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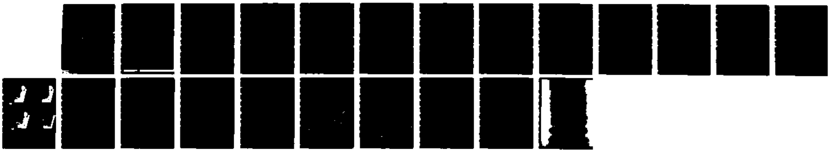

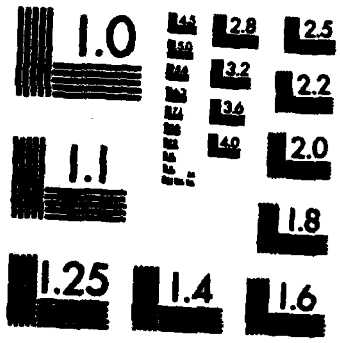

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Uniform Mass Distribution Properties and

Body Size Appropriate for the 50 Percentile

Male Aircrewmember During 1980-1990

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Date: 27 March 1981

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UNIFORM MASS DISTRIBUTION PROPERTIES AND BODY SIZE APPROPRIATE FOR THE 50 PERCENTILE MALE AIRCREWMEMBER DURING 1980-1990

INTRODUCTION. The design and analysis of aircraft seating, restraint and interior systems requires careful consideration of human factors relating to the mission to be performed and to the characteristics of the occupant. If comparisons are to be made among different system concepts, it is desirable to have a uniform basis for describing the characteristics of the human occupant and of any tools used as a human surrogate in the design, analysis or evaluation of the system. To this end, the U.S. Army Aeromedical Research Laboratory initiated an effort for the promotion of a tri-service "Standard Man" military specification in February 1980. The immediate goal of that effort was to develop a specification for body dimensions, joint locations, sitting heights, and mass distribution of military aircrewmen. A meeting was held at the U.S. Air Force Aeromedical Research Laboratory in March 1980, to discuss this effort and to establish a program to accomplish the work.

The meeting was attended by representatives of the U.S. Army, Navy and Air Force and various civilian organizations. At this meeting it was stated that uniform anthropometric and mass distribution data was needed for military male aircrew, with the understanding that female aircrew data would be deferred. The data were needed for (a) input to math models of seated military aircrew exposed to impact and long term acceleration loads, (b) input to math models and anthropomorphic dummies of parachutists exposed to varying impact loads, (c) input data for anthropomorphic test dummies in escape capsules, and (d) input to math models and anthropomorphic test dummies of seated military aircrew in crashworthy (shock absorption) seats.

The 50th percentile male aircrewmember was selected as the initial occupant to be defined, inasmuch as there was general agreement that differences in recorded data for this size was small among the various users. An Anthropometry Task group and a Mass Distribution Task group were formed to work on this effort.

A second meeting was held at the FAA Civil Aeromedical Institute in October 1980. For that meeting, Dr. K. W. Kennedy of the Anthropometry Task group provided a status report on the Air Force program to develop appropriate anthropometric and kinematic properties of a proposed family of anthropomorphic test dummies, most likely to be sized after the 5th percentile USAF female, and 5th, 50th and 95th percentile USAF male based on projected 1980-1990 data. After considerable discussion, it was agreed to develop standard representation for a 50th percentile male in the relaxed seated position, with head oriented in the Frankfort plane. Several references were reviewed, and it was agreed that the USAF drawing board manikin (1), in the 50th percentile male size, could serve as a basis for further development. This manikin is sized to USAF 1980-1990 size projections. This manikin, and drawings for similar manikins representing the 5th percentile female, 5th percentile male and 95th percentile male, were subsequently furnished for evaluation. This report describes that evaluation and provides recommendations for the standard representation of the 50th percentile seated male aircrewmember.

The USAF Drawing Board Manikins.

The USAF two dimensional drawing board manikins (1) were developed by Dr. K. Kennedy at the request of the NASA Lyndon B. Johnson Space Center to represent the anticipated 1980-1990 body size distribution of USAF fliers. They are covered by U.S. Patent 4,026,041, dated May 31, 1977.

The 50th percentile male manikin is shown in Figure 1. Drawings for the manikins are included in Appendix 1. Fabrication instructions, and drawings of simplified versions of the manikins are contained in Reference 1. In using that reference, note that the captions for the drawings of the "50%ile" and "95%ile" USAF manikins (simplified version) have been reversed.

The anticipated 1985 anthropometric dimensions used in developing the manikins are given in the reference. Instructions for the use of the manikins are included in Appendix 2. The manikins provide several features beyond the requirements for the present study, e.g. head gear, boot size, heart position, slumped and erect seating positions, functional reach, and range of limb sizes for each torso size.

Evaluation of USAF Manikin.

A comparison of the mean anthropometric data used to develop the USAF manikins and the data describing USA Aviators was accomplished by Kennedy, and is shown in Table 1. These values are considered to be sufficiently close to the 50th percentile values as to be used interchangeably. Perhaps the most significant differences between these two data sets are those relating to height. The difference in standing height amounts to 3.8 cm. Even if a growth rate of 0.8 cm per decade, as used to project the USAF data to the 1985 date were used to project the Army data, a difference of 2.6 cm would remain. In regards to the male civilian airman, data indicate that the average stature and weight of all (first, second and third class) airmen is 179 cm and 80.82 kg, respectively (2). This is within 0.6 cm and 0.7 kg of the projected USAF aircrewmember. Since these differences are inconsequential for most design purposes, the results of this study will have equal application to civilian and military aircrewmembers.

Since link lengths form the basis for the uniform dimensions being developed in this study, the link lengths of the USAF manikins were measured directly. These data are shown in Table 2. Singley and Haley (3) in discussing mathematical modeling of helicopter seating systems, proposed a linkage system which corresponds closely to those of the manikin, although the torso is divided differently. Dimensions of the non-torso links are included in Table 2. The total torso length, from hip pivot to head pivot, indicated by Singley and Haley, is 69.1 cm. This corresponds exactly to the sum of the lower torso, mid torso, upper torso and neck link lengths on the USAF 50th percentile male manikins. The hip pivot to seat pan (buttocks depth) measurement indicated by Singley and Haley is 7.6 cm, corresponding to 8.7 cm measured on the manikin, and the head pivot to top of head dimension indicated by Singley and Haley of 14.3 cm corresponds to a dimension of 16.2 cm on the manikin. Thus the larger erect sitting height of the manikin appears due to the larger head and buttocks dimensions of the manikin relative to that proposed by Singley and Haley.

A number of comparisons can be made with many other references intended to aid the designer in the layout of work stations. One of the more useful of these is "Humanscale 1/2/3" (4), which gives a variety of information on sizes of people, seating considerations and requirements for the handicapped and elderly. Included in this reference are dimensions for link systems and simple drafting template designs. Data from this reference have been entered into Table 2 for stature approximating that represented by the manikin, and the 1970 US Army aviator. With the exception of the head pivot to top of head dimension, all dimensions are in close agreement. The pivot point selection criteria are not discussed in this reference, so the one discrepancy mentioned may be due to the selection of the head-neck pivot point.

Reynolds (5) calculated limb lengths for the same predicted population as was used for the USAF manikins. His data for the 50th percentile white male arm and leg link lengths are included in Table 2. Again, agreement is good.

Finally, a comparison was made with the Part 572 50th percentile anthropomorphic test device (6). This is the only standardized test dummy commonly available, and is often used for evaluation of aircraft seating and restraint systems. Data were taken from fabrication drawings or from Hubbard (7), and are shown in Table 2. Larger differences are noted here than in the other comparisons.

Mass Distribution.

The specification of mass distribution properties for human bodies requires the determination of the center of mass for each body segment and knowledge of the inertia tensor for each segment. Although some limited data exists for those segments whose boundaries can be well defined, segmentation of the torso in a meaningful manner remains an unsolved problem. A summary of the state-of-the-art was given by Reynolds in 1978 (5). Since that time, two major additional studies have been completed. McConville, et al (8), used biostereometric techniques to estimate volume, center of volume and inertial properties of 24 body segments on each of 31 male subjects. Beier, et al (9) completed direct measurements of the center of mass and inertial properties of fresh unembalmed head segments for 19 male cadavers and two female cadavers ranging in age from 19 to 64 years.

No data on link length is provided in the McConville report, so that the location of the center of volume can be inferred only from the anthropometric landmarks on the subject. To relate these data to the manikin, the most direct approach would be to create a link system relative to the

McConville data which can be related to that of the manikin. To do this, data on the location centroids of the cut planes dividing the body into segments in McConville's report were obtained. These cut planes were originally selected to reasonably allocate an appropriate mass to each body segment rather than to pass through "hinge points." The average centroid distances are included in Table 2. The relationships of the center of volumes to the centroids of the cut planes are shown in Figure 2. For the limbs, the elbow and knee cut plane centroids provide an adequate representation of the hinge points, but for the torso a relationship between the cut plane centroids and the manikin hinge points must be established. This was accomplished by developing a full scale lateral view layout of the mean value anthropometric and cut plane data from the McConville report, and then locating the same vertebral hinge points on that layout as were used in developing the manikin. Lack of adequate landmark commonality between the few references which describe the vertebral hinge points (10,11,12,13) and the McConville report necessitates some degree of emperical judgement, but the final result is believed to be of practical use. The C7/T1 hinge point was located with reasonable accuracy from the cervical landmark, and the various references used to "reconstruct" the vertebral column from that point down to the pelvis. The T8/T9 hinge point was found to lie within a range of ± 1.5 cm about the center of volume of the thorax as determined in the McConville report. The L3/L4 hinge point was found to lie within ± 2 cm of the center of volume of the abdomen section. Depending on the data used and the method of applying the data, the hinge points locations were located around the centers of volume in a fairly even manner. Considering the emperical factors in this projection, it is felt that T8/T9 hinge point and the center of volume of the torso, as well as the L3/L4 hinge point and the center of volume of the abdominal segment can be considered coincident.

Similar methods were used for the other body segments. An inconsistency between the McConville and Beier data exists relative to the fore-aft location of the center of gravity of the head. McConville indicates a distance to the c.g. of 0.85 cm behind the tragion, whereas Beier indicates an average distance of 0.83 cm ahead of the auditory meatus. Even when considering the difference in reference points, this still results in a discrepancy of over 1 cm in the y axis center of mass location in a critical body segment. This will be insignificant for +Gx accelerations, but may be more meaningful for an impact with significant vertical forces. Since this problem cannot be resolved within the scope of this report, it is proposed to compromise both sets of data and locate the center of mass of the head directly above the tragion. The inertial properties of the head are in very close agreement.

During the process of consolidating these factors, it was concluded that an approximation to an average male aircrewmember, scaled to be representative of the crewmembers active during the years 1980-1990 can be devised if the following factors are acceptable:

a. The USAF 50th percentile male drawing board manikin (1) represents the appropriate body contours and link lengths of the population.

b. The inertial properties of body segments are calculated using the data provided by biostereometric measurements (8), scaled to match the dimensions of the population and the characteristics of the manikin.

c. Using the equations provided in reference (8), volumes and volume moments of inertia are calculated for an 81.5 kg, 178.4 stature subject, corresponding to the weight and stature used for developing the manikin.

d. Since the biostereometric data provides a slight overestimate of volume properties, a density of 0.9638 gm/cm^3 is used for all segments, rather than 1 gm/cm^3, so that their total mass will sum to 81.5 kg.

e. The same density, 0.9638 gm/cm^3, is used to convert the volume moments of inertia to mass moments of inertia.

f. The mass moments of inertia about the transverse (x and y) limb/axis are averaged to avoid problems of specifying orientation of these axis (this yields average values that are within 4 percent of the calculated values about the x and y axis).

g. The centers of mass appropriate for the manikin are related to the biostereometric data through estimates of vertebral column placement (for the torso), or by accepting biostereometric cut plane locations to be representative of hinges at the elbow, wrist, knee and ankle.

h. The orientation of the vector representing the moment of inertia about the z axis of the limb segments is assumed to lie along the link representing that segment on the manikin (estimated error is less than 10°).

i. The body is assumed to be bilaterally symmetric, and left side and right side data averaged to yield "typical" data.

j. The center of mass of the head is considered to be directly in line with the head pivot and the ear point on the manikin, splitting difference between the McConville and Beier data.

k. The differences in inertial properties between the various possible seated conditions and the standing position in which the biostereometric data were taken are acknowledged to be unknown, but it is considered acceptable to apply the biostereometric segment data to the seated position segments until better data are available.

l. The center of mass of the lower torso segment is located along the link from the hip pivot to the lower torso pivot at a position corresponding to the height of the center of volume of the biostereometric pelvis segment above a seating surface obtained by measuring downward from the biostereometric standing vertex a distance equal to the mean sitting height of the biostereometric subjects. The sitting height of the biostereometric subjects differs from the sitting height of the data used to develop the manikin by less than 1 percent.

m. The center of mass of the foot is located along a line segment through the ankle pivot, parallel to the top surface of the foot, at a distance from the pivot equivalent to the cut plane centroid to center of volume determined from the biostereometric data.

These last three factors are necessary because of lack of explicit data pertaining to the problem at hand. Further research in these matters, particularly in regard to factor "k" is warranted.

Following this procedure, the mass, the mass moment of inertia properties, the distance to segment mass centers and the orientation of the principal axes of inertia shown in Table 3 were calculated. These are shown applied to the normal seated position in Figure 3 and to the slumped seated position in Figure 4.

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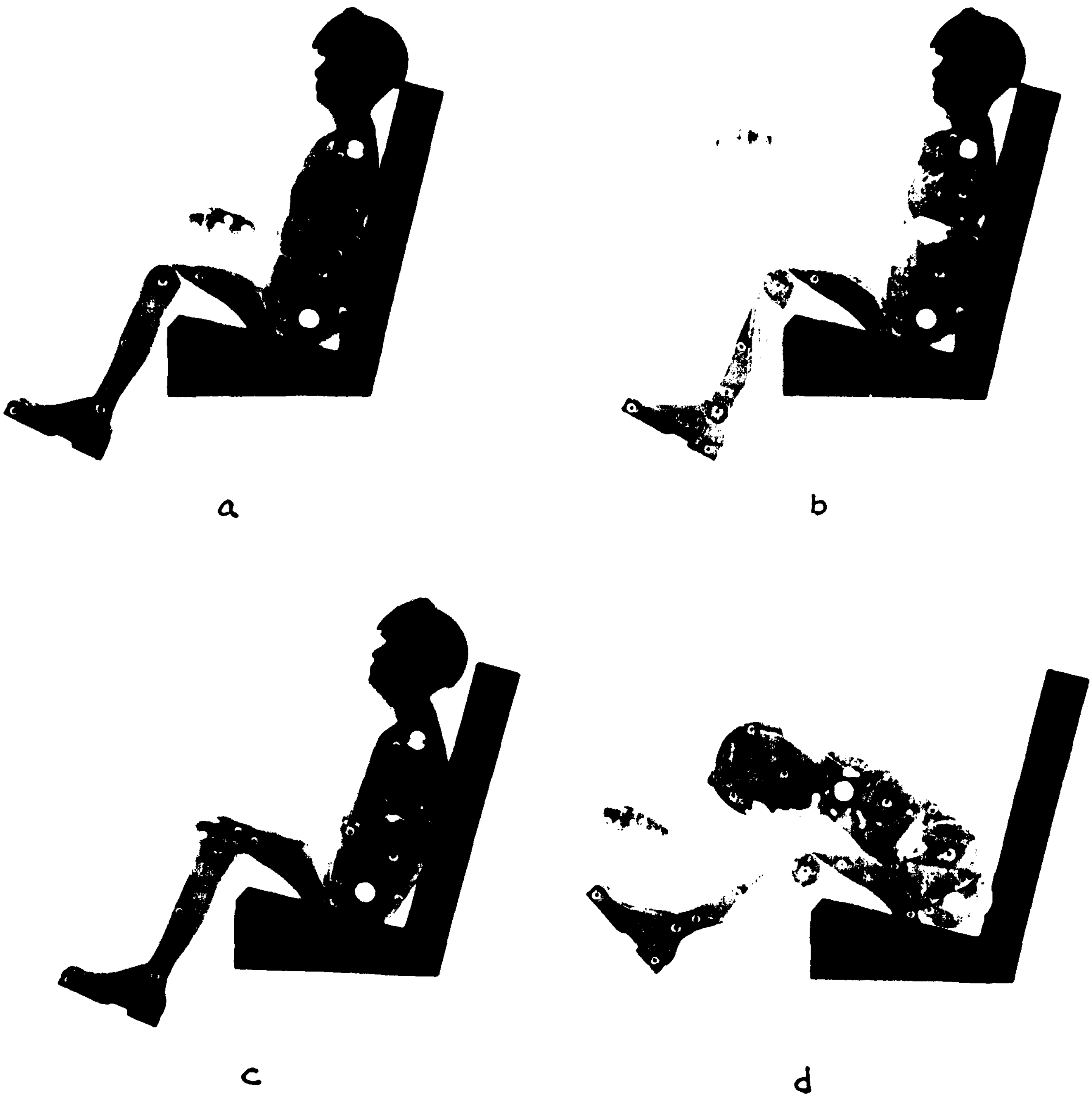
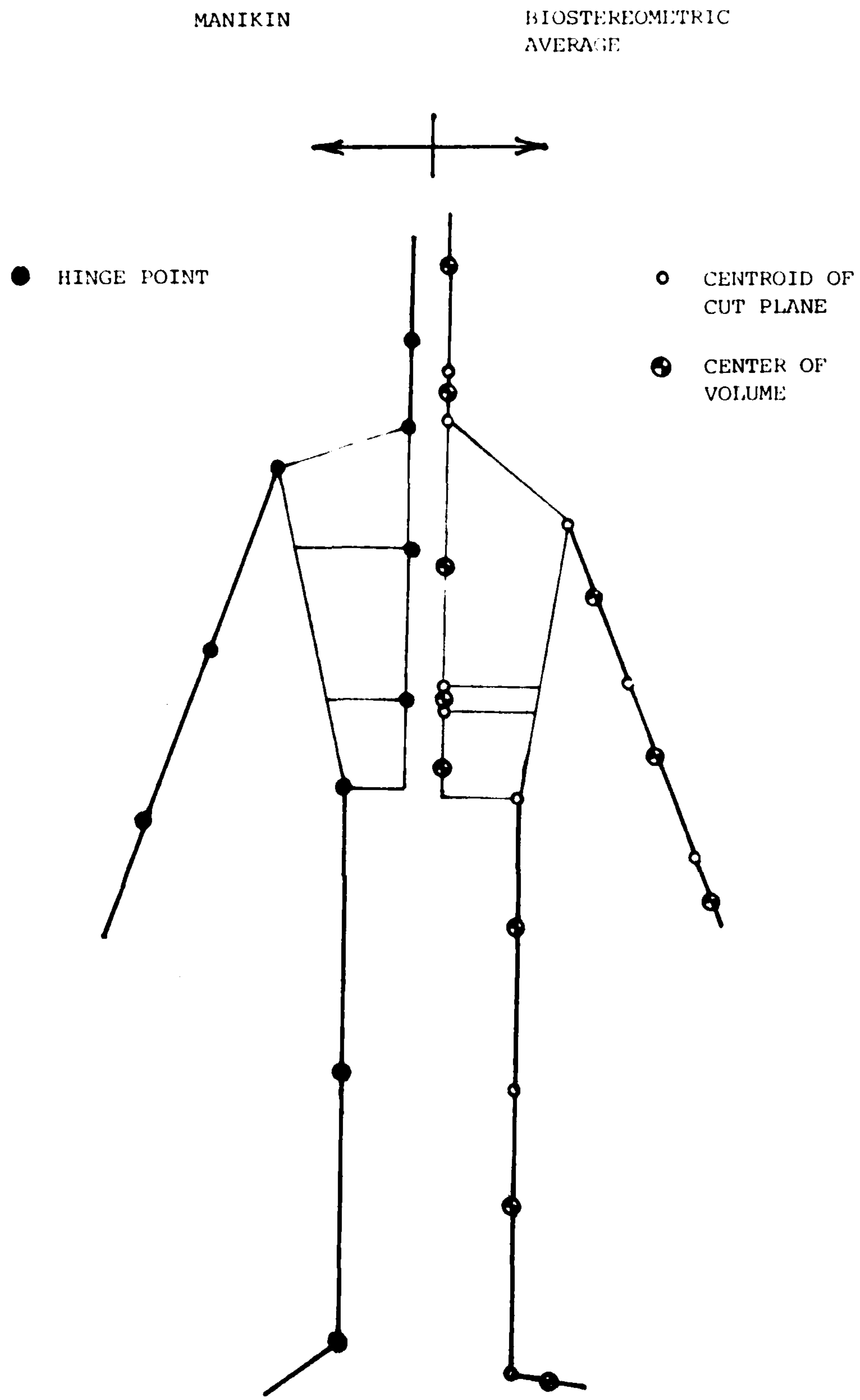


50th PERCENTILE USAF MANIKIN (REF 1) IN
a: ERECT SEATED POSITION
b: ERECT SEATED POSITION, ARMS EXTENDED
c: RELAXED SEATED POSITION
d: FORWARD FLEXED SEATED POSITION

FIGURE 1



CENTROIDS OF CUT PLANES AND CENTER OF SEGMENT VOLUME (REF 8), AND LINK LENGTHS BETWEEN HINGE POINTS OF 50TH PERCENTILE USAF MANIKIN (REF 1)

FIGURE 2

ANTHROPOMETRIC DATA:

USAF PILOTS (PROJECTED) VS USA AVIATORS 1970

		USAF Projected 1980-90 $\bar{X}$	USA Aviators 1970 50TH* ($\bar{X}$)
a.	Weight (kg)	91.5	77.35 (77.63)
b.	Height (cm)	178.4	174.58 (174.56)
c.	Cervicale Height	153.0	149.68 (149.65)
d.	Head and Neck Height	26.4	25.90
e.	Sitting Height (Erect)	93.6	90.90 (90.92)
f.	Sitting Height (Relaxed) (-2.2 cm)	91.4	(88.7)
g.	Thigh Clearance Height	16.8	14.71 (14.70)
h.	Knee Height, Sitting	56.1	52.93 (53.00)
i.	Popliteal Height	44.0	42.26 (42.33)
j.	Buttock-Popliteal Length	50.80	49.07 (49.08)
k.	Buttock-Knee Length	60.8	60.15 (60.19)
l.	Head Breadth	15.6	15.3 (15.26)
m.	Bi-Acromial Breadth (Bi-Gleno Humeral [Shoulder Joint])	40.9	---
n.	Chest Breadth	33.0	34.3 (34.40)
o.	Bi-Cristale Breadth	28.1	---
p.	Hip Breadth, Seated	38.1	37.7 (37.79)
q.	Bi-Acetabular (Hip) Joint Breadth	17.8	---
r.	Knee Joint Range of Movement	180° to 67° (113°)	---

TABLE 1

TABLE 2

	S[illegible] (REF [illegible])	SCHNEIDER [illegible]	[illegible] (REF 4)	[illegible] SCALE (REF 4) 74 [illegible] MALE	REYNOLDS (REF 5)	[illegible] 572 DUMMY (REF 6,7)	AVERAGE 50 CENTROID [illegible] (REF 2)
FOOT [illegible]	9.8	1.9	9.8	8.9		?	–
LOWER LEG	41.2	41	42.2	41.1	42.1	41.4	[illegible]
UPPER LEG	43.5	41.8	43.2	42.[illegible]	43.2	[illegible]	44.5
LOWER TORSO	13.8	–	–	8.[illegible]		–	13.2
[illegible] TORSO	23.5	–				–	4.1
[illegible] TORSO	18.6	–				–	40.8
UPPER TORSO	13.2				–	–	7.4
NECK	16.2	14.3	18.6	18.[illegible]		–	
[illegible] TOP OF HEAD	29.5 (2)	28.8	28.1	[illegible]	30.5	25.9	26.4
UPPER ARM	27.9	26.8	25.1	25.4	27.3	25.0	28.6
LOWER ARM	19.5	17.9	19.3	19.1	–	–	–
HAND	–	–	25.6	35.1	–	–	–
SHOULDER PIVOT WIDTH	–	–	17.8	17.5	–		
HIP PIVOT WIDTH							

(2) UPPER ARM LENGTH WAS MEASURED FROM [illegible]
TO "ER" MARK ON MANIKIN UPPER ARM

TABLE 3: [illegible] 50 % MALE

SEGMENT	MASS, kg	PRINCIPAL MOMENTS OF INERTIA, kg cm² ABOUT THE [illegible] AXES			center of mass ... cm from / pivot
		X	Y	Z	
HEAD	4.[illegible]4	[illegible]	[illegible]	147	5 7 / head
NECK	[illegible]	[illegible]	21	[illegible]	4.[illegible] / neck
UPPER TORSO	24.95	50[illegible]	[illegible]	[illegible]165	0 / upper torso
MID TORSO	2.41	16[illegible]	[illegible]3	[illegible]56	0 / lower torso
LOWER TORSO	11.80	1084	[illegible]	[illegible]	14 / [illegible]
UPPER ARM	[illegible]	[illegible]	[illegible]	[illegible]	14.2 / [illegible]
LOWER ARM	1.38	87	87	13	11.8 / elbow
HAND	0.51	12	12	5	6.8 / wrist
UPPER LEG	9.55	1592	1592	435	22 / knee
LOWER LEG	3.84	584	584	[illegible]	17 / knee
FOOT	0.96	8	44	44	6 / ankle

NOTES:

(1) ALL COMPUTATIONS BASED ON STATURE = 178.4 cm,
WEIGHT = 179.71 lb (81.5 kg)
DENSITY = 0.9638 gm/cm³

(2) PIVOT POINTS REFER TO THE PIVOTS OF THE 50th PERCENTILE MALE MANIKIN.

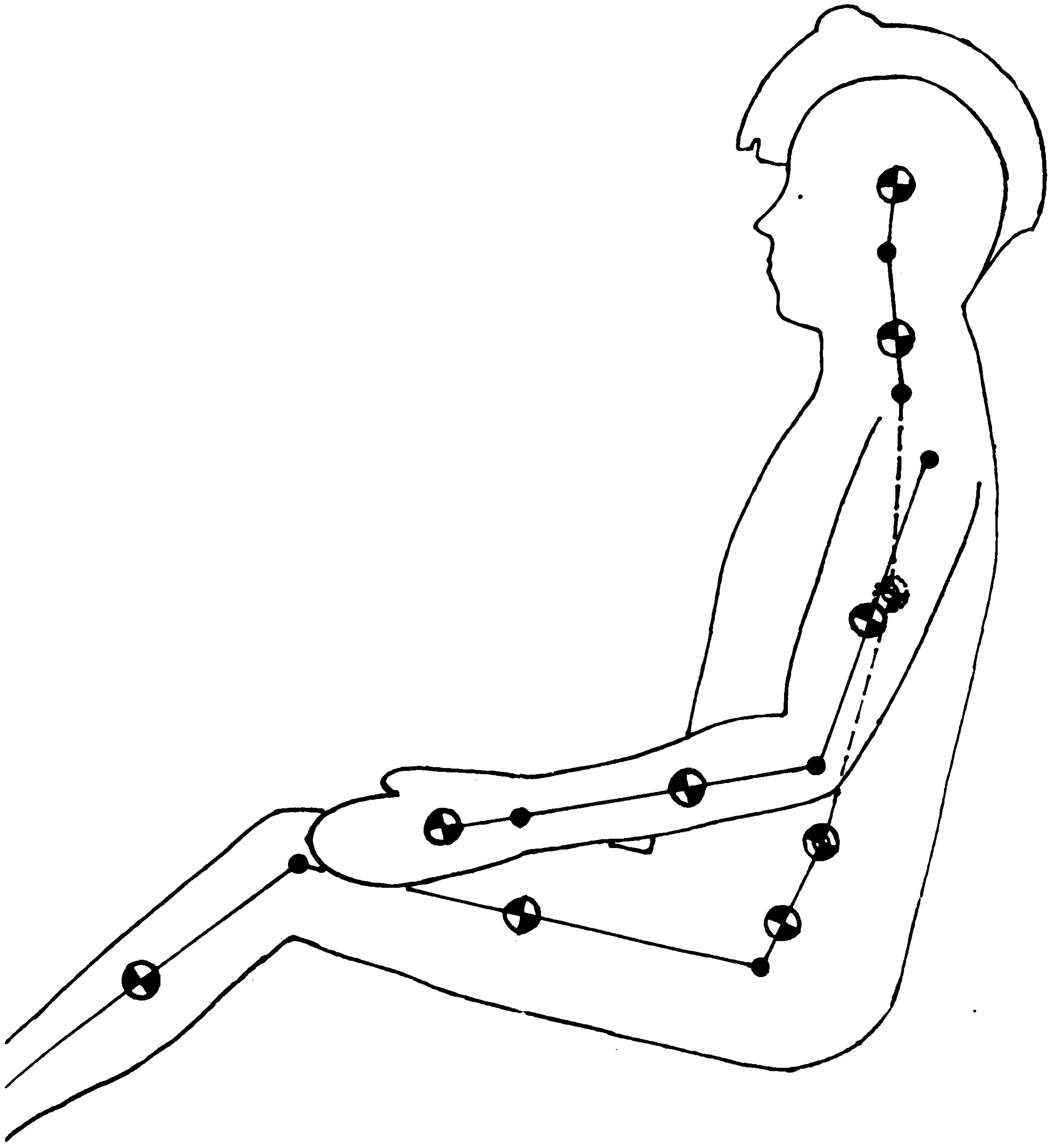
(3) CENTER OF MASS FALLS [illegible] LINE FORMING LINK BETWEEN PIVOTS, EXCEPT FOR:

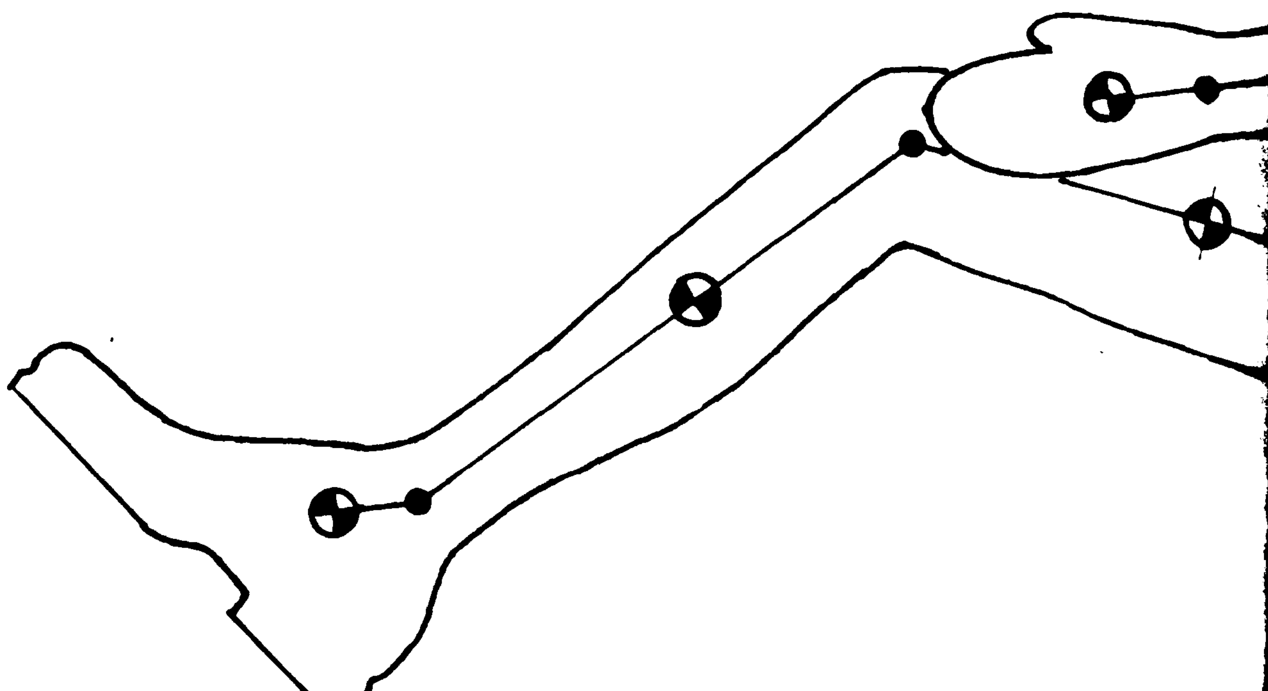
HEAD: USE LINE FROM HEAD PIVOT THROUGH EAR POINT
HAND: USE LINE FROM WRIST PIVOT THROUGH [illegible]
FOOT: USE LINE THROUGH ANKLE PIVOT PARALLEL TO THE TOP OF THE FOOT.

(4) THE "Z" AXIS LIES ALONG THE LINK LINE, EXCEPT FOR
HEAD: Z AXIS 26° [illegible] LINK LINE
UPPER TORSO: Z AXIS 15° [illegible] LINK LINE
LOWER TORSO: Z AXIS 33° BEHIND LINK LINE

(5) THE "X" AXIS IS PERPENDICULAR TO THE "Z" AXIS IN THE PLANE OF THE MANIKIN.

(6) THE "Y" AXIS IS PERPENDICULAR TO THE "X" AND Z AXES





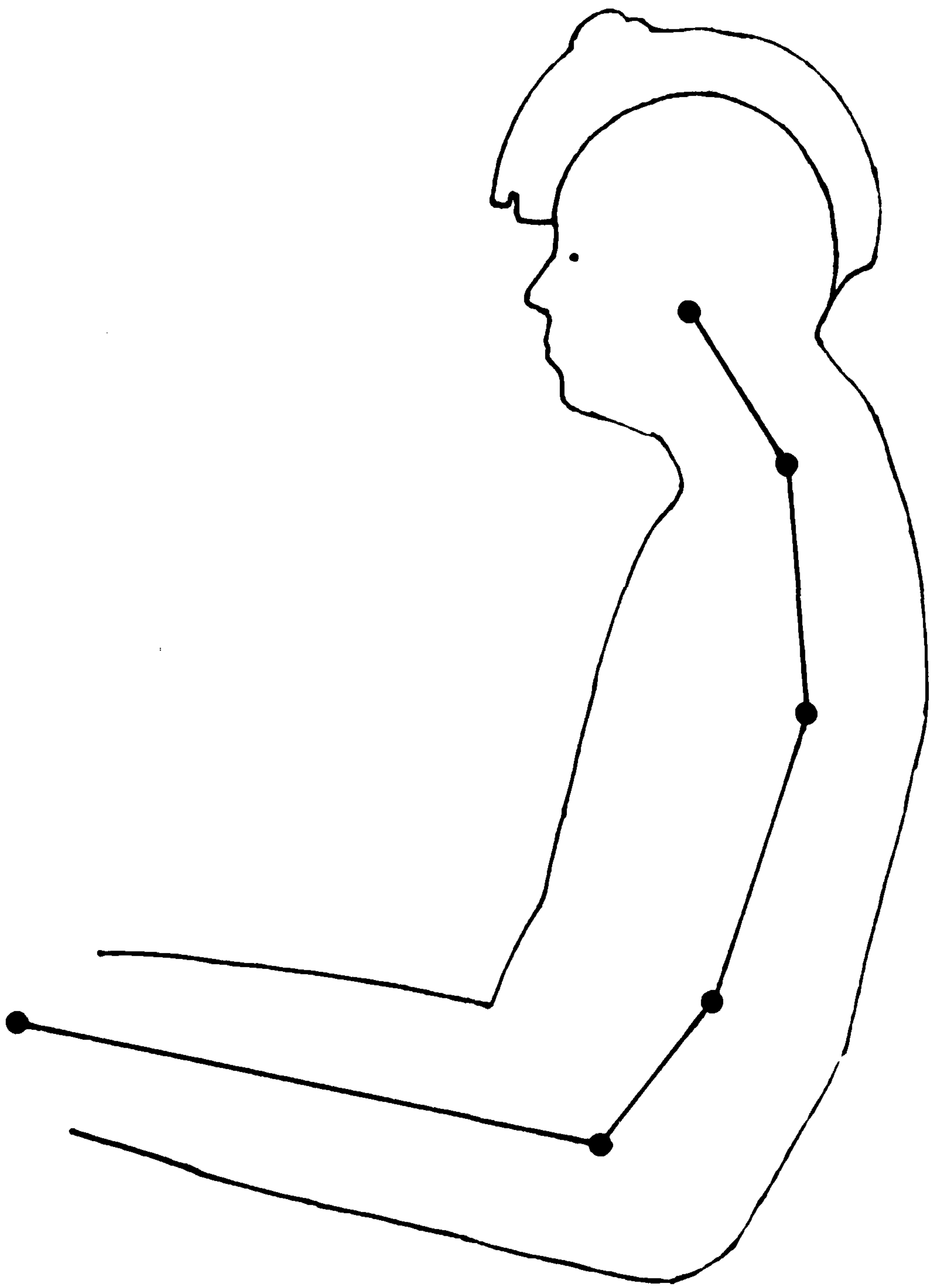
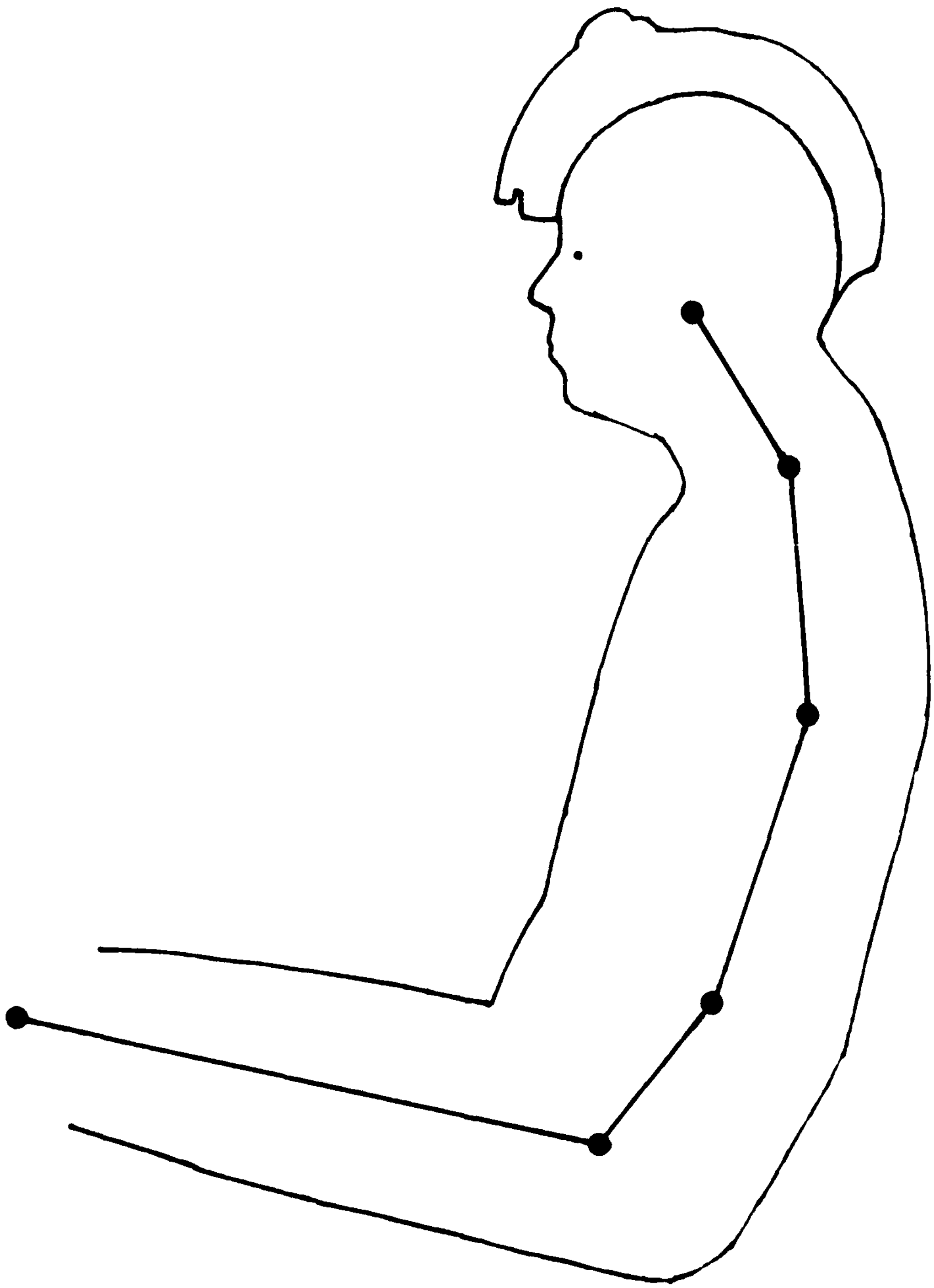


Figure 4.



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