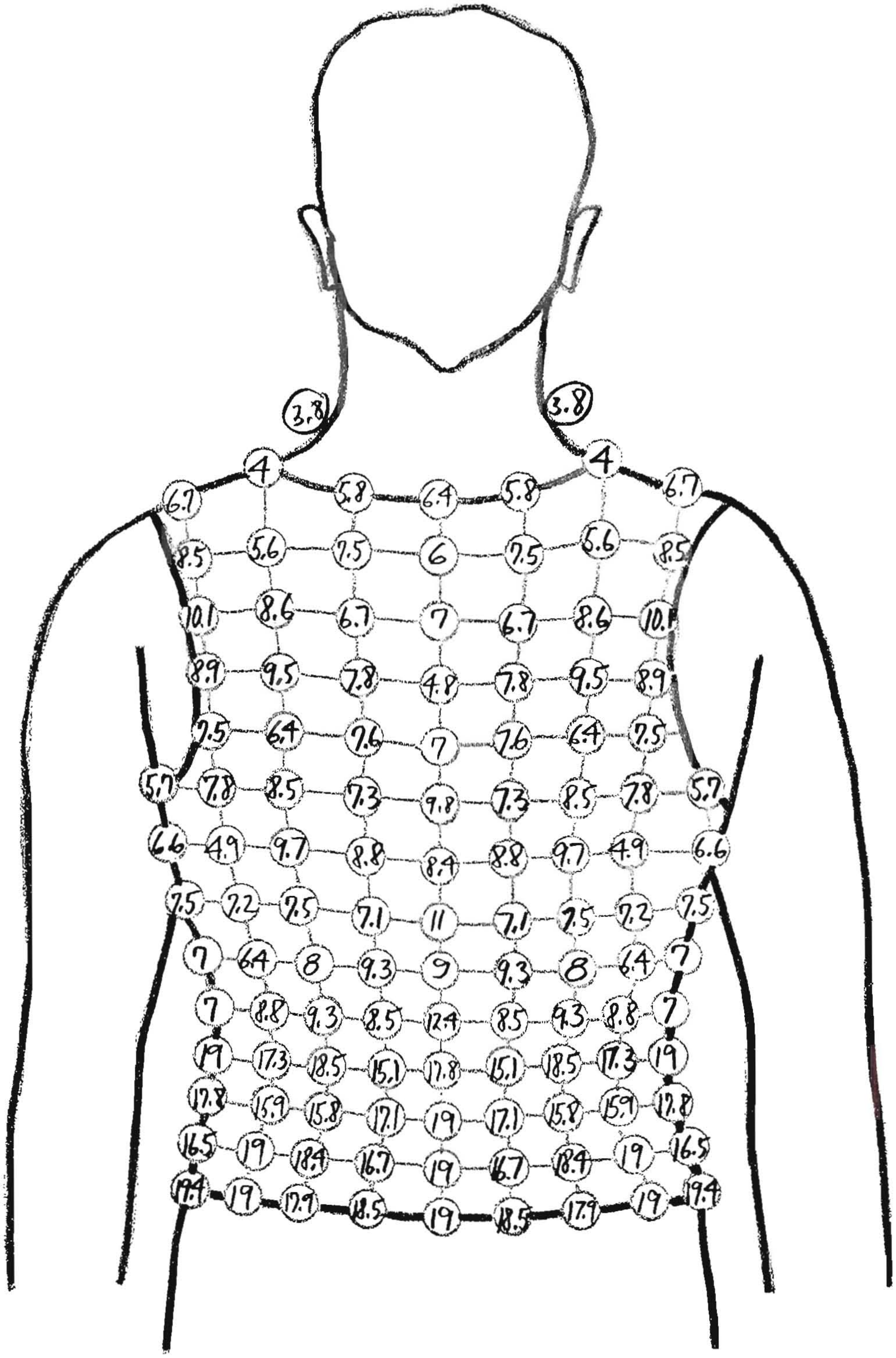
(Front Averaged)



Test Subject 4

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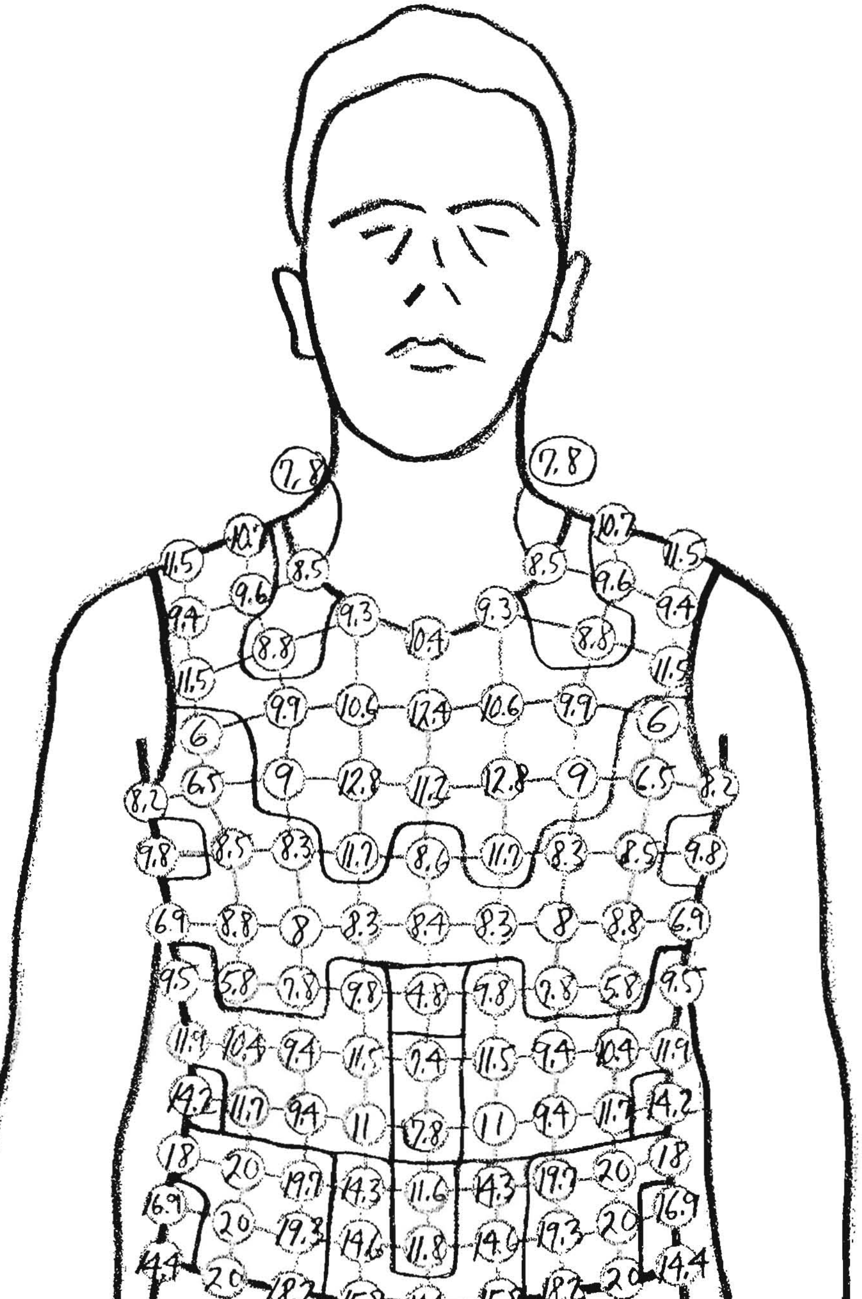
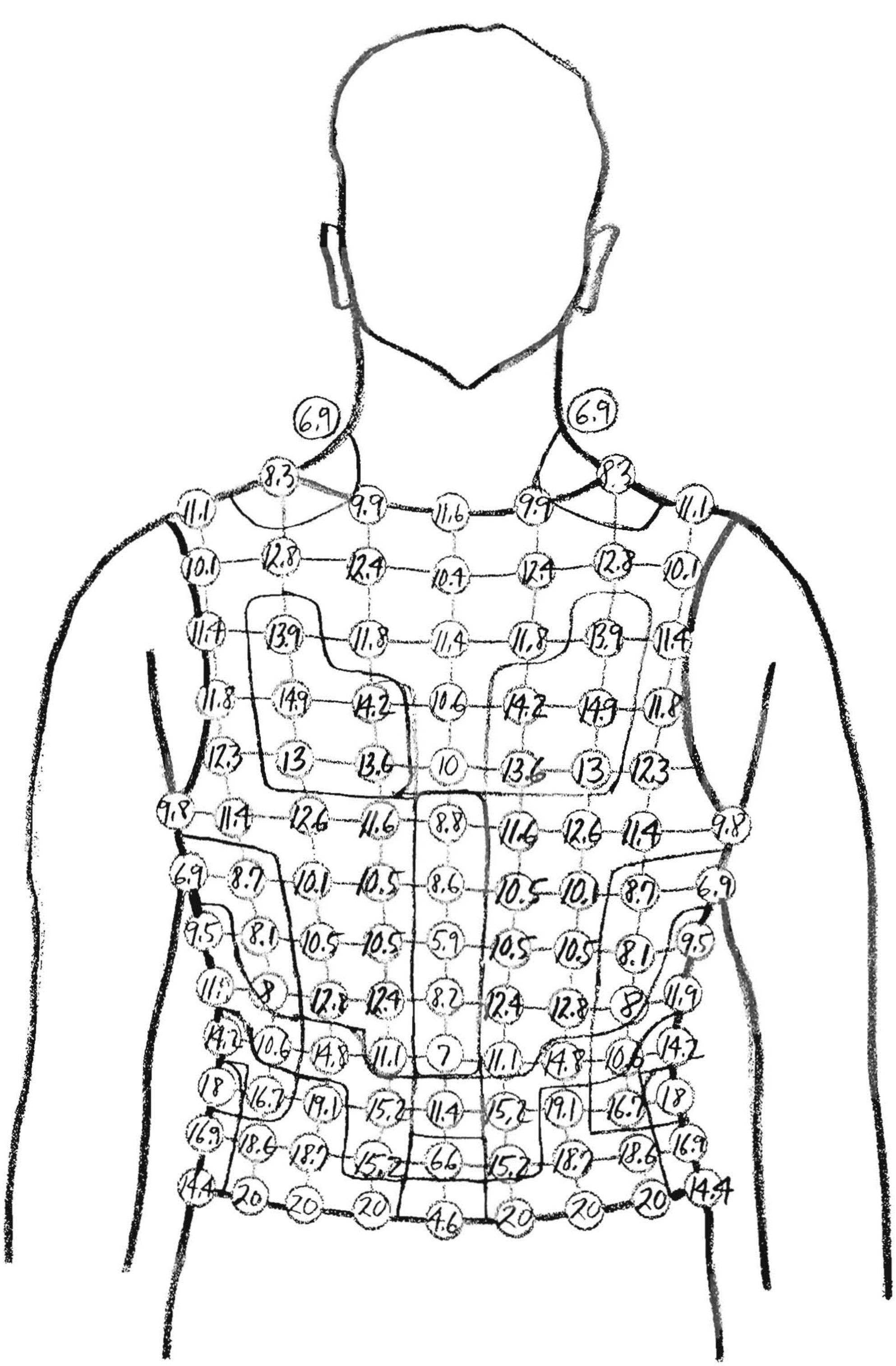


Test Subject 5

(Front Averaged)



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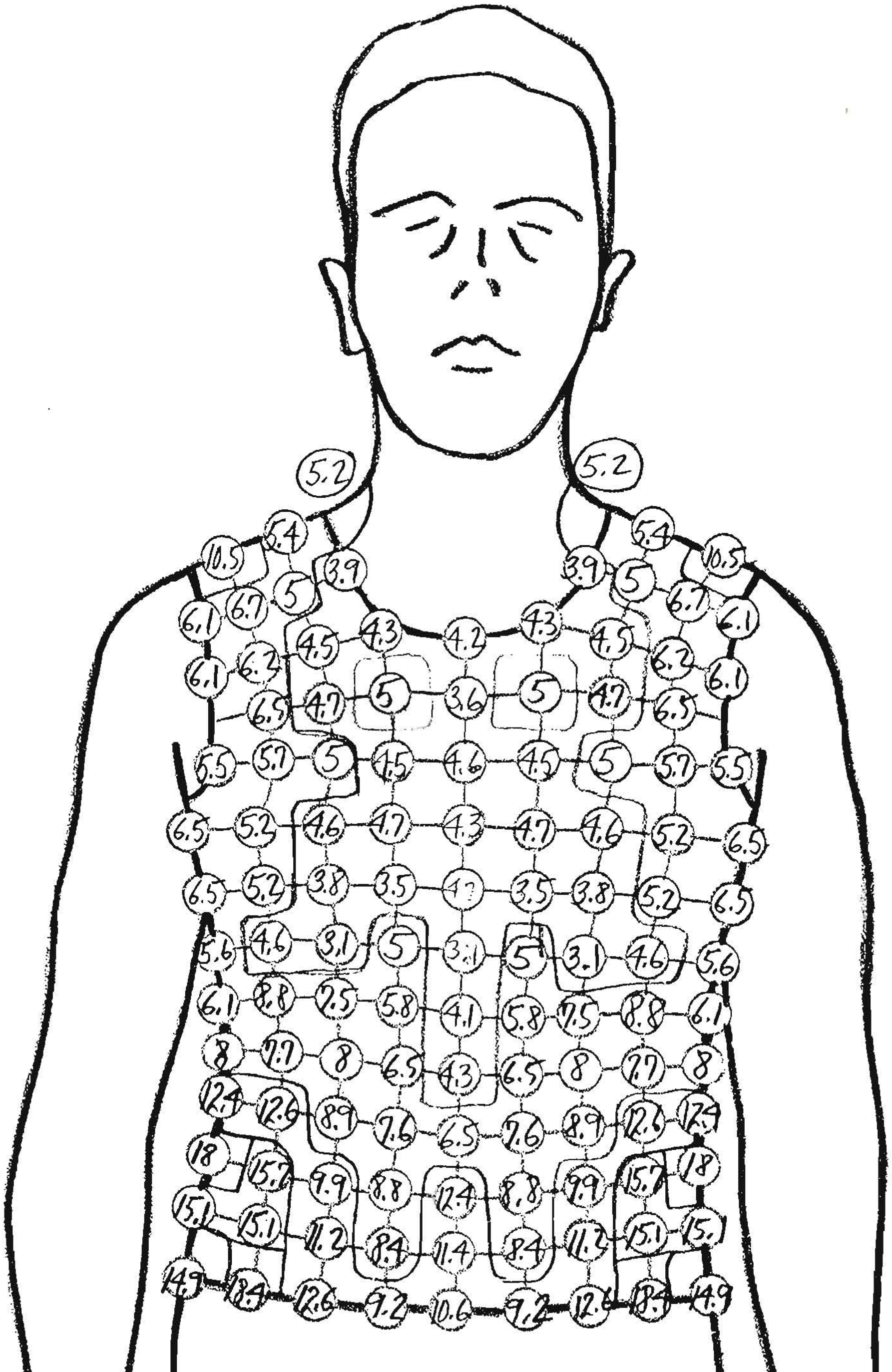

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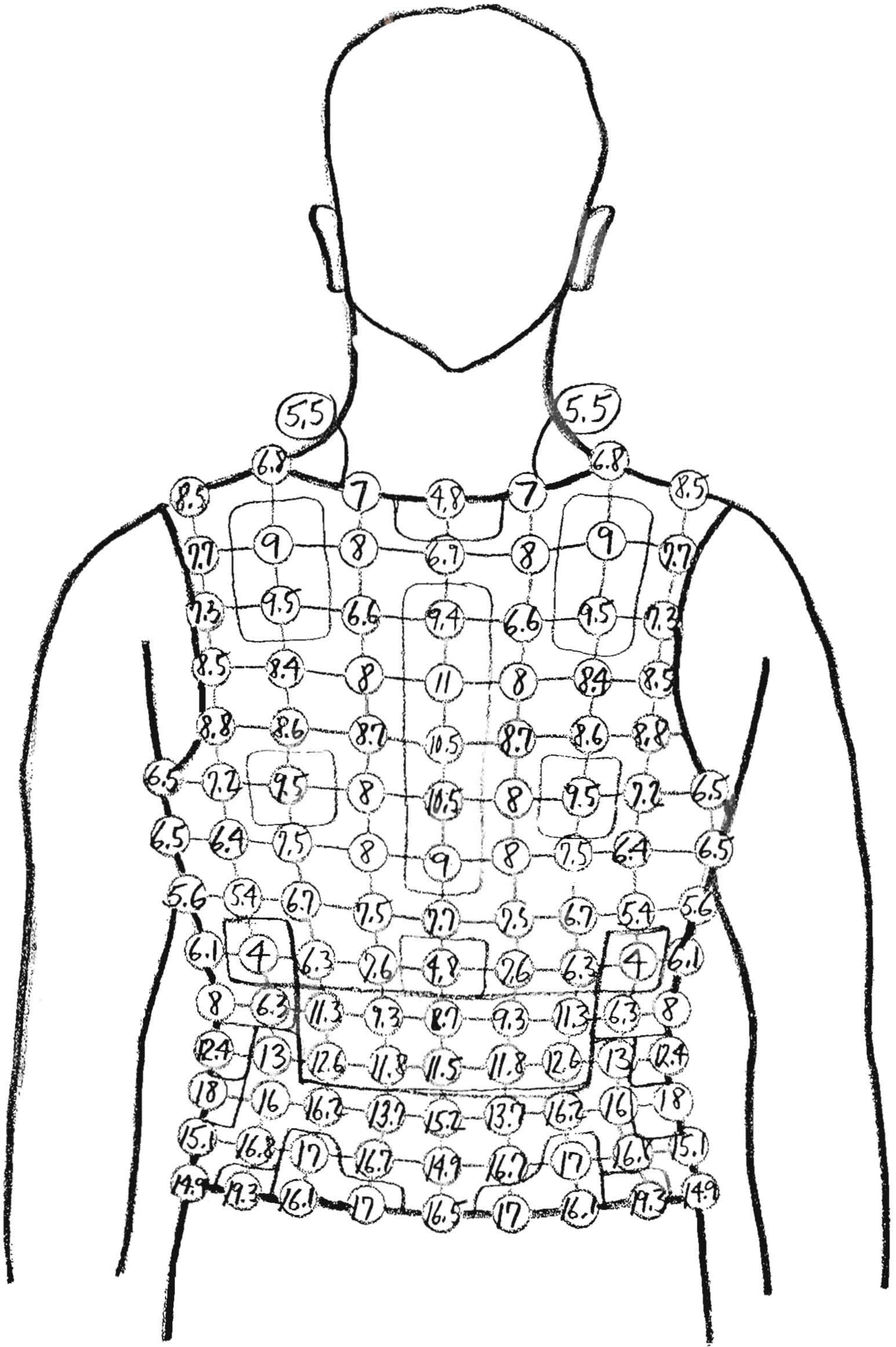

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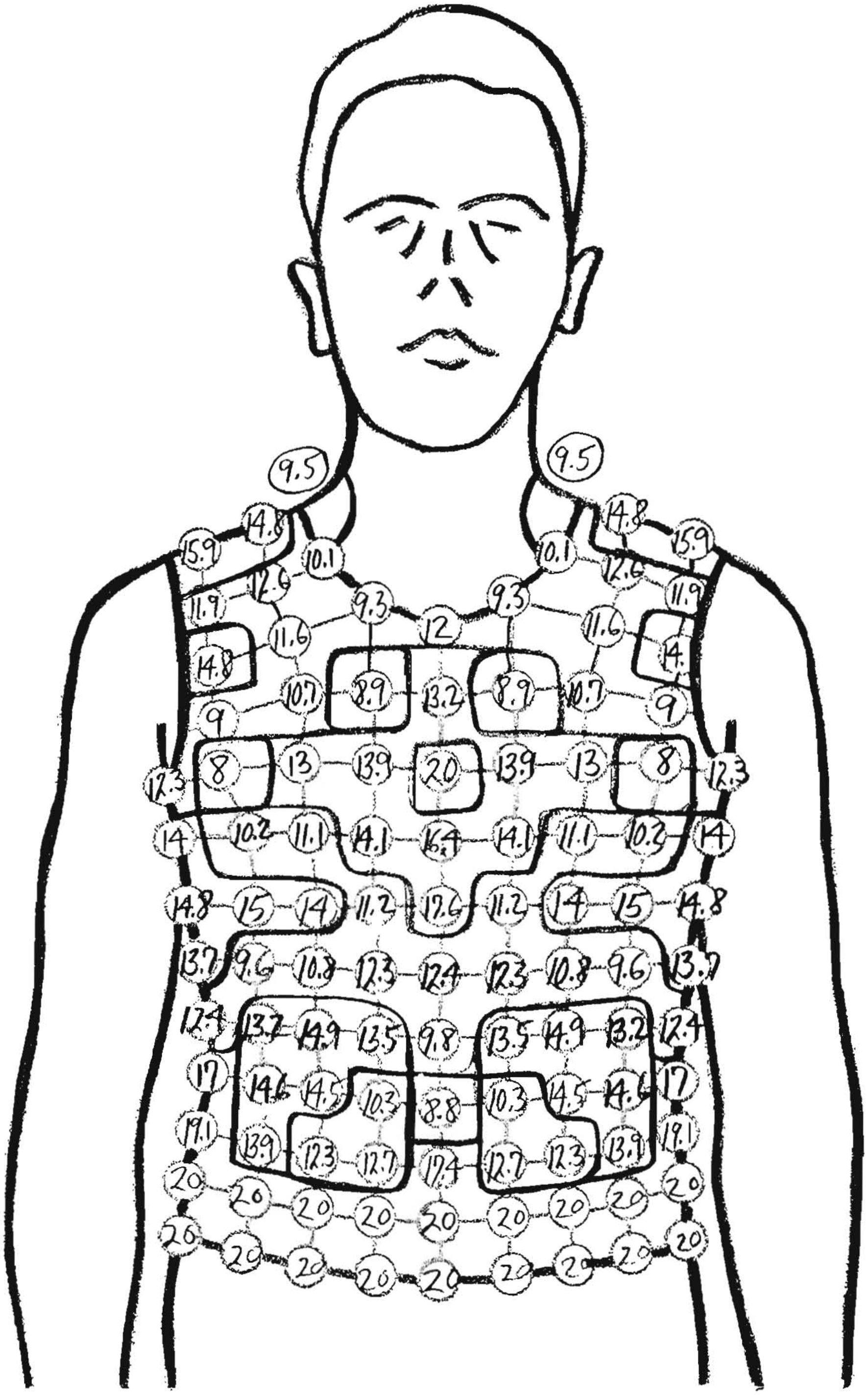

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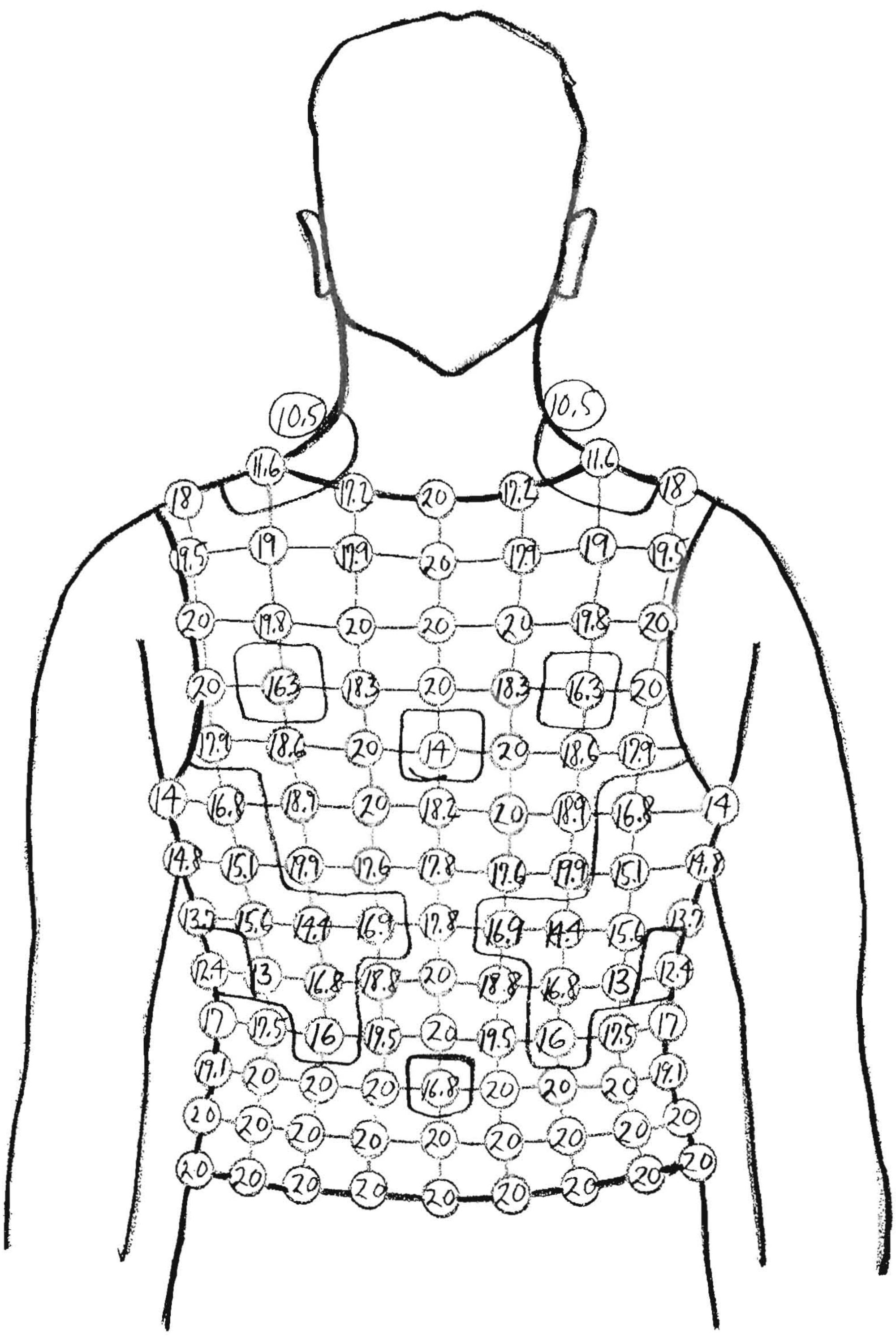

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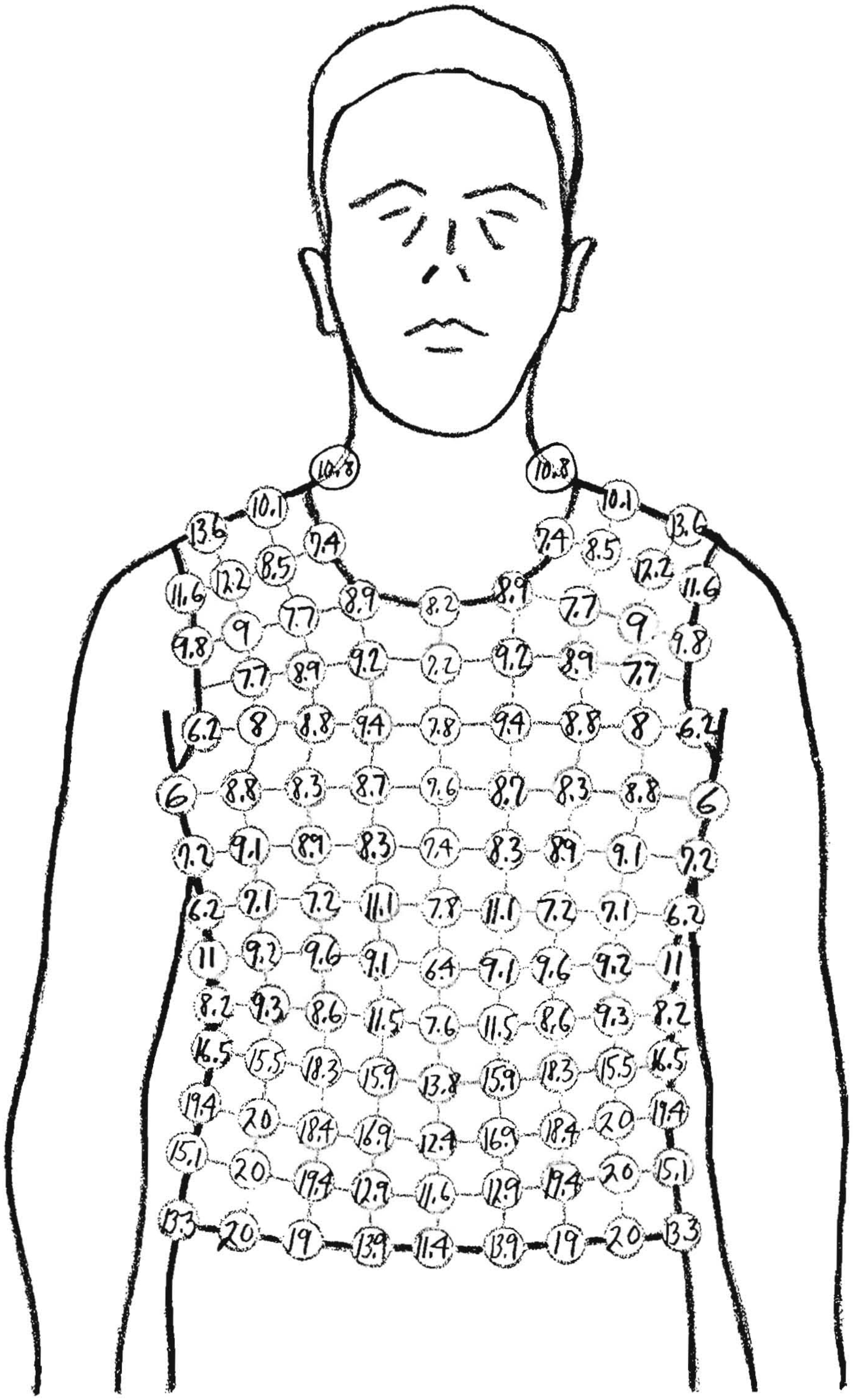

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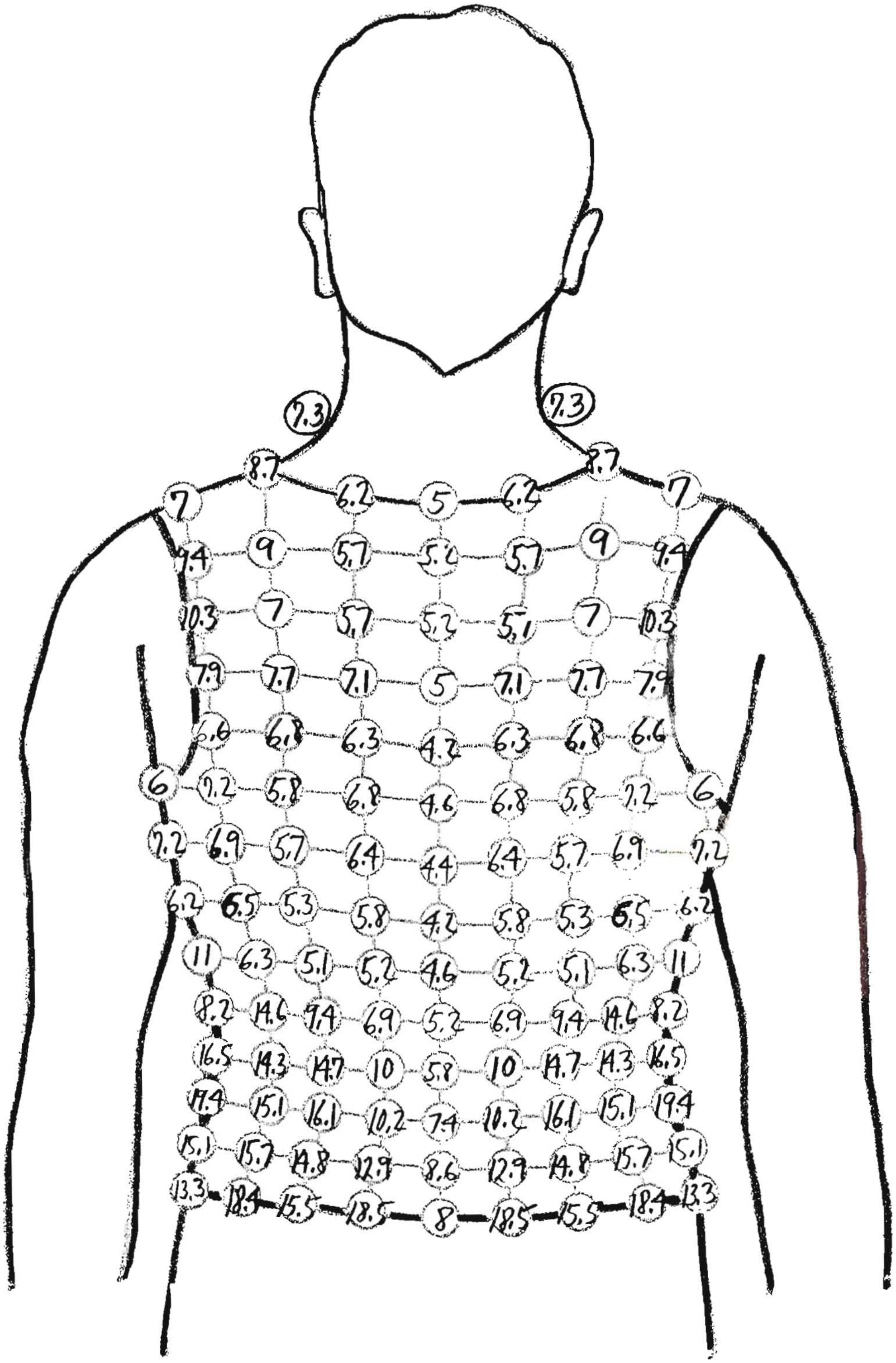

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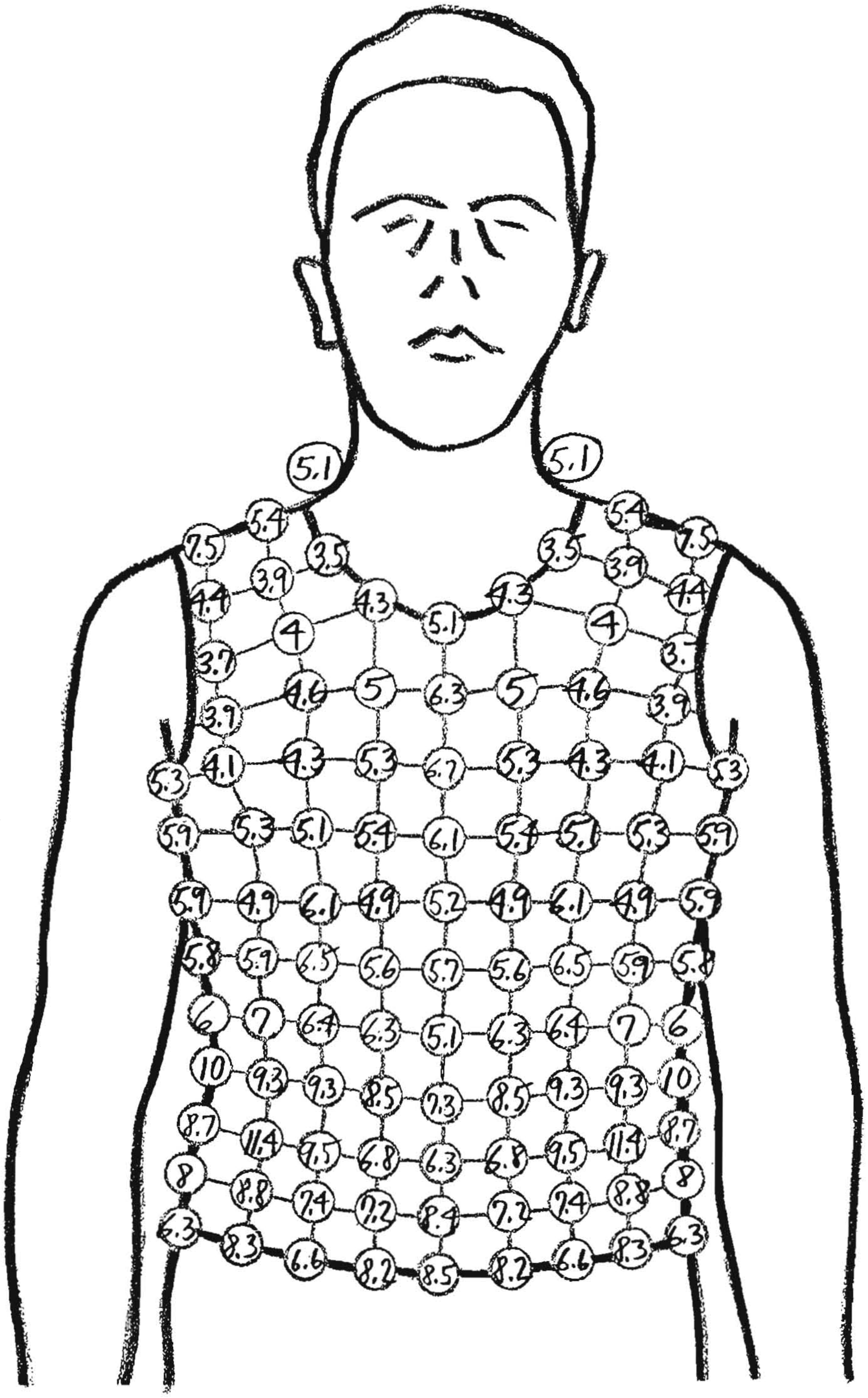

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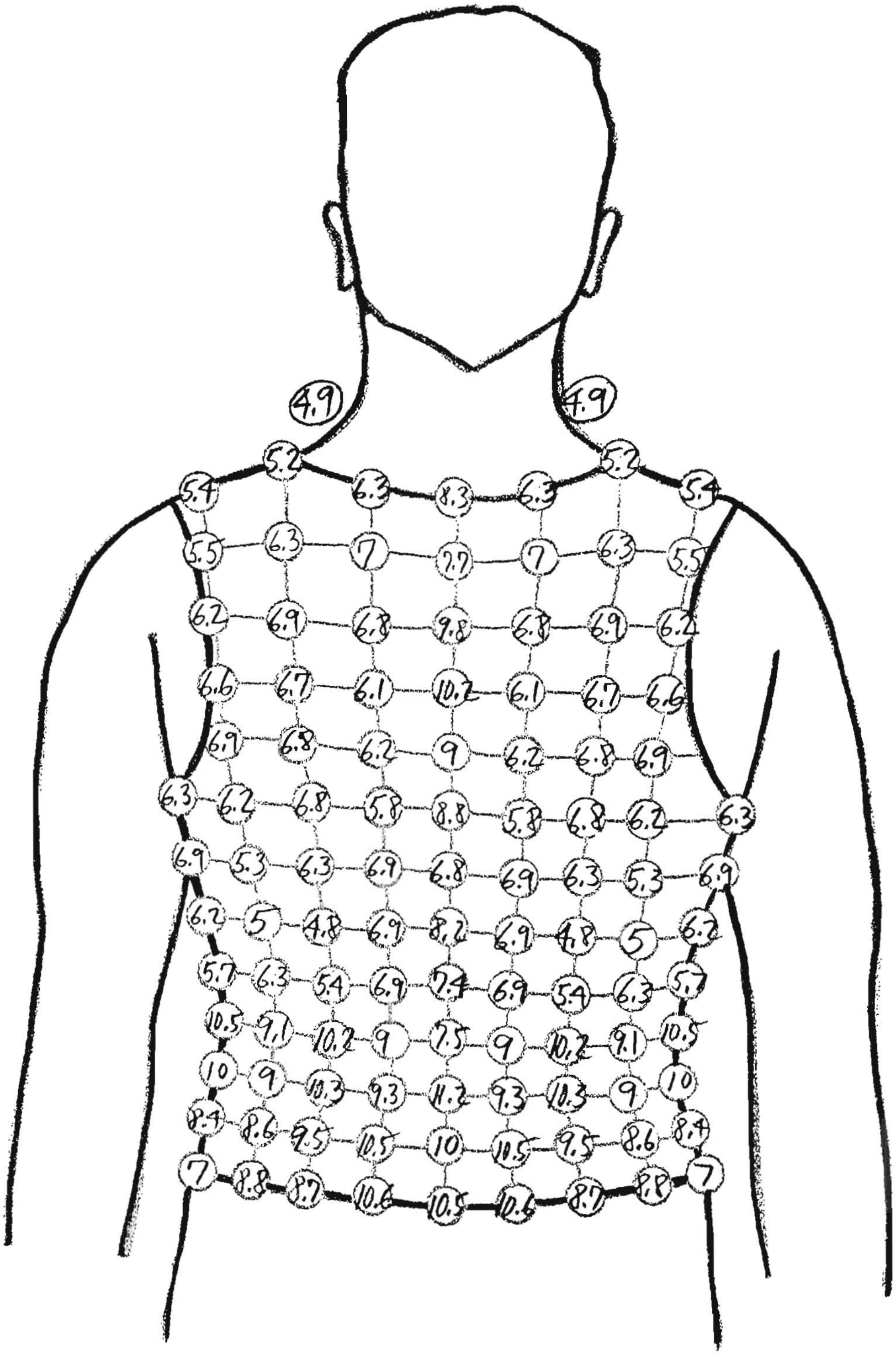
(Front Averaged)



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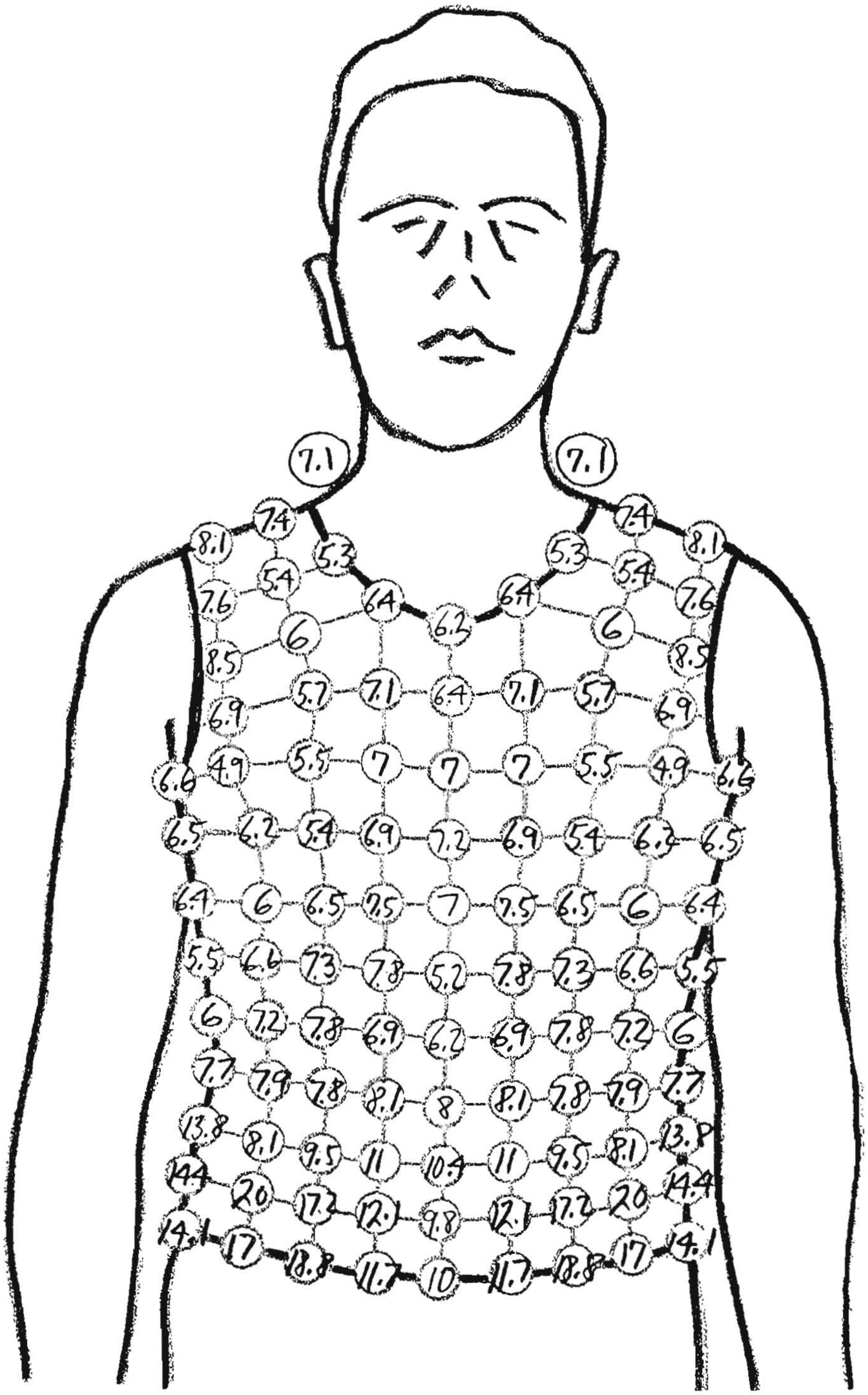
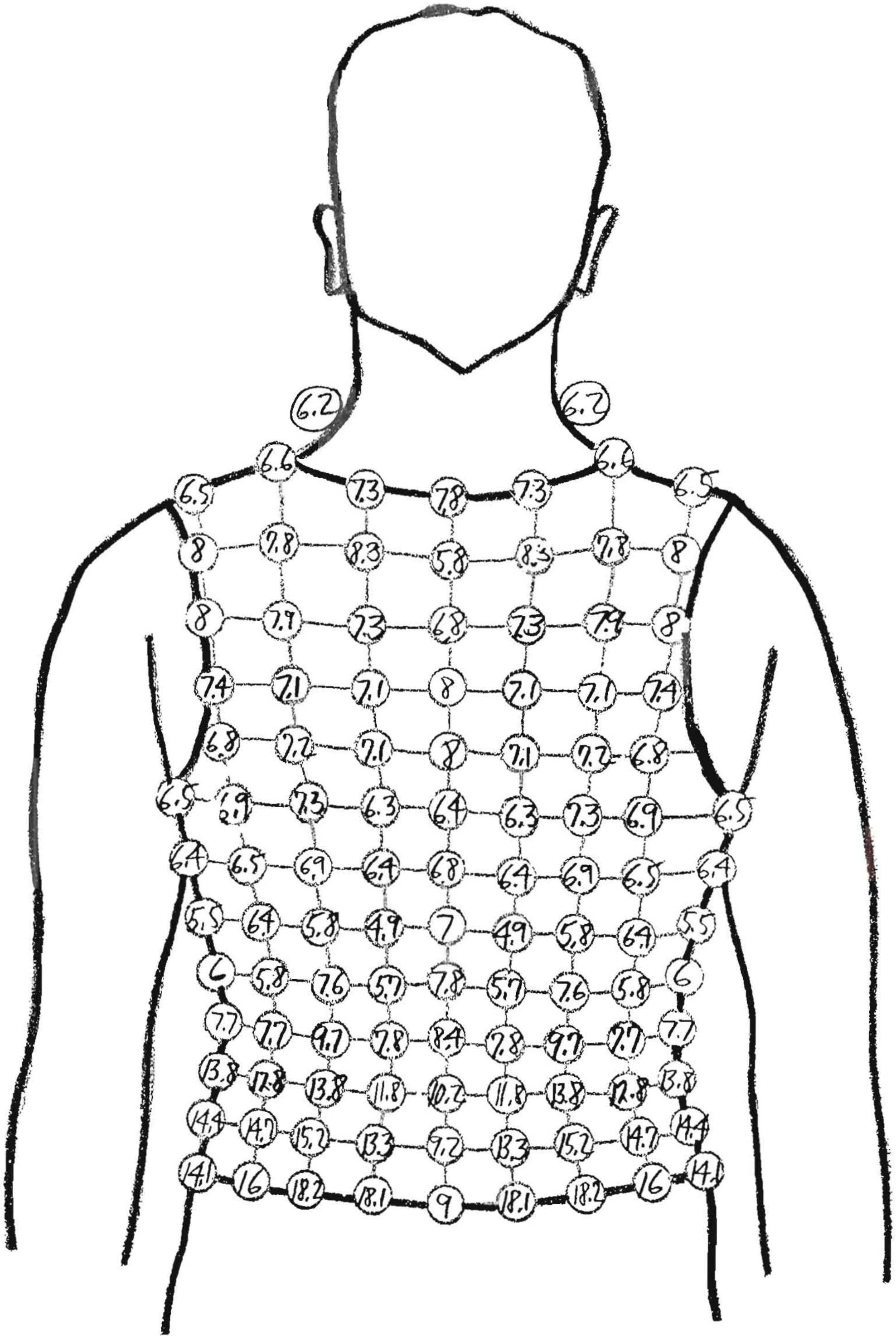
(Rear Averaged)



Test Subject 10

(Front Averaged)



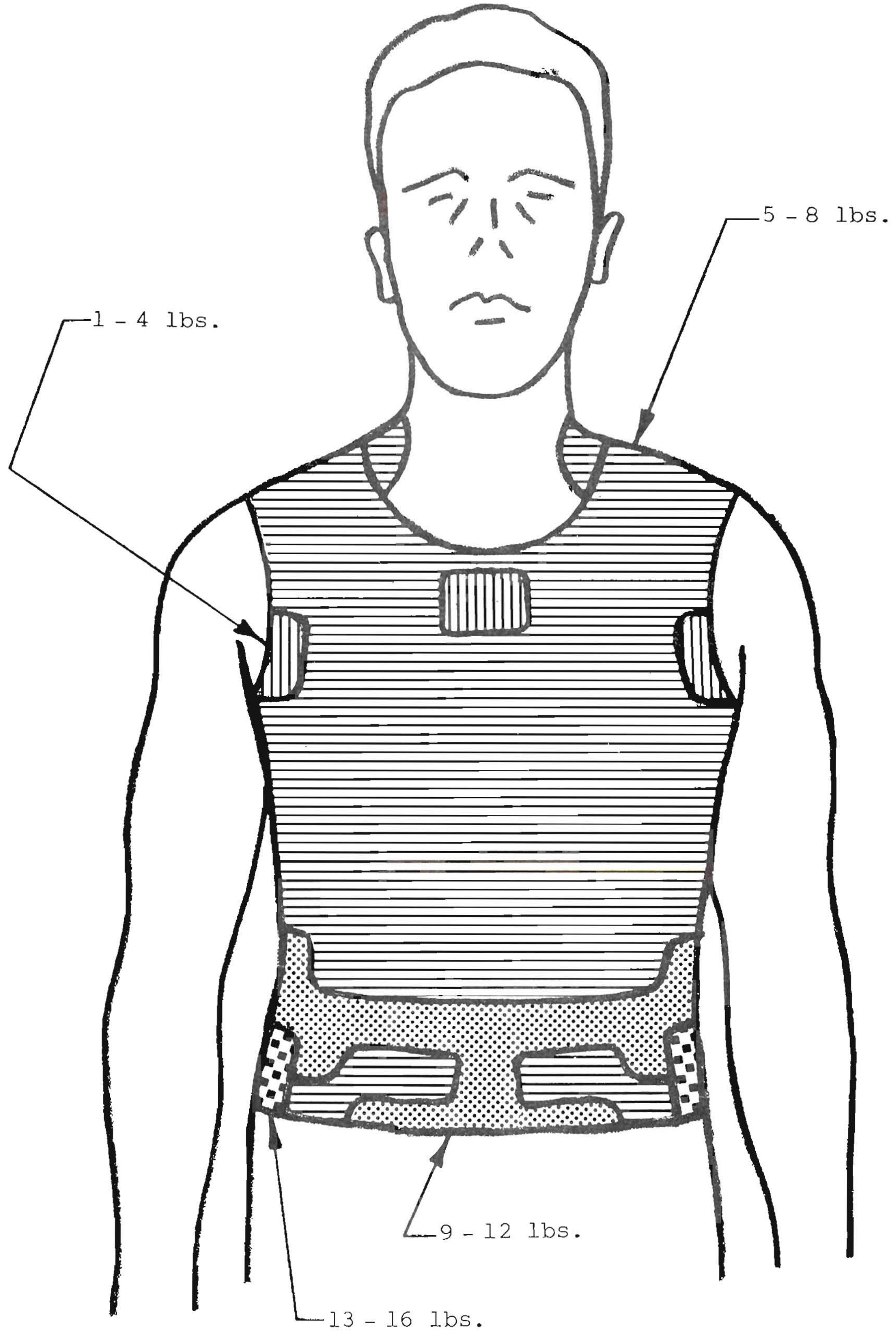
Test Subject 10

(Rear Averaged)

APPENDIX C

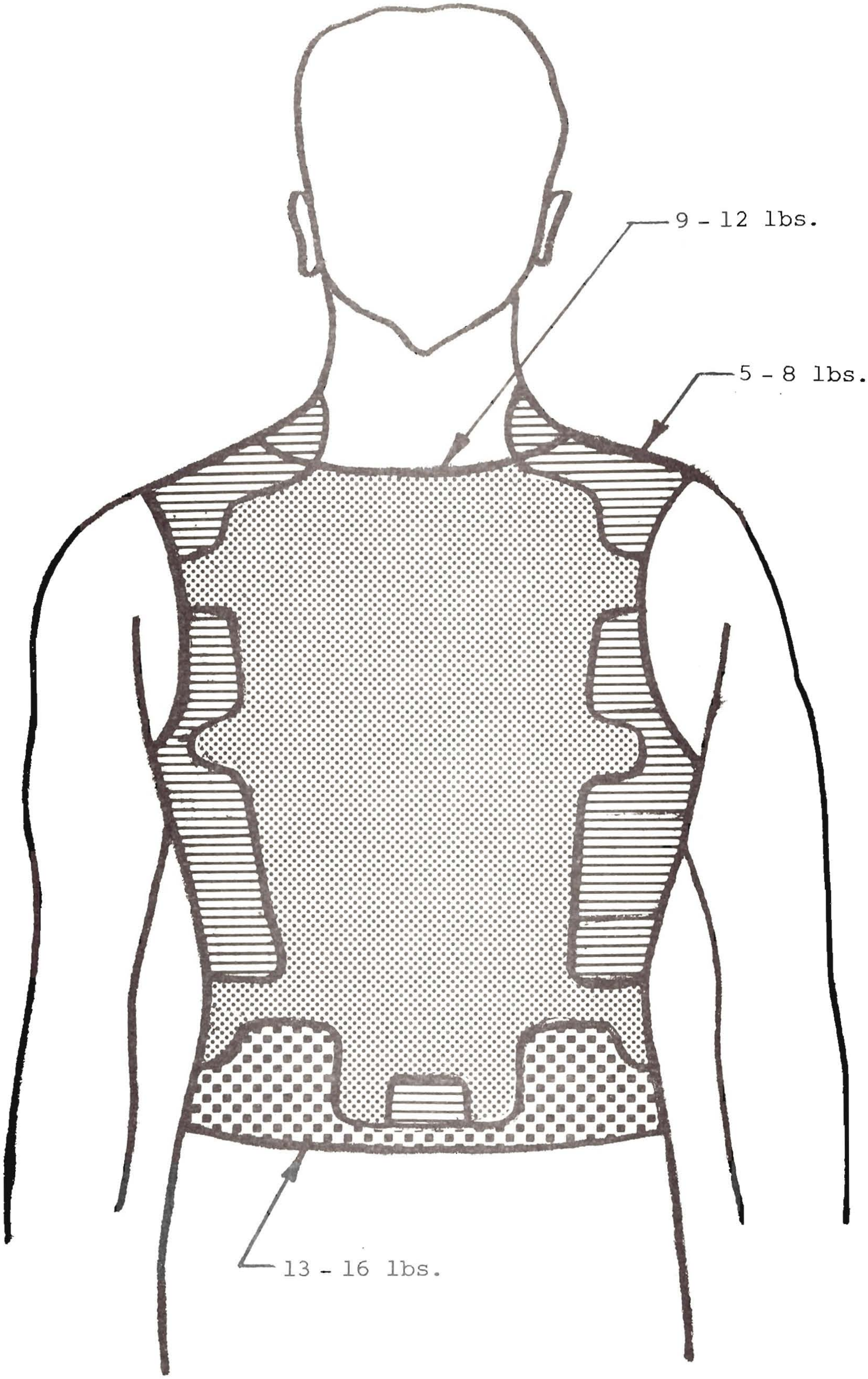
TORSO SENSITIVITY DATA
INDIVIDUAL ISOBAR CHARTS

(Test Subjects 1 through 10)



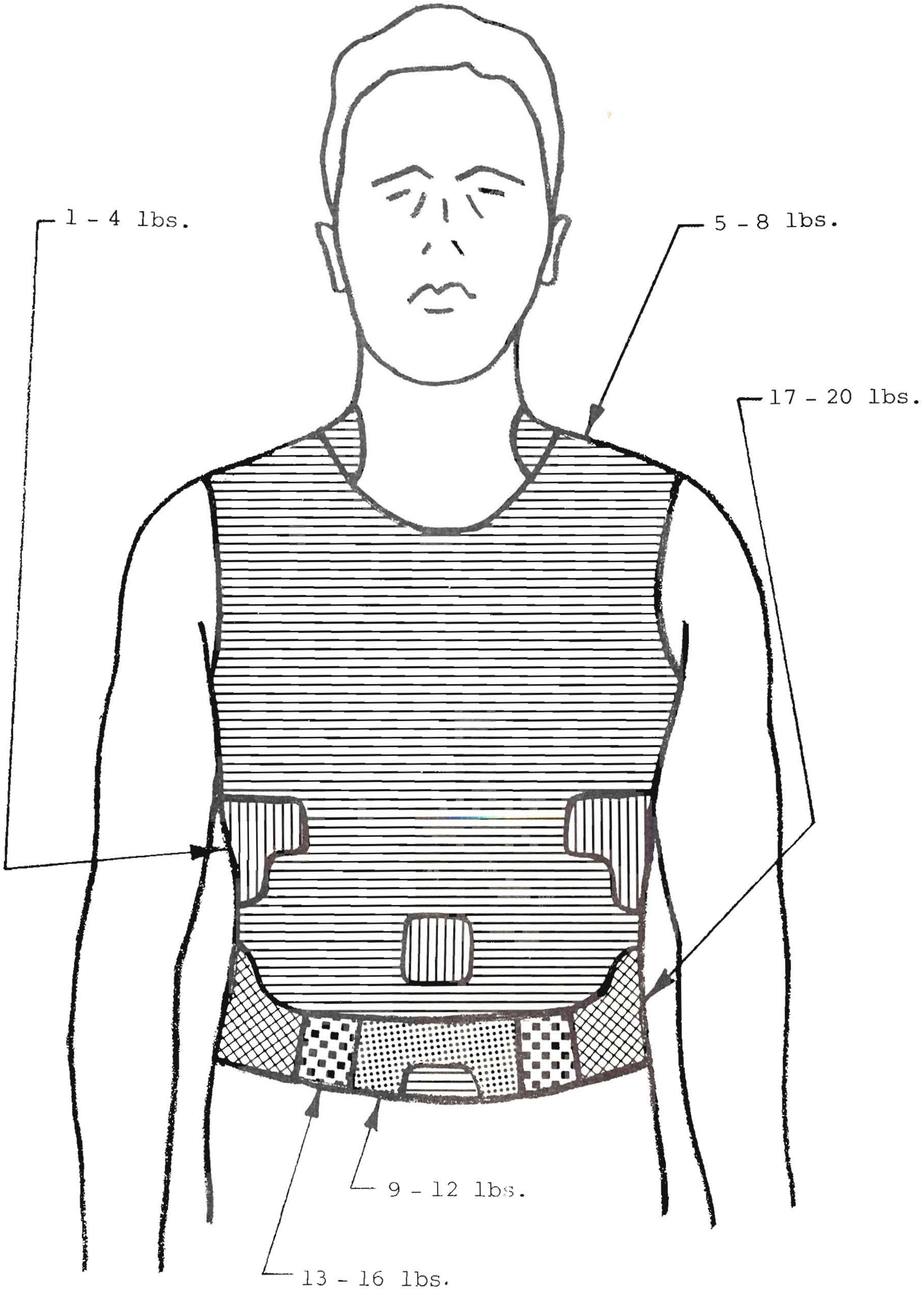
"Isobar" Torso Sensitivity Chart

Anterior View - Test Subject No. 1



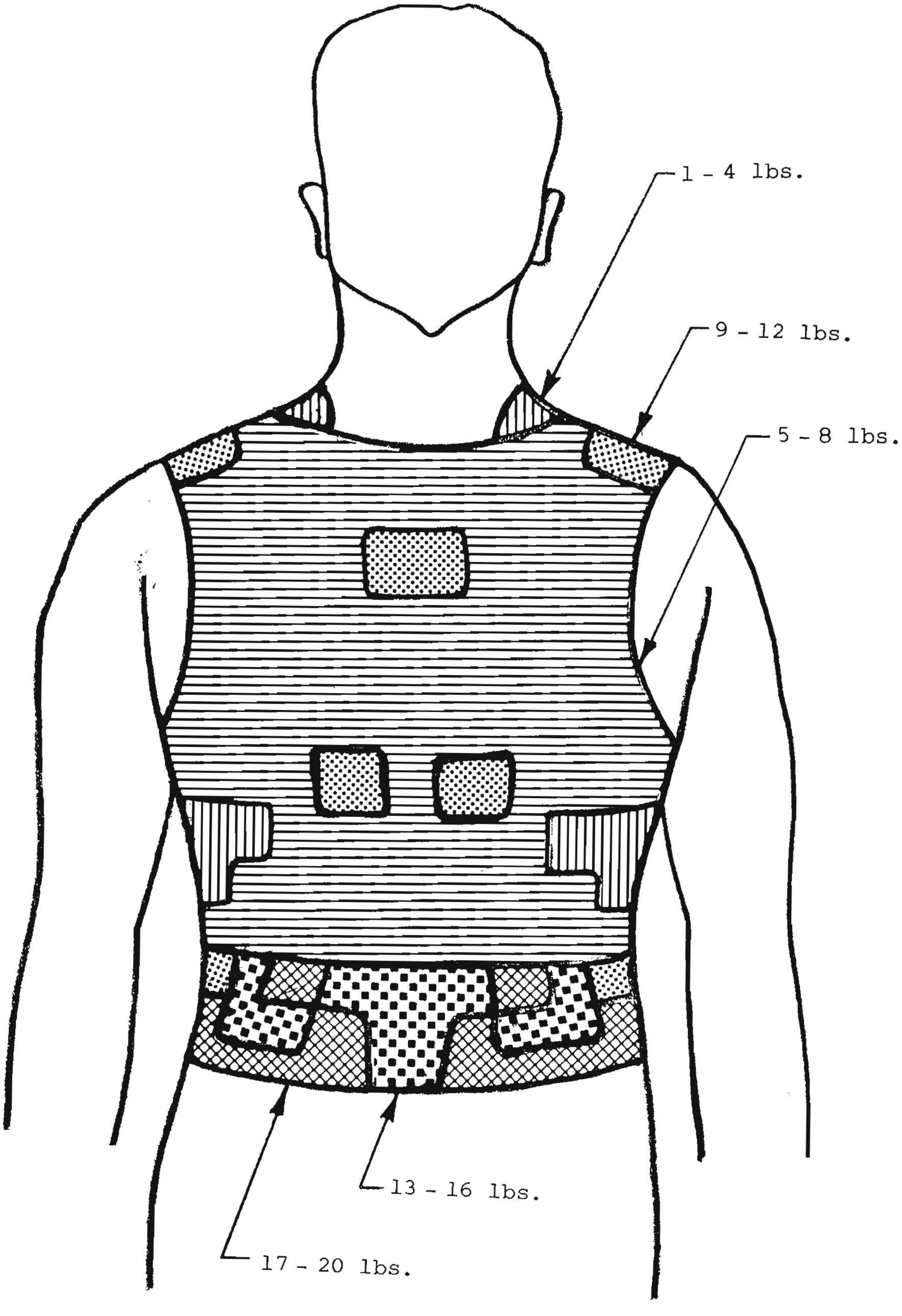
"Isobar" Torso Sensitivity Chart

Posterior View - Test Subject No. 1



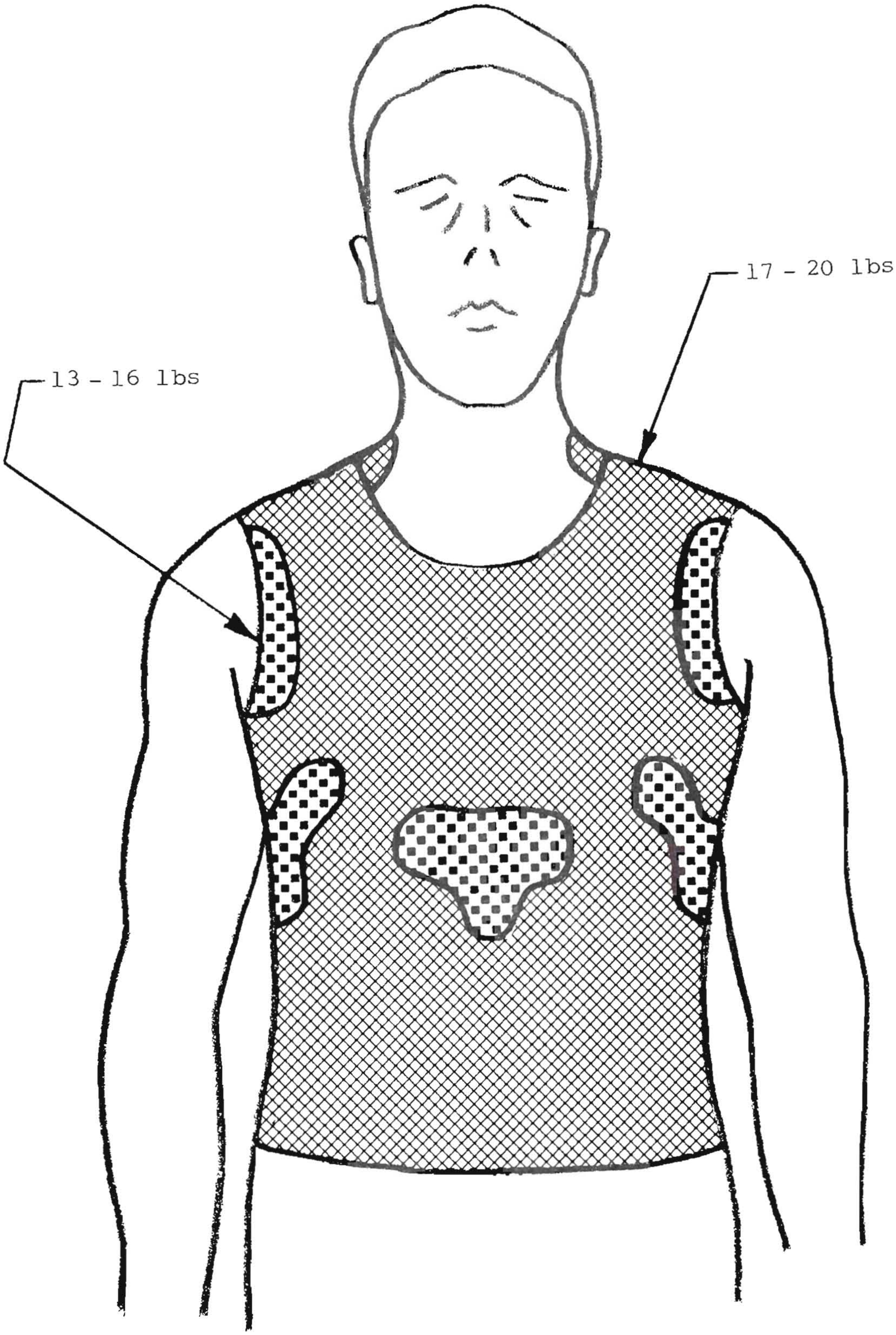
"Isobar" Torso Sensitivity Chart

Anterior View - Test Subject No. 2



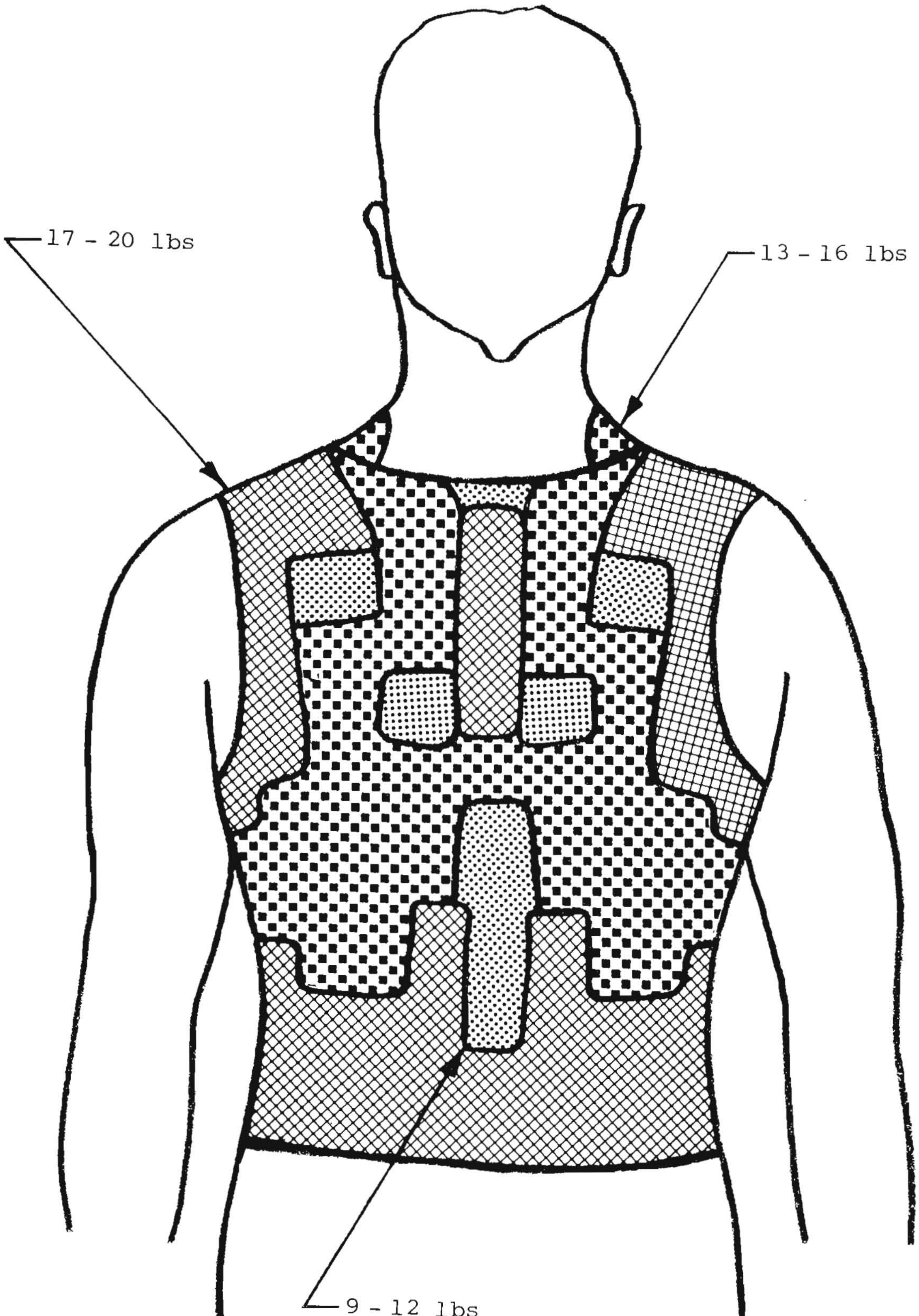
"Isobar" Torso Sensitivity Chart

Posterior View - Test Subject No. 2



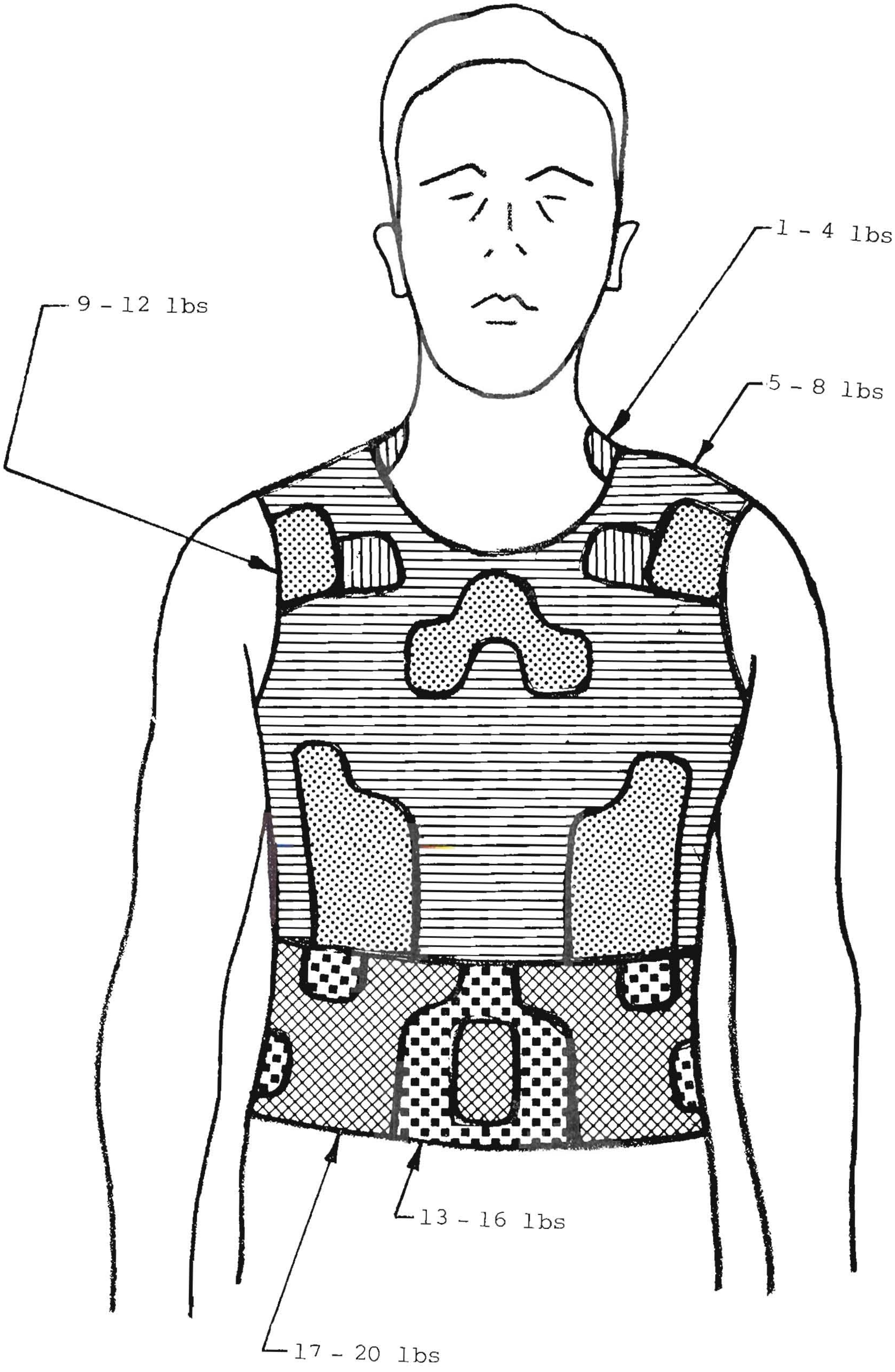
Test Subject 3

(Front)



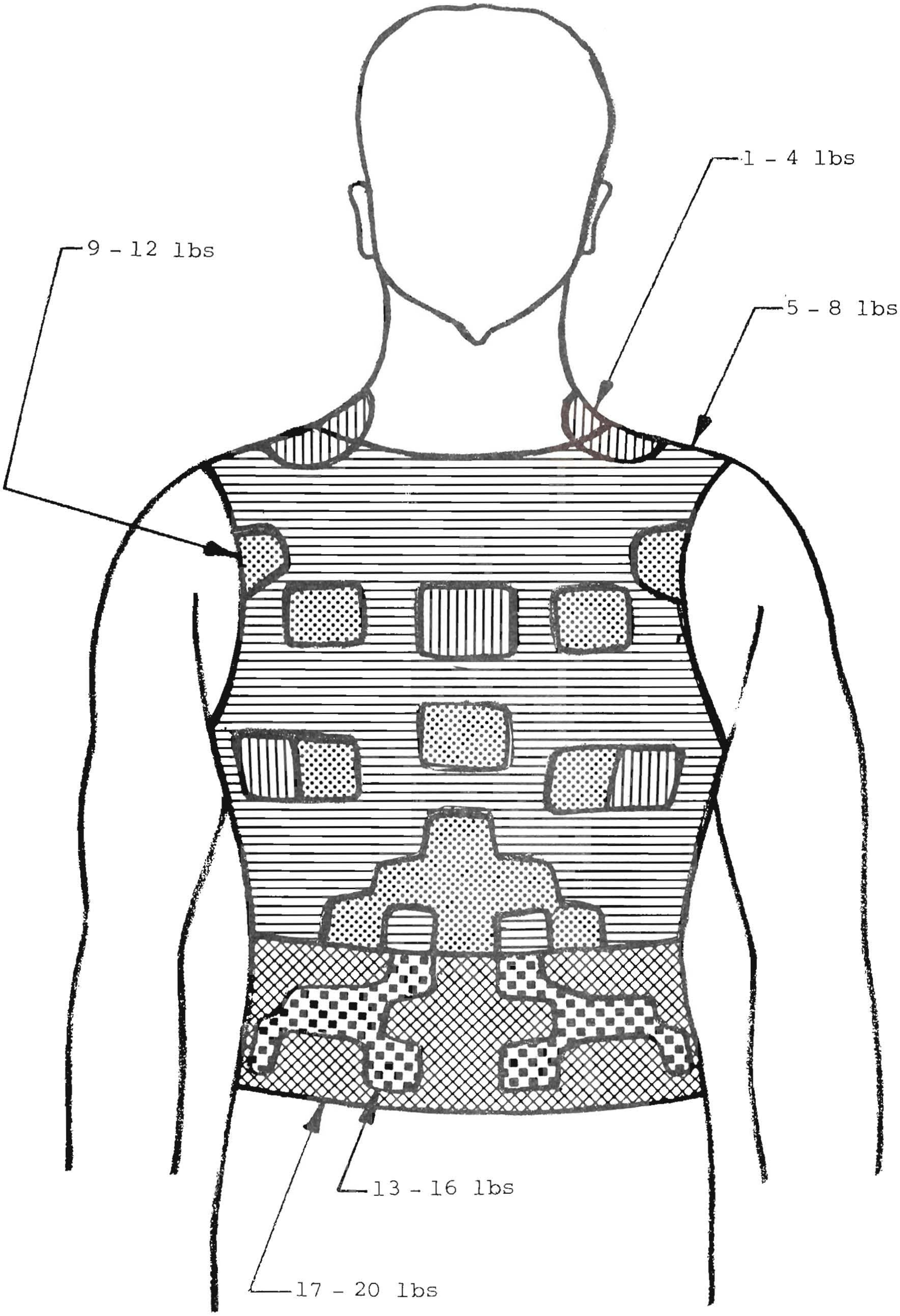
Test Subject 3

(Rear)



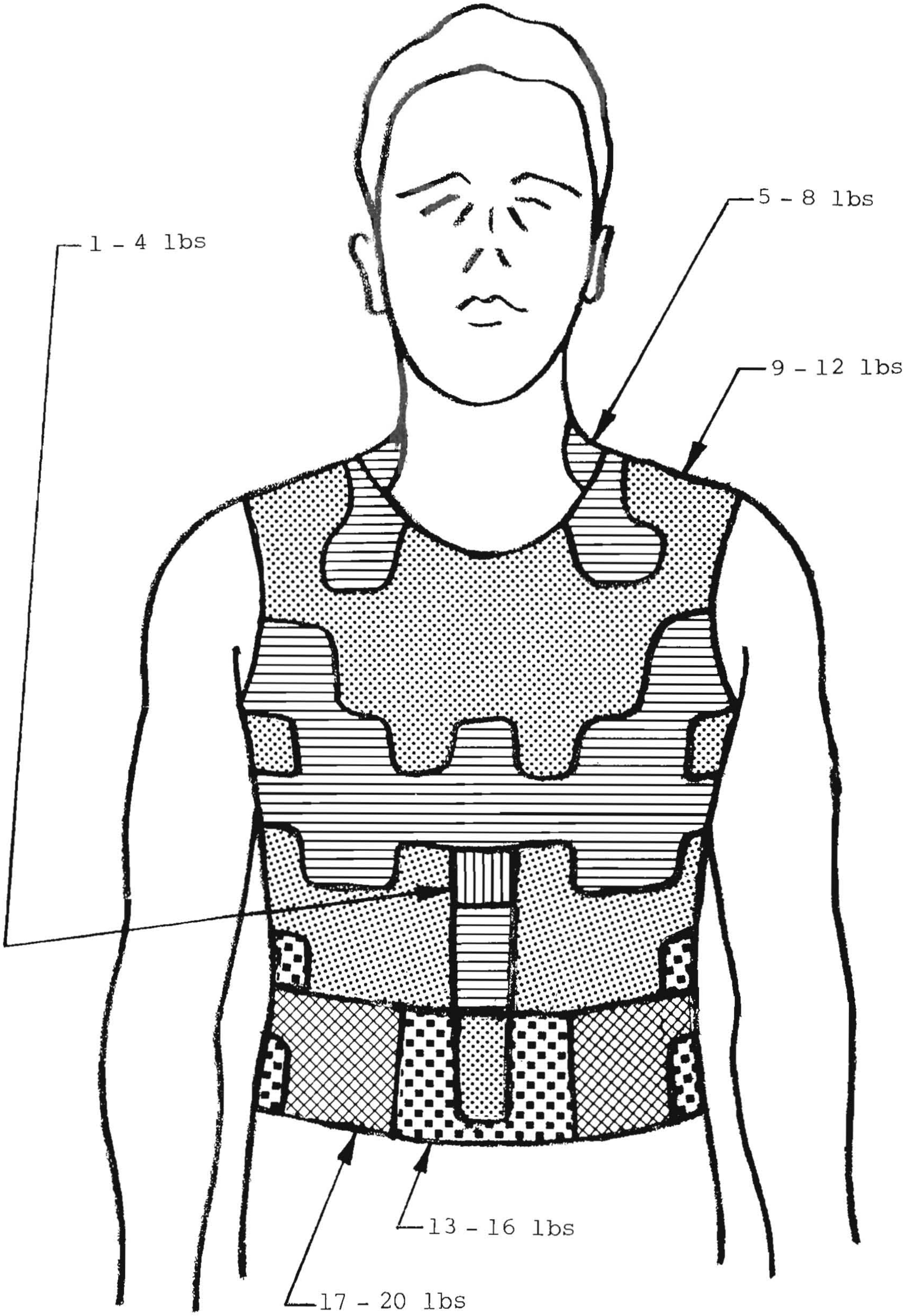
Test Subject 4

(Front)



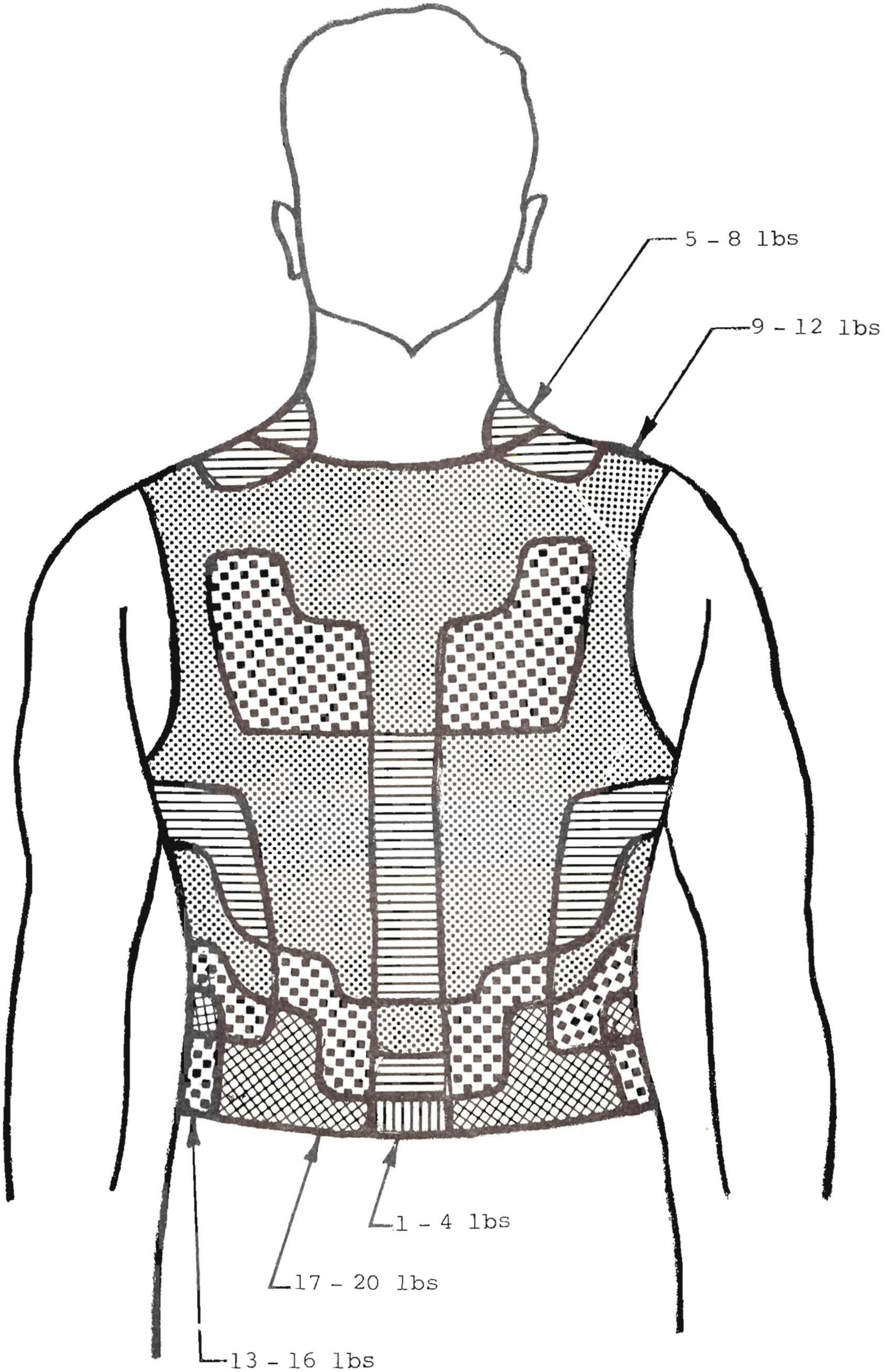
Test Subject 4

(Rear)



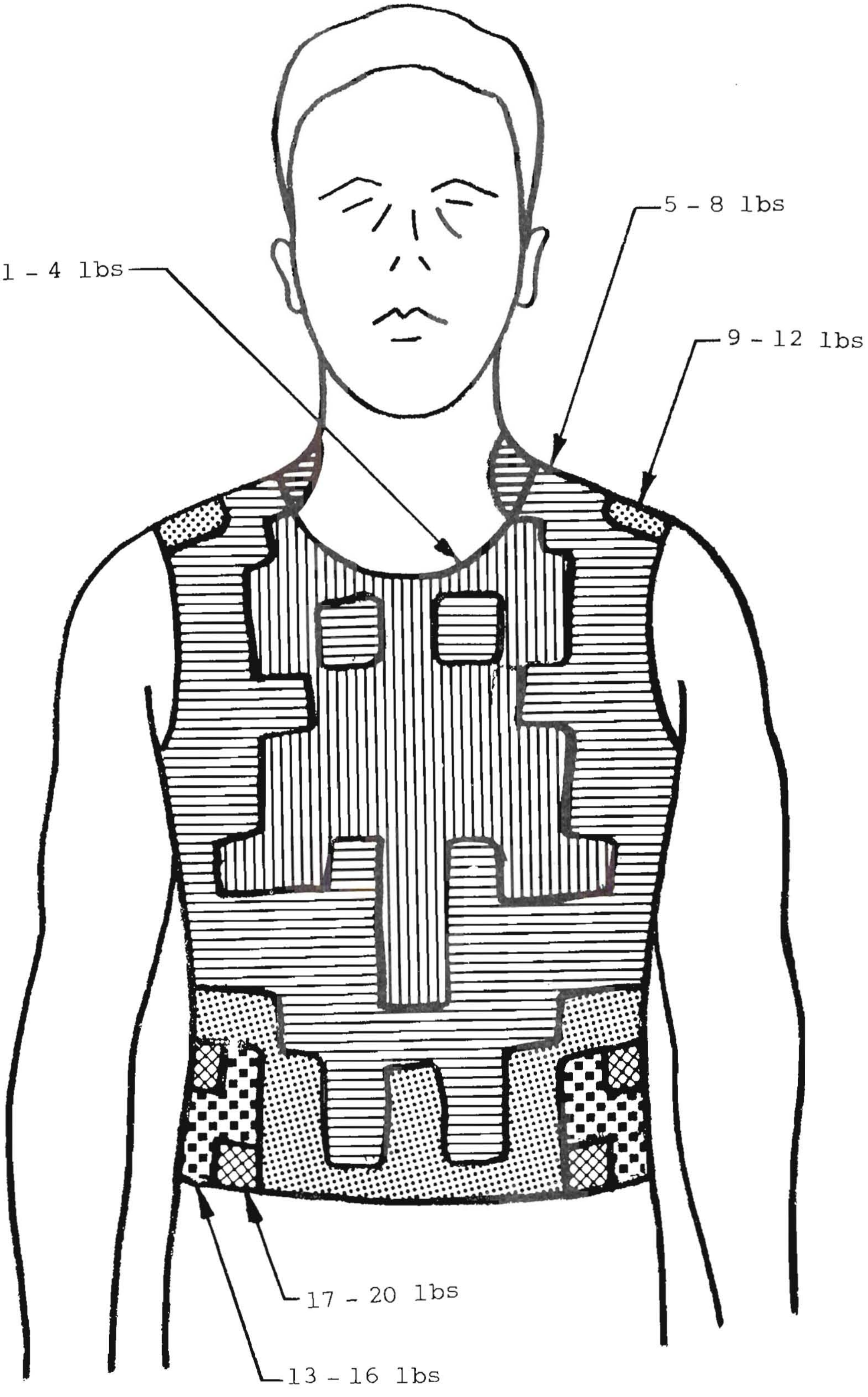
Test Subject 5

(Front)



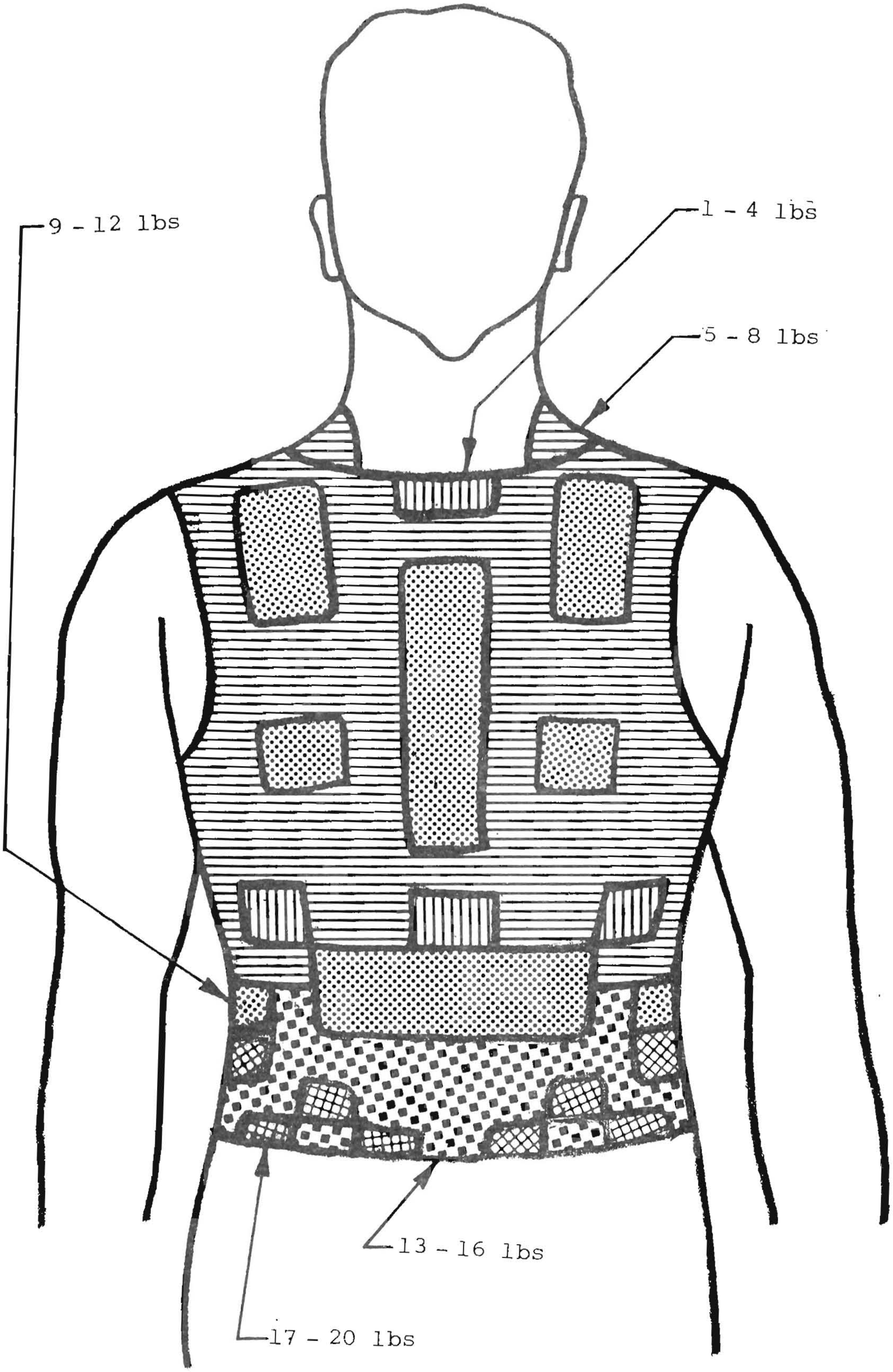
Test Subject 5

(Rear)



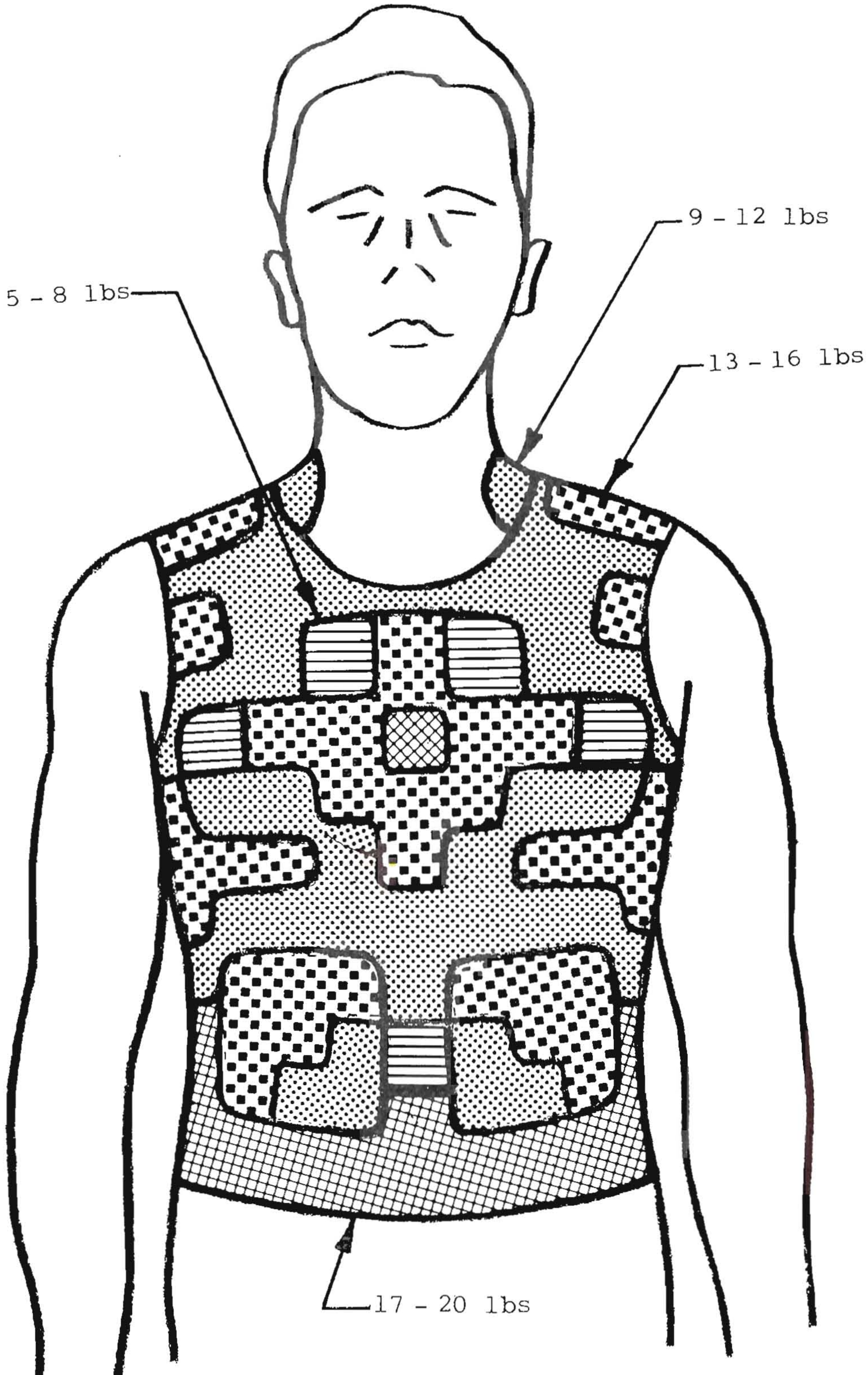
Test Subject 6

(Front)



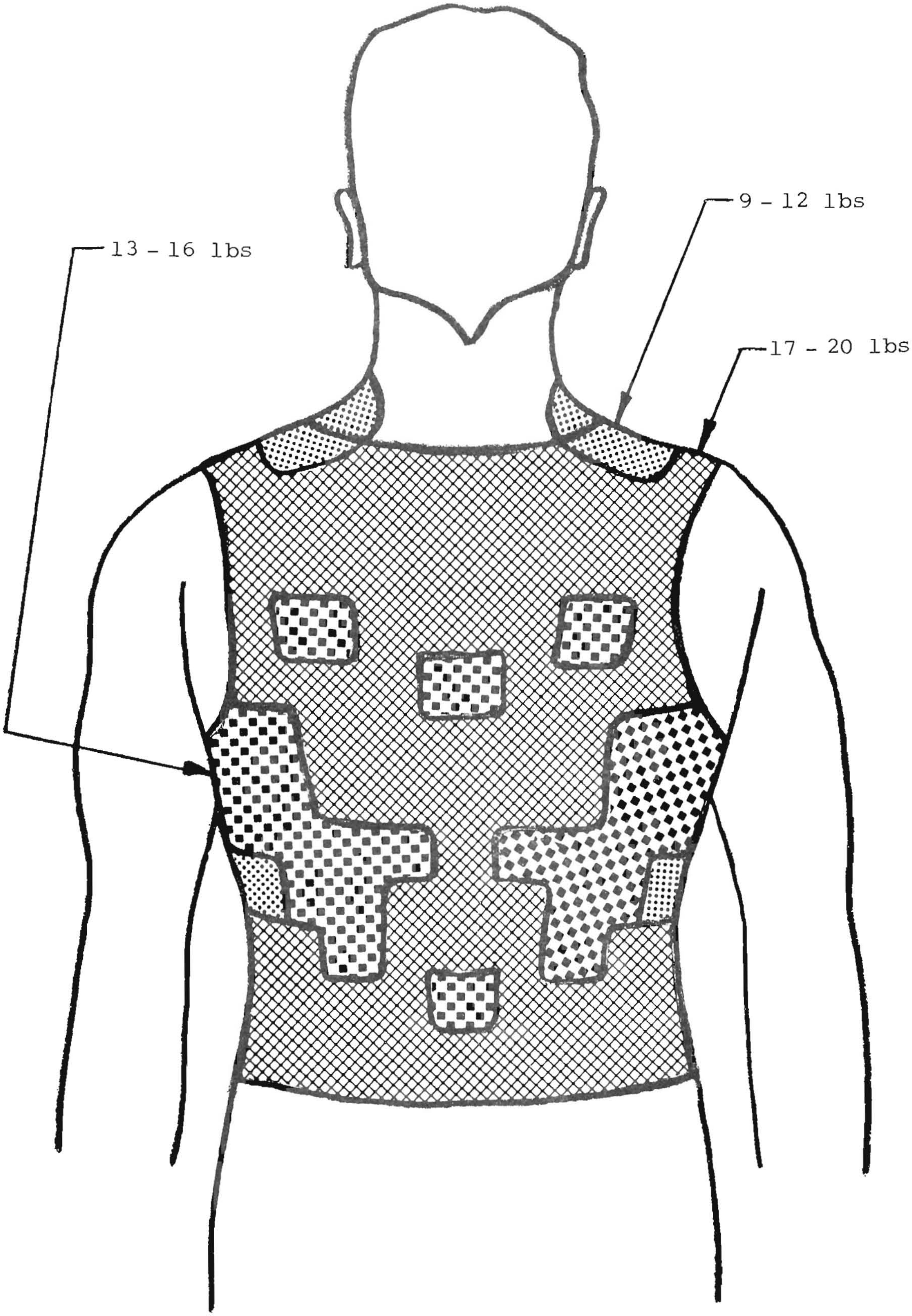
Test Subject 6

(Rear)



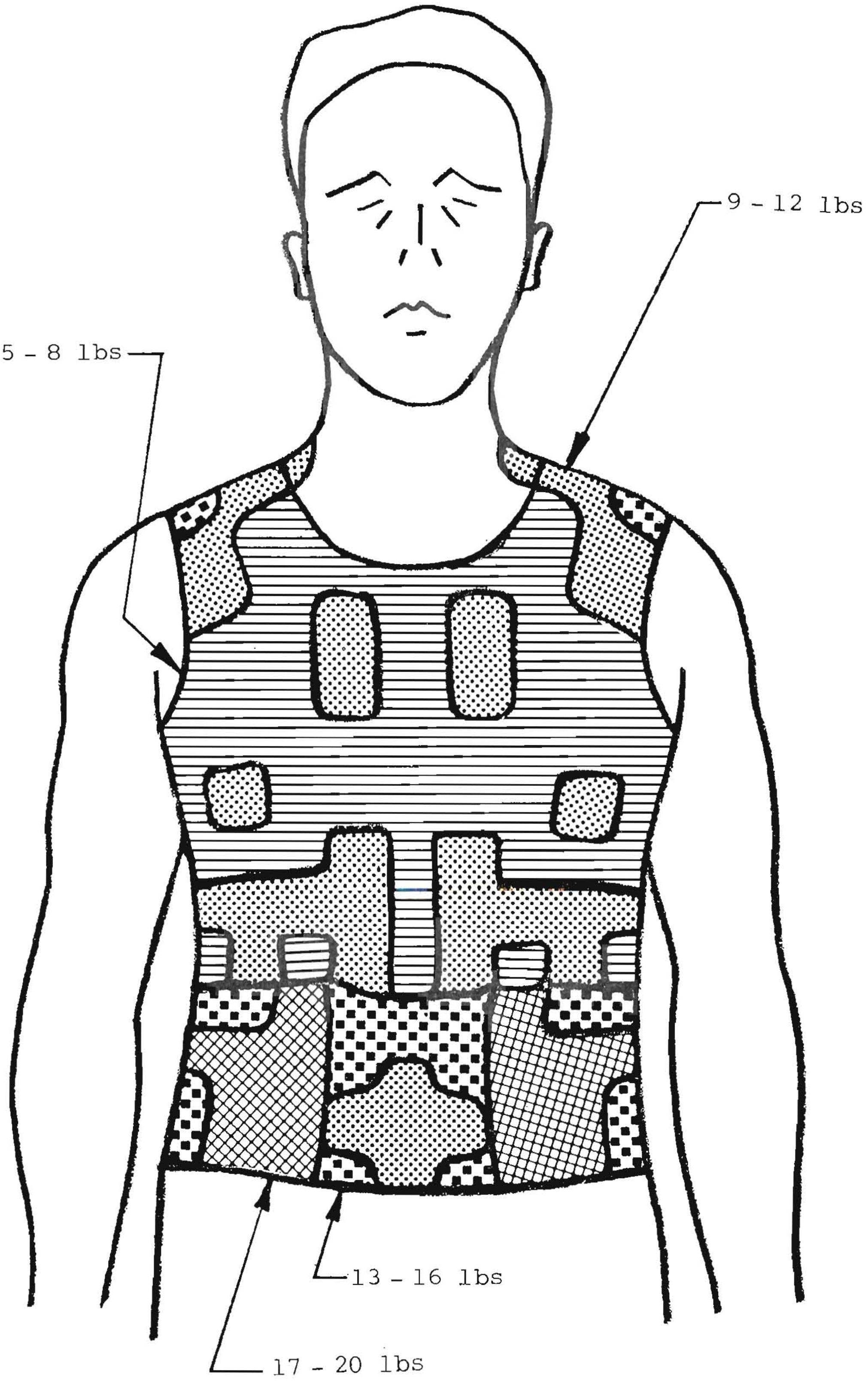
Test Subject 7

(Front)



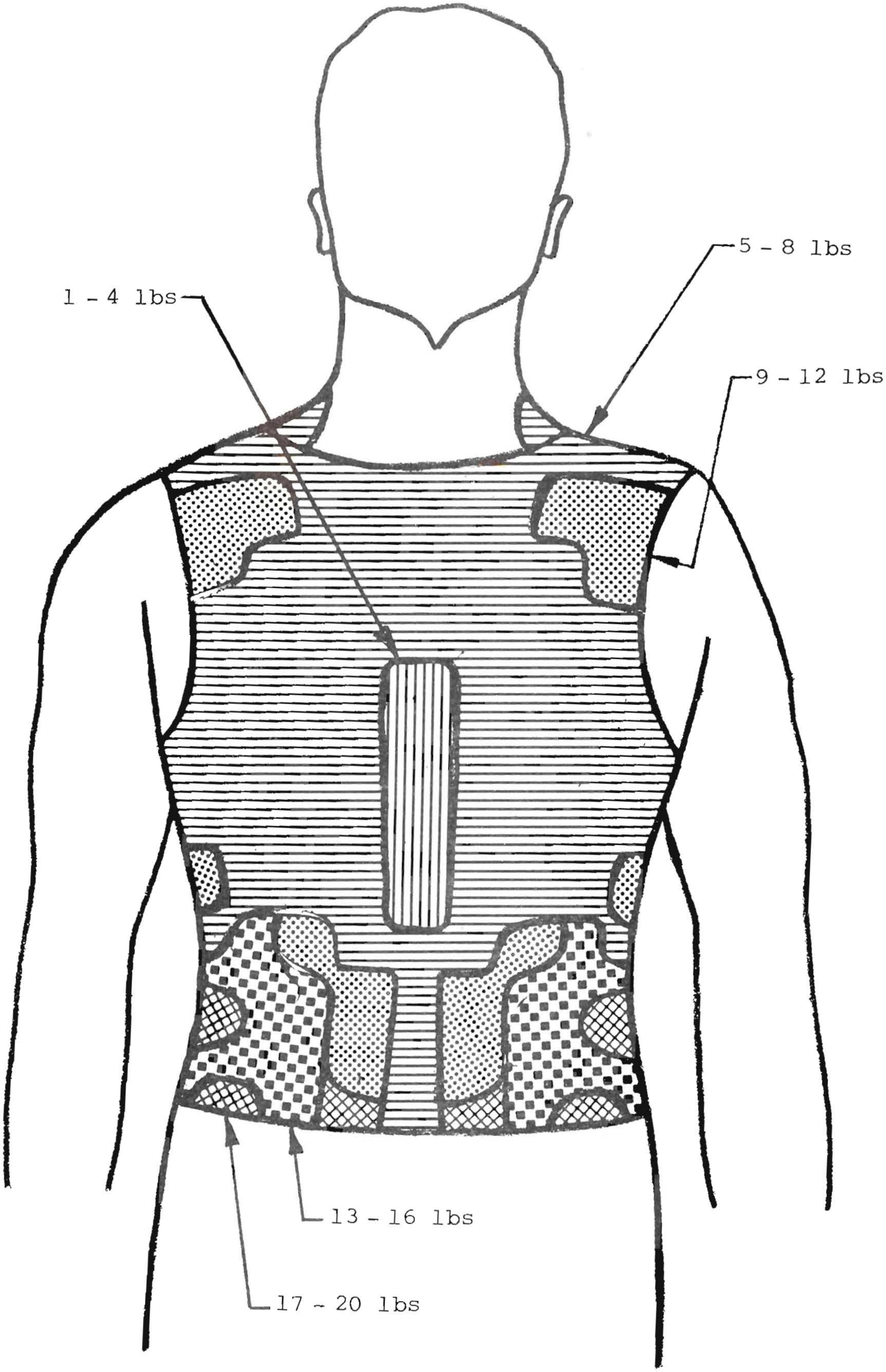
Test Subject 7

(Rear)



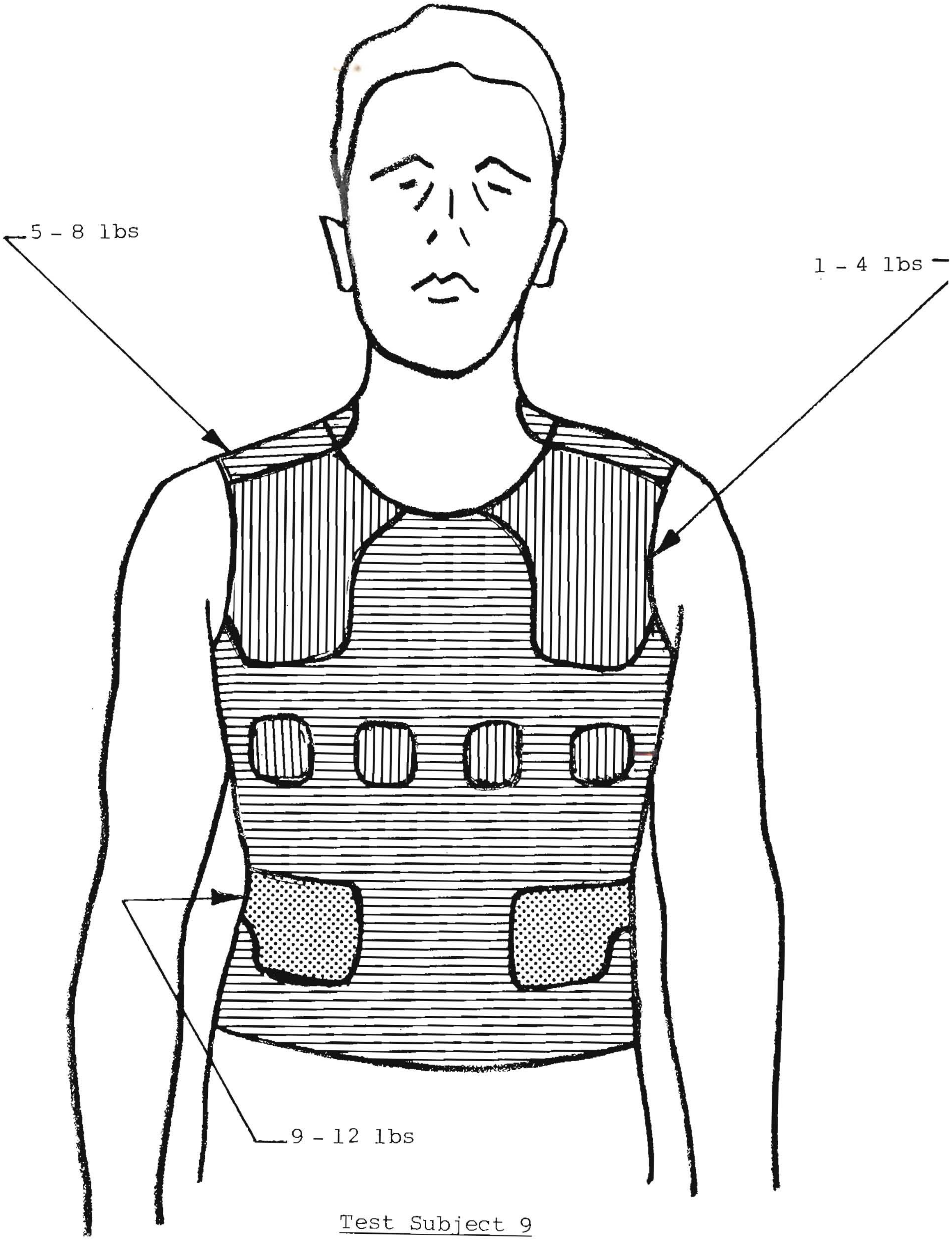
Test Subject 8

(Front)



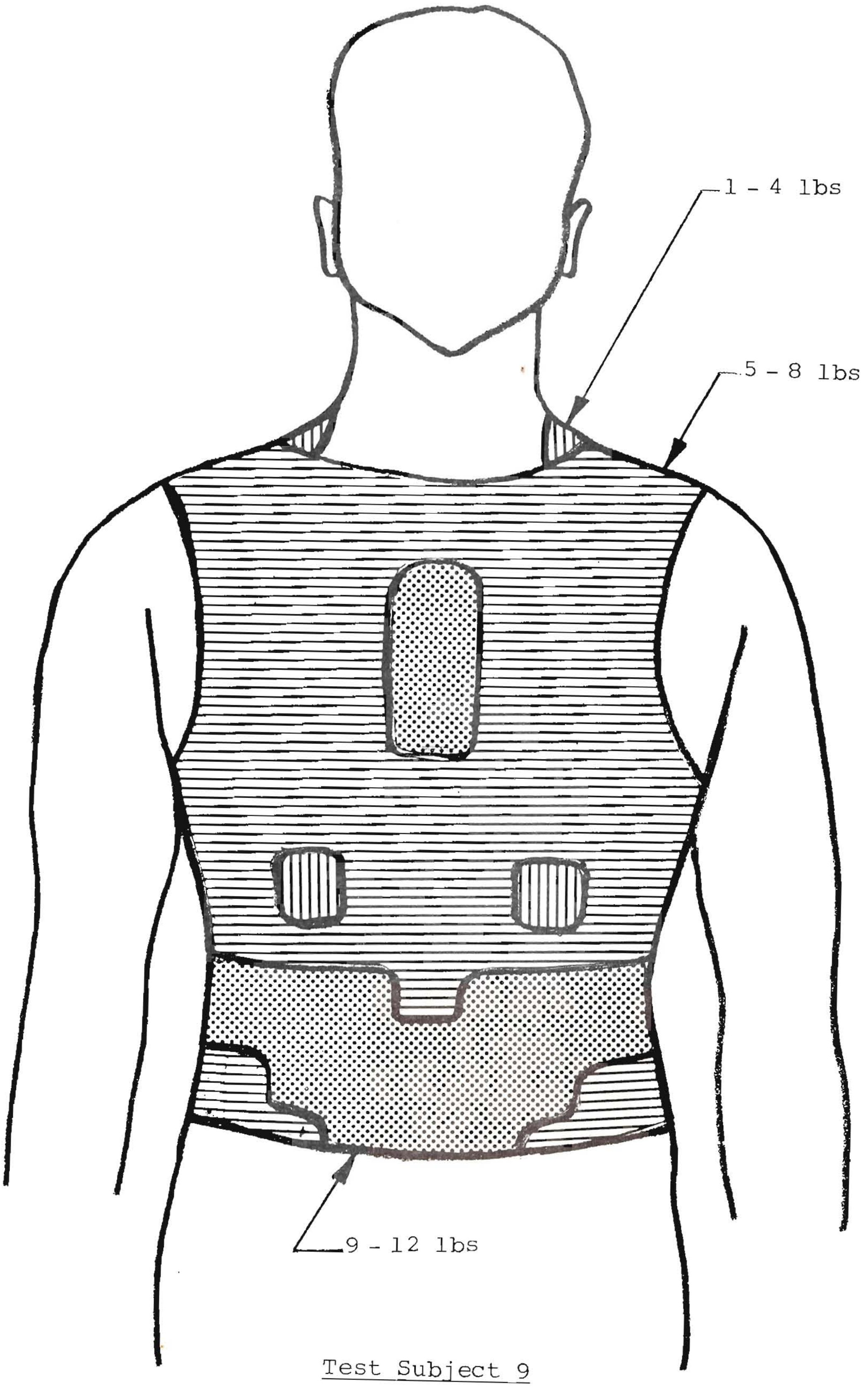
Test Subject 8

(Rear)



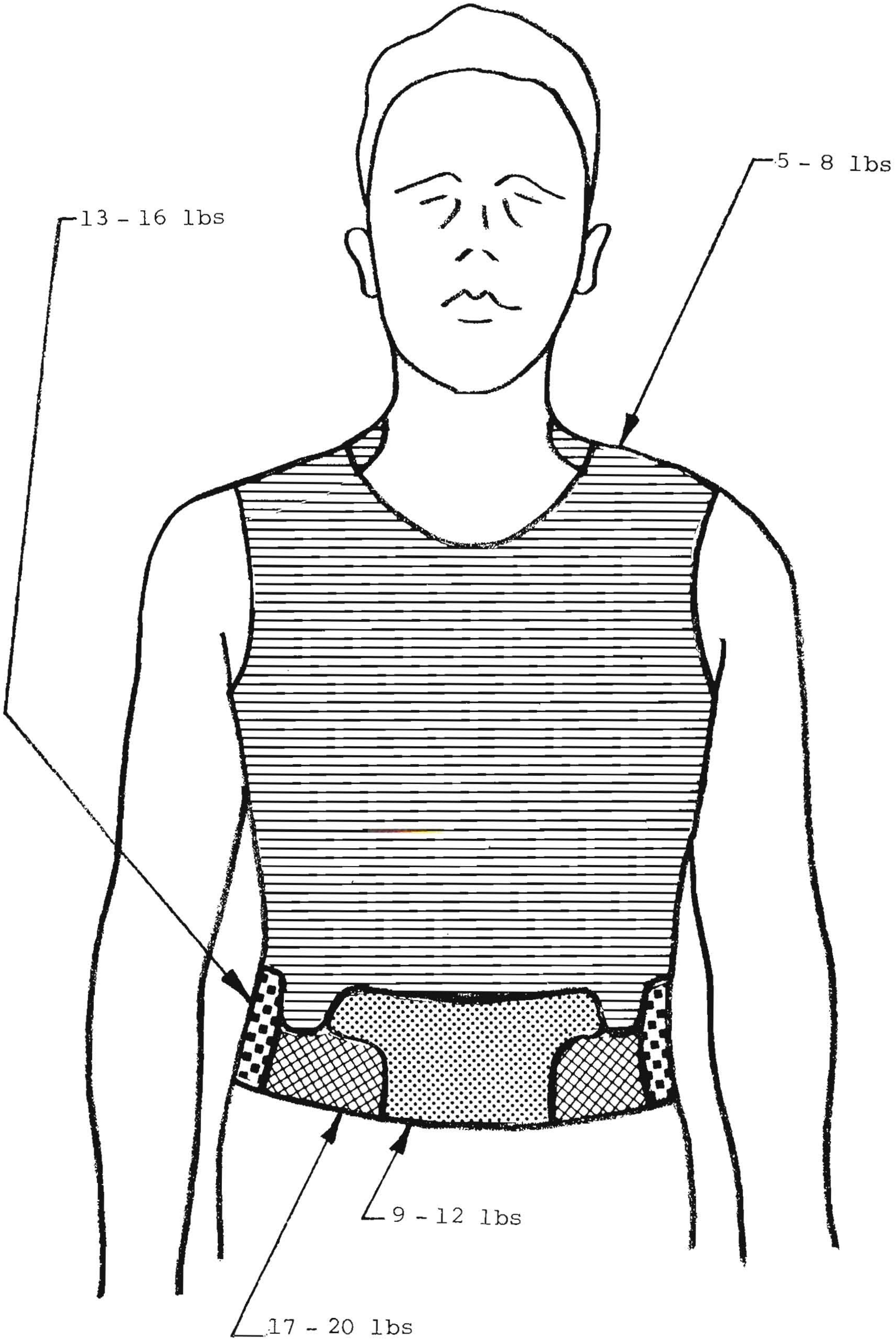
Test Subject 9

(Front)



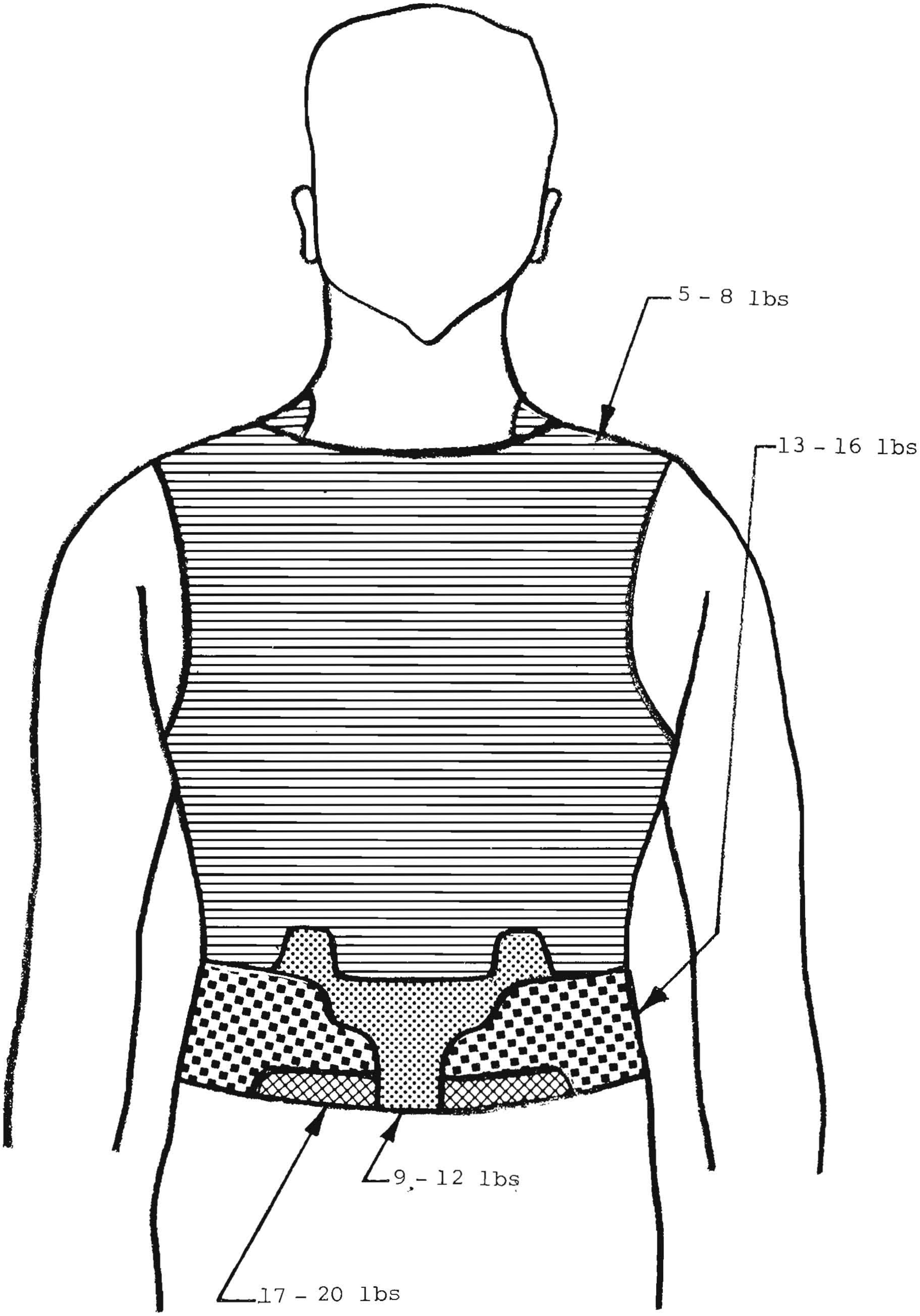
Test Subject 9

(Rear)



Test Subject 10

(Front)



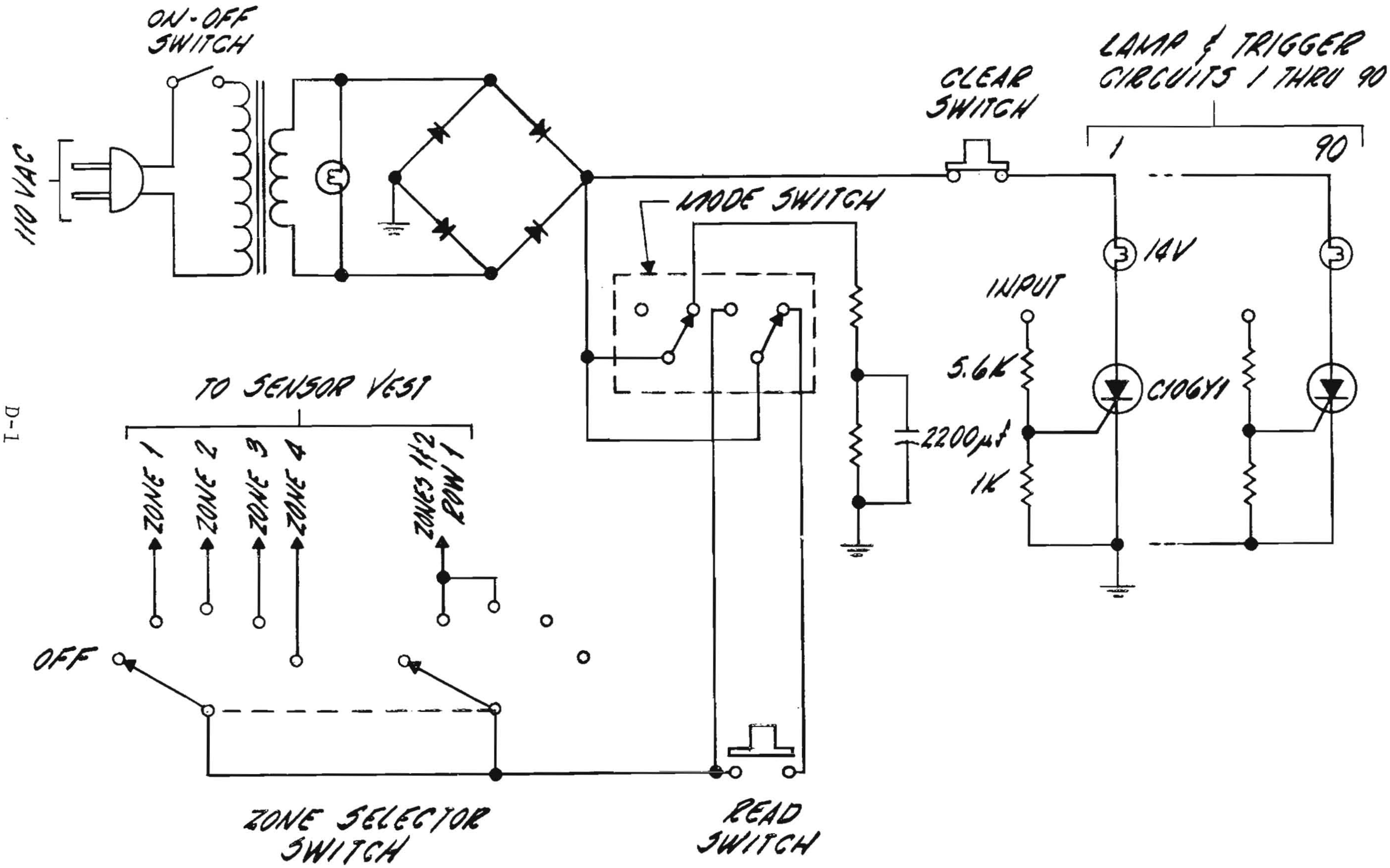
Test Subject 10

(Rear)

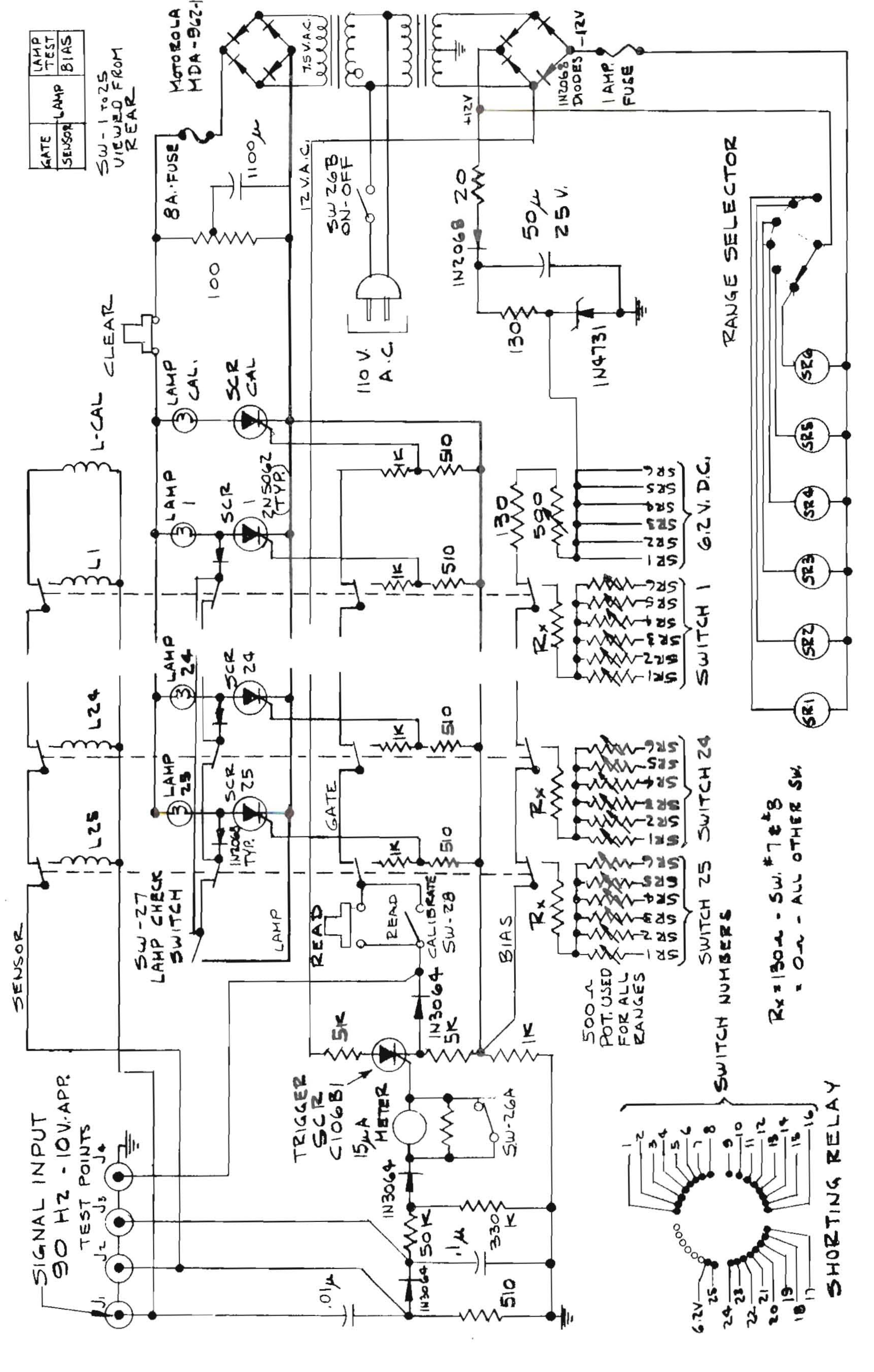
APPENDIX D

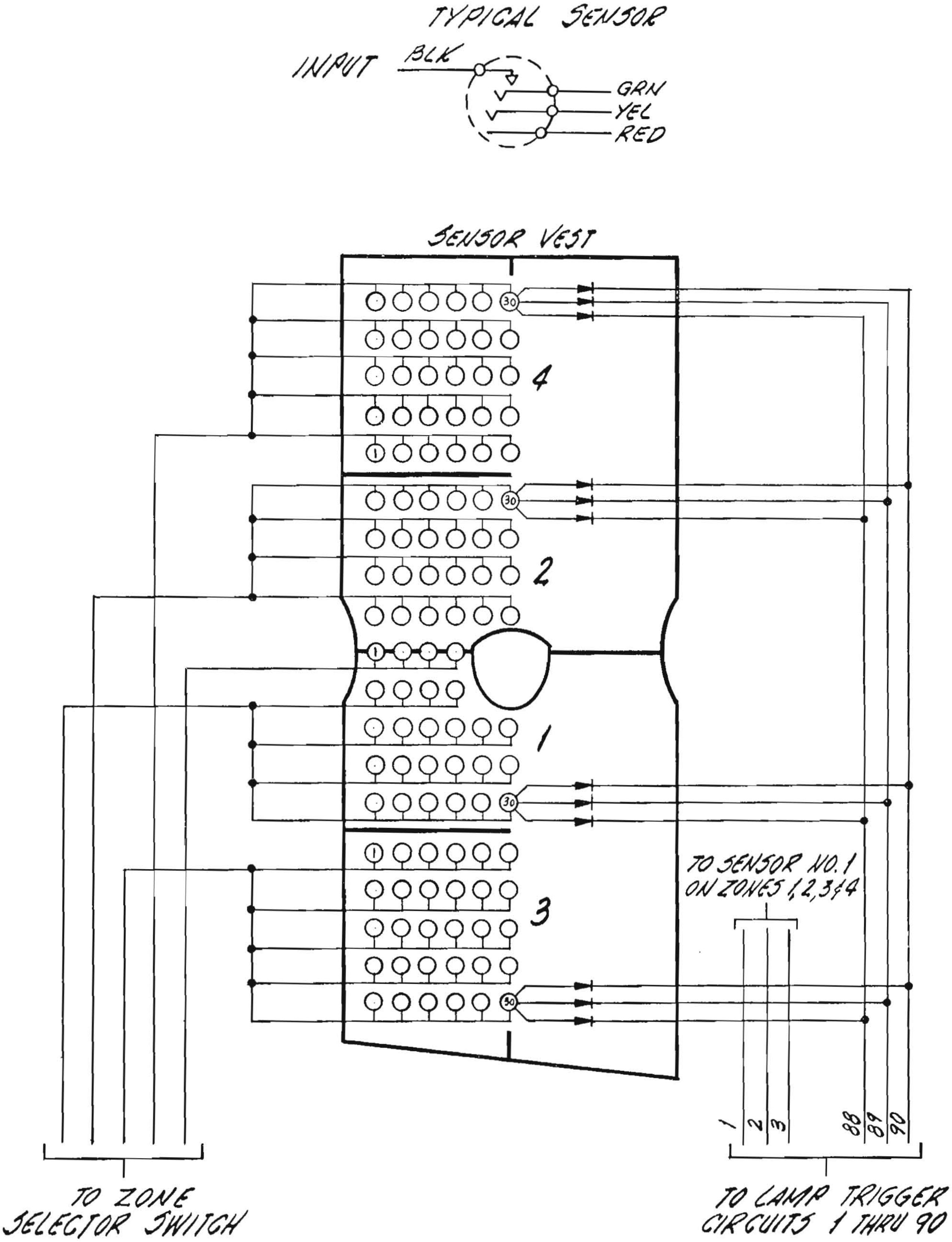
SCHEMATIC DIAGRAM FOR PROTOTYPE #1

(Progressive Electrical Contact Sensor Garment and Light Display)



Schematic Diagram - Light Control Console Prototype #1


SIGNAL INPUT
90 HZ - 10V. APR.
TEST POINTS
J1 J2 J3 J4
SENSOR
GATE
LAMP
BIAS
READ
L-CAL
L1
L24
L25
CLEAR
LAMP CAL.
SCR CAL
LAMP 1
SCR 1
2N5062 (TYP.)
LAMP 24
SCR 24
LAMP 25
SCR 25
1N3064 TYP.
SW-27 LAMP CHECK SWITCH
READ CALIBRATE SW-28
TRIGGER SCR C106B1
15μA METER
SW-26A
1N3064
50K
.1μ
330K
510
.01μ
5K
1K
100
1100μ
8A. FUSE
MOTOROLA MDA-962-1
7.5 V.A.C.
12 V.A.C.
SW-26B ON-OFF
110 V. A.C.
+12V
-12V
1N2068 DIODES
1 AMP FUSE
1N2068
20
50μ 25 V.
130
1N4731
590
6.2 V. D.C.
SWITCH 1
SWITCH 24
SWITCH 25
SWITCH NUMBERS
Rx
500Ω POT. USED FOR ALL RANGES
RANGE SELECTOR
SR1 SR2 SR3 SR4 SR5 SR6
Rx = 130Ω - SW. #7 & 8
= 0Ω - ALL OTHER SW.
SHORTING RELAY
6.2V
SW-1 TO 25 VIEWED FROM REAR
GATE | LAMP | LAMP TEST
SENSOR | | BIAS

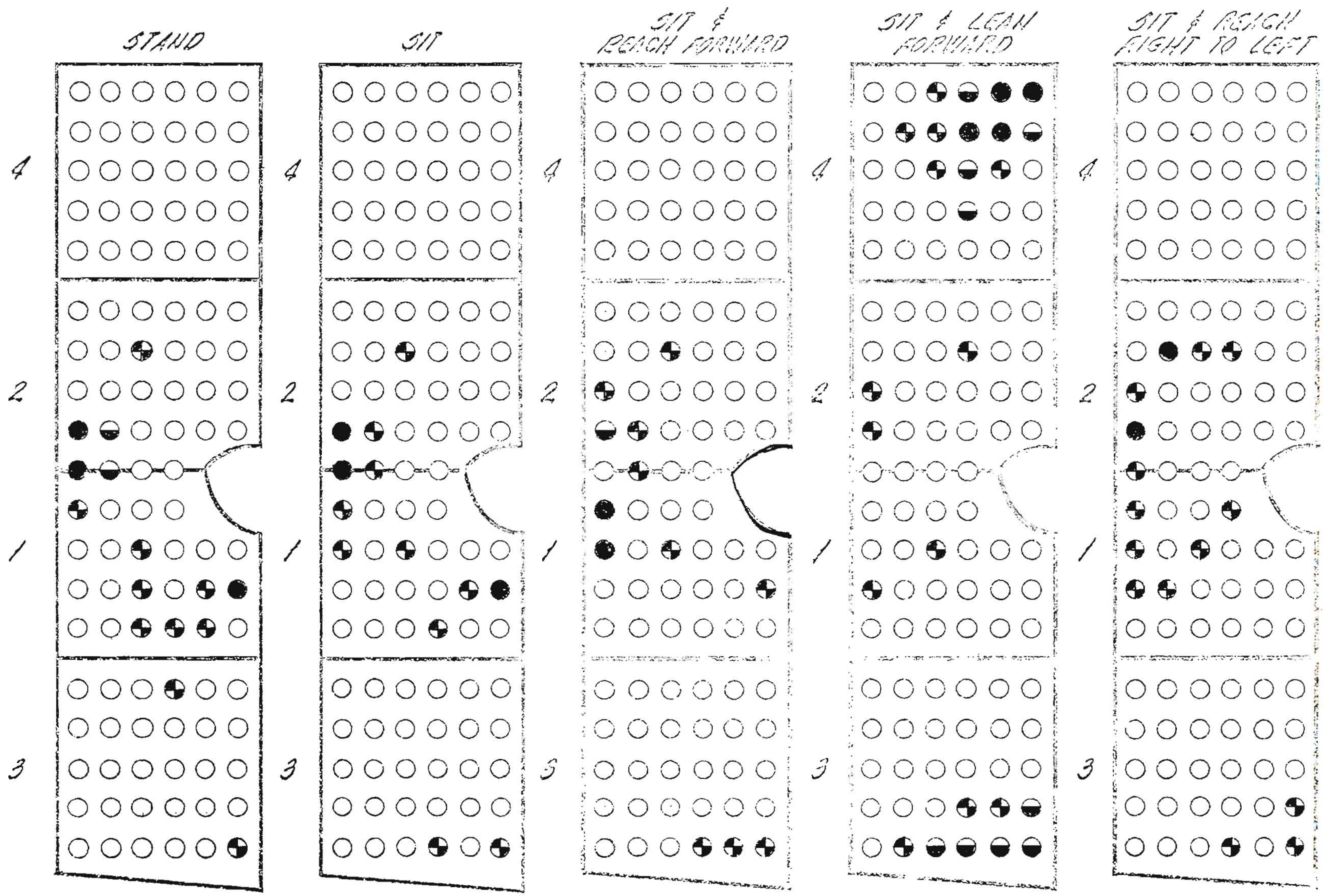


Schematic Diagram - Progressive Electrical Contact Sensor Garment

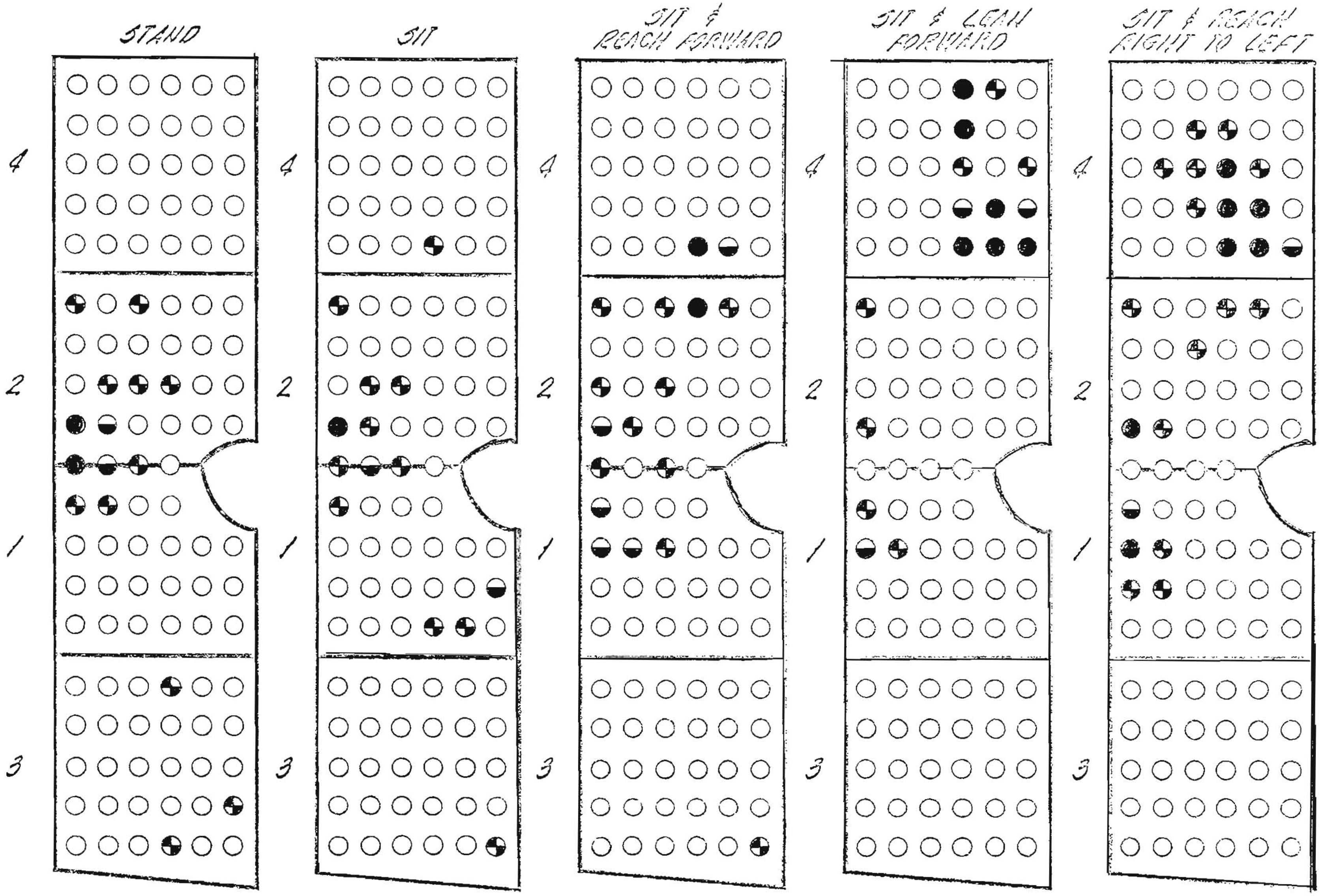
APPENDIX E

ARMOR SUSPENSIONS EVALUATION DATA

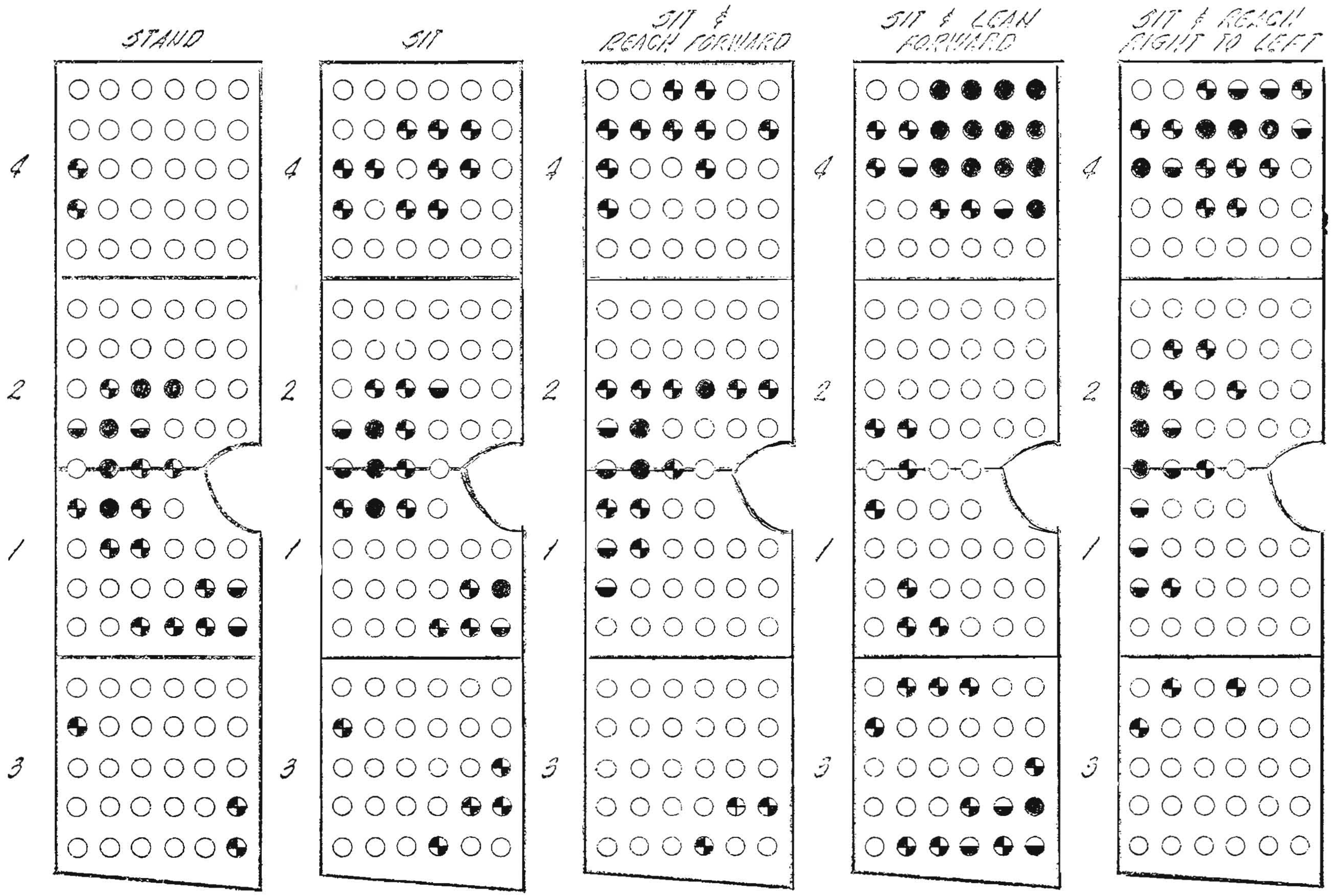
SUBJECT : K. MAYERHOFER SUSPENSION SYSTEM: ARMY STANDARD ● RED ◒ YELLOW ◕ GREEN



SUBJECT : R. RODZEN SUSPENSION SYSTEM: ARMY STANDARD ● RED ◒ YELLOW ◕ GREEN

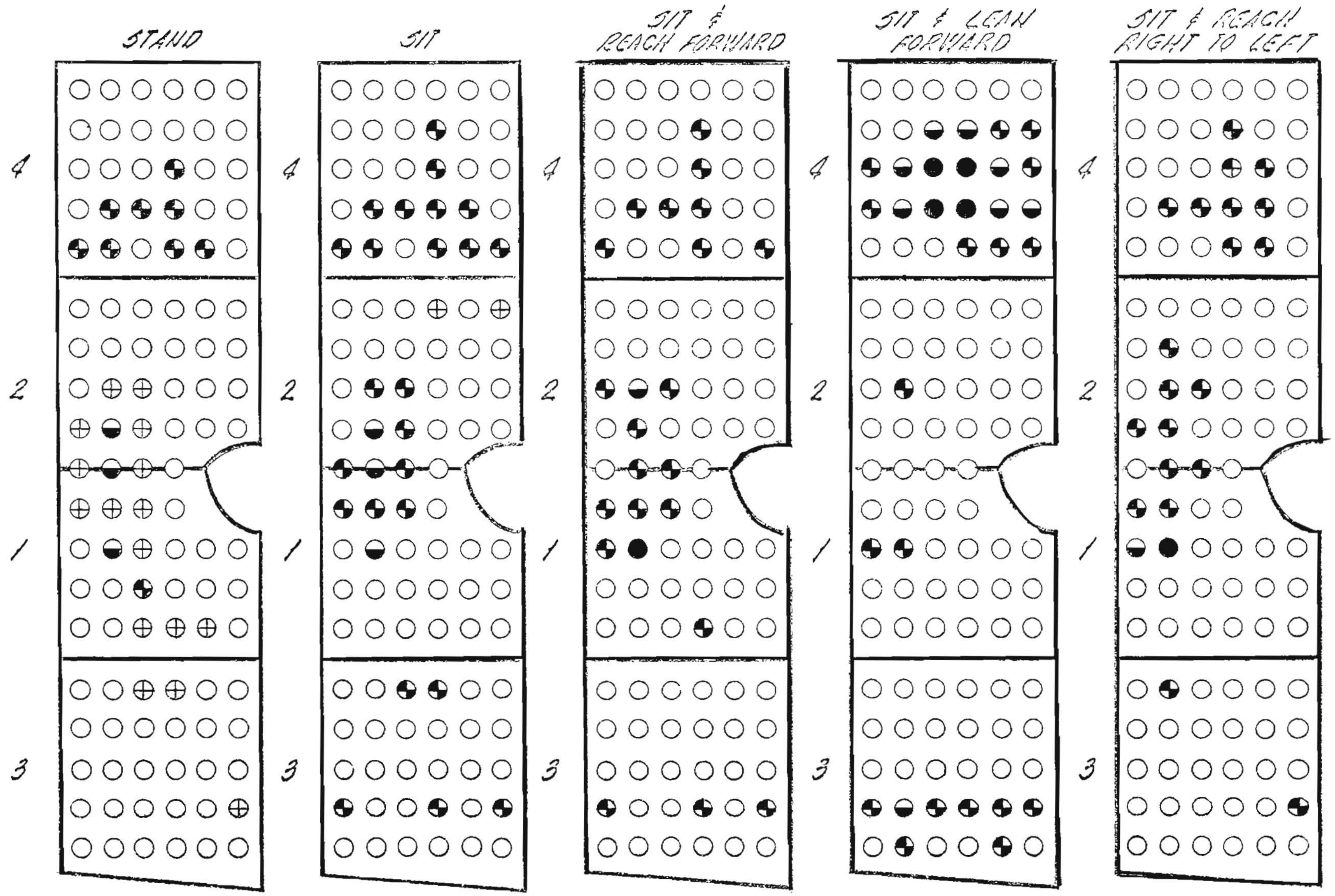


SUBJECT : C. HALL   SUSPENSION SYSTEM : ARMY STANDARD   ● RED ◒ YELLOW ◕ GREEN

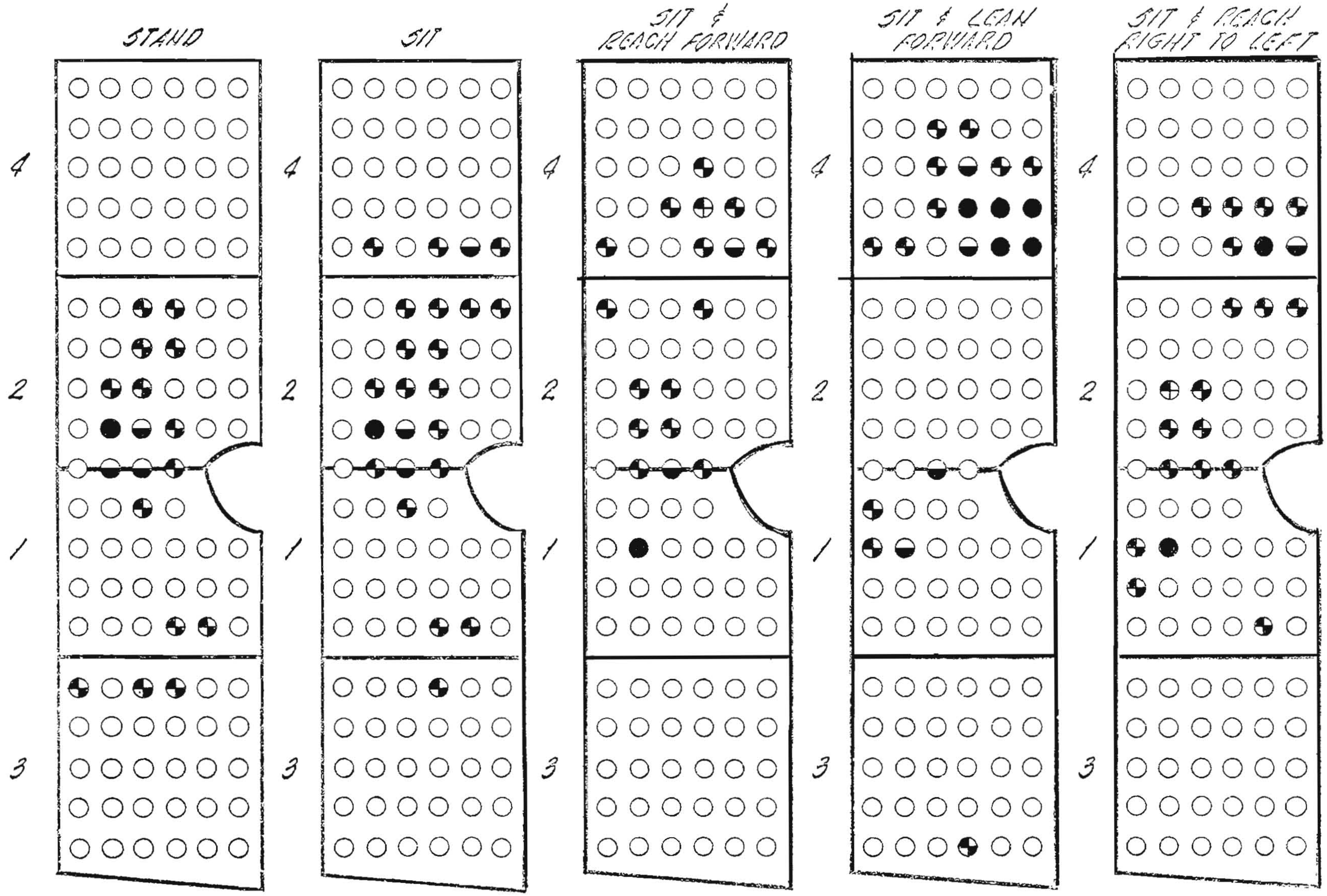


SUBJECT : K. MAYERHOFER SUSPENSION SYSTEM: NET SUPENSION

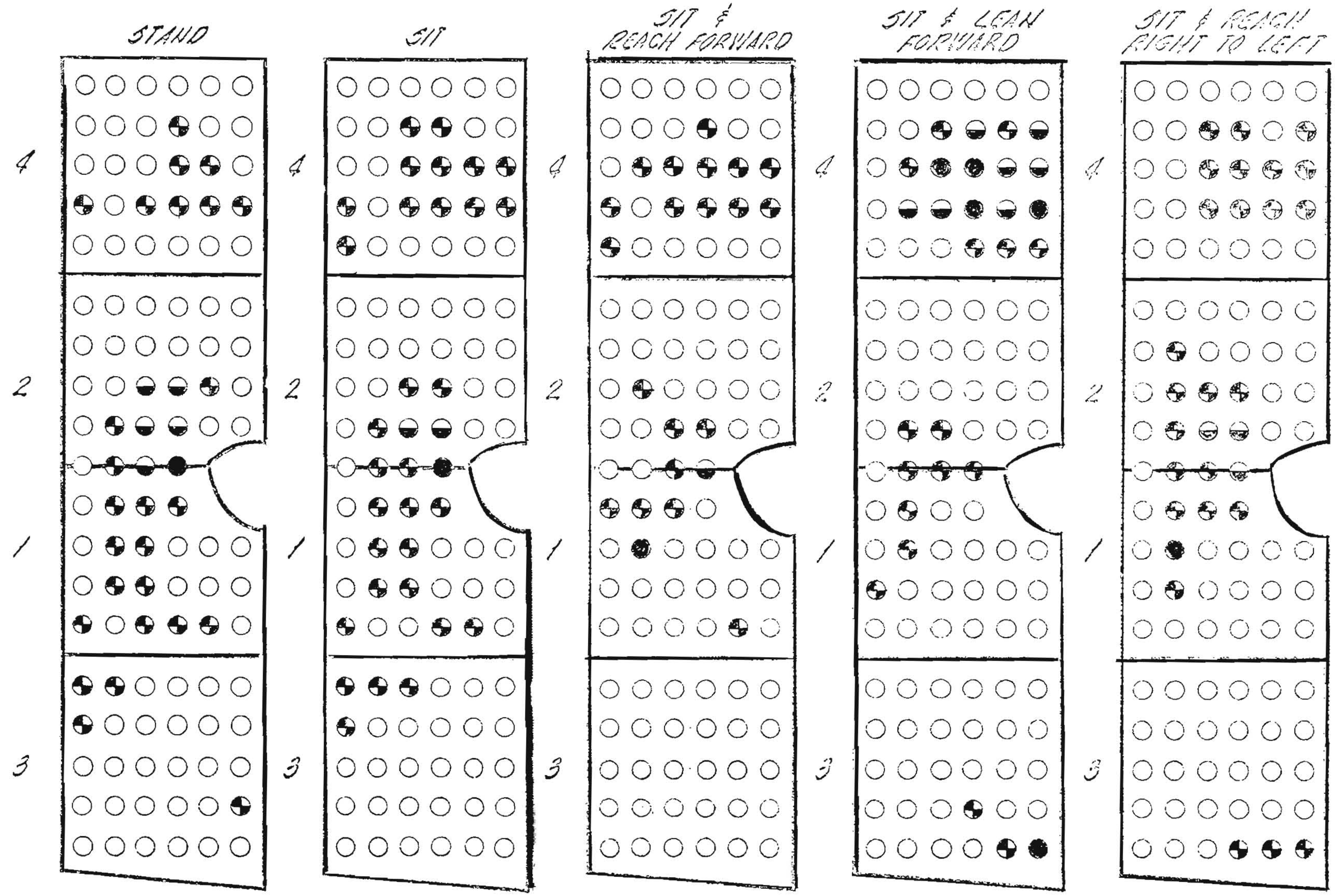
● RED ◒ YELLOW ◕ GREEN



SUBJECT : R. RODZEN   SUSPENSION SYSTEM: NET SUSPENSION   ● RED ◒ YELLOW ⊕ GREEN



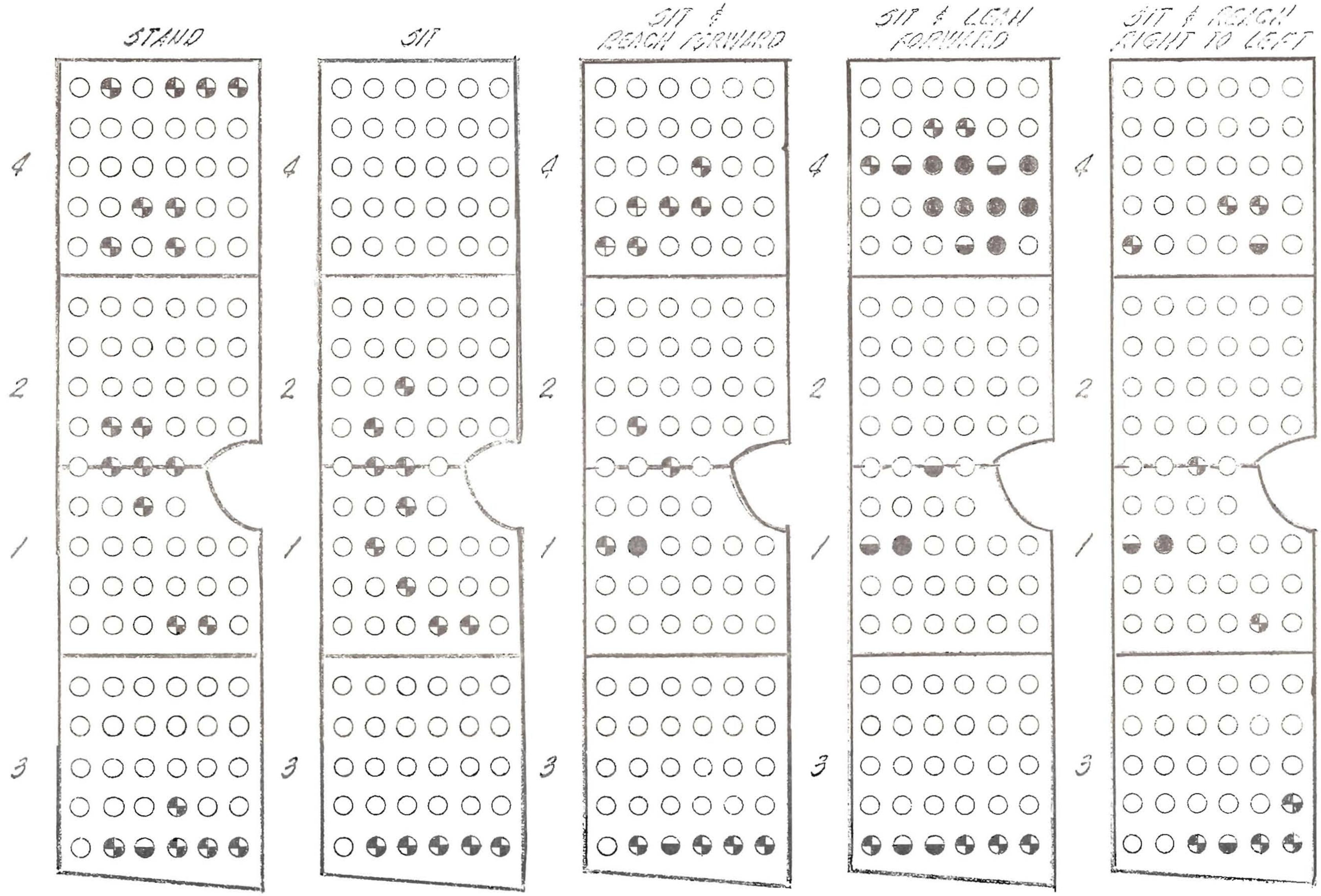
SUBJECT: C. HALL SUSPENSION SYSTEM: NET SUSPENSION ● RED ◒ YELLOW ◕ GREEN



SUBJECT : R. RODZEN

SUSPENSION SYSTEM : NET SUSPENSION WITH WAIST AUGMENTATION

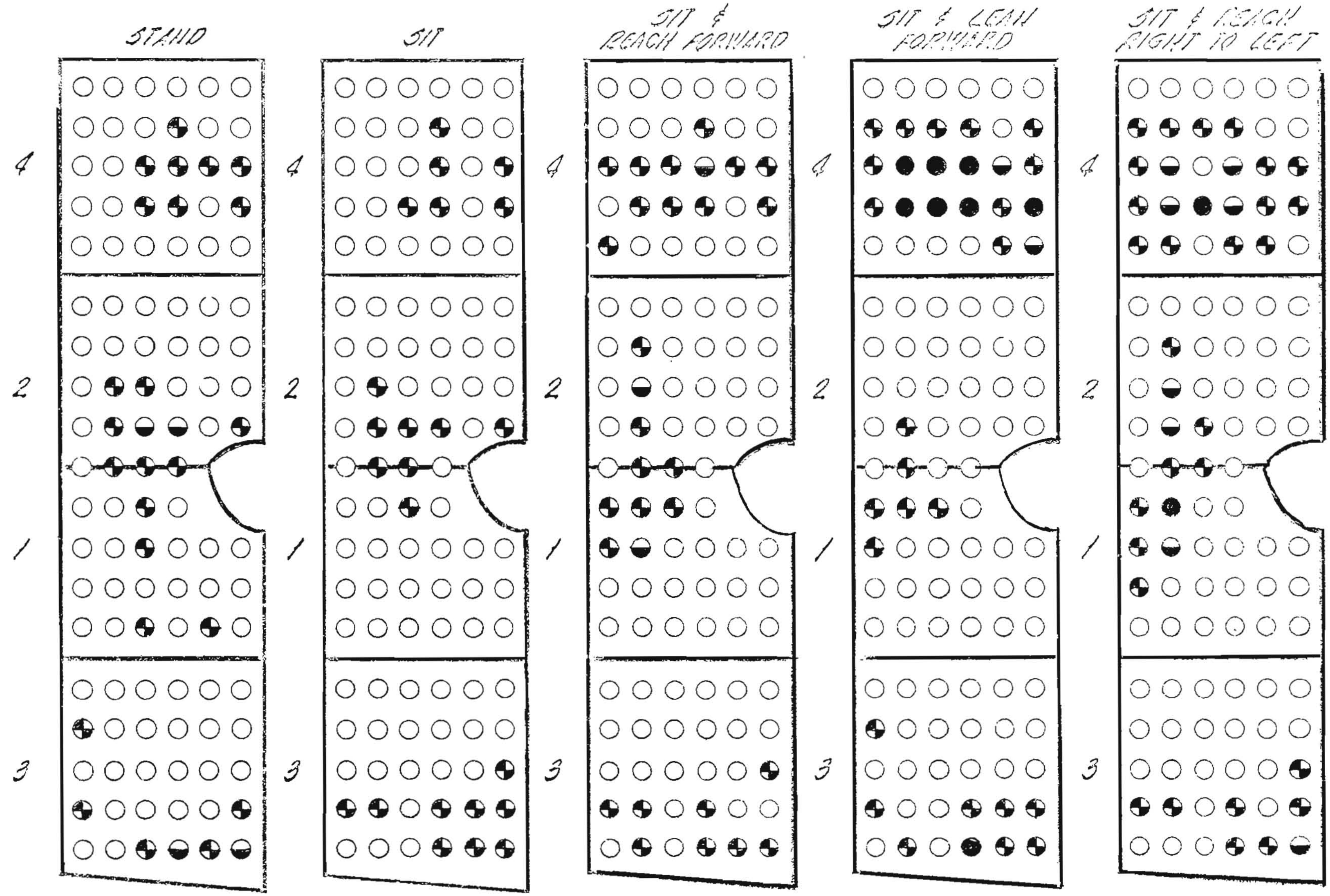
RED YELLOW GREEN



SUBJECT : C. HALL

SUSPENSION SYSTEM : NET SUSPENSION WITH WAIST AUGMENTATION

● RED ◒ YELLOW ◕ GREEN



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13. ABSTRACT

The purpose of this program was to design, develop, and fabricate an instrument which could locate and sense loads induced on the body of a person wearing protective armor, and to compare suspensions and suggest improvements which could be incorporated in current or future load-carrying systems.

The development of a "Personnel Armor Load Profile Analyzer" saw the attainment of a method of sensing loads, the integration and positioning of sensors in a suitable garment, a method of displaying information, and the correlation of output data to torso sensitivity.

It was found that armor suspension systems could effectively be evaluated using this instrument. Static and dynamic load patterns were displayed and the shift in these patterns with articulation could be observed. The data obtained from the display could provide guidelines for improving suspension system design by determining whether a particular suspension was effective in distributing loads on the optimum load-bearing areas of the torso. The progressive electrical contact sensor approach provided a direct reading system with maximum reliability, ruggedness, and versatility. In addition, the system did not require special signal conditioning equipment. The variable inductance sensor approach produced an analog sensor output converted to a digital display.

(cont'd)

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Determination	8		4			
Positioning	8		4			
Loads (forces)	9		4			
Measuring instruments	10		9			
Instruments	10		9			
Body armor	4		4			
Suspending (hanging)	4		4			
Development			8			
Design			8			
Fabrication			8			

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13. ABSTRACT (cont'd)

A review of the load-sensing and display techniques developed during the program and the supplementary work related to the selection of the final systems is provided. The results of an evaluation study of different suspension systems are presented and data presentation and interpretation are discussed.