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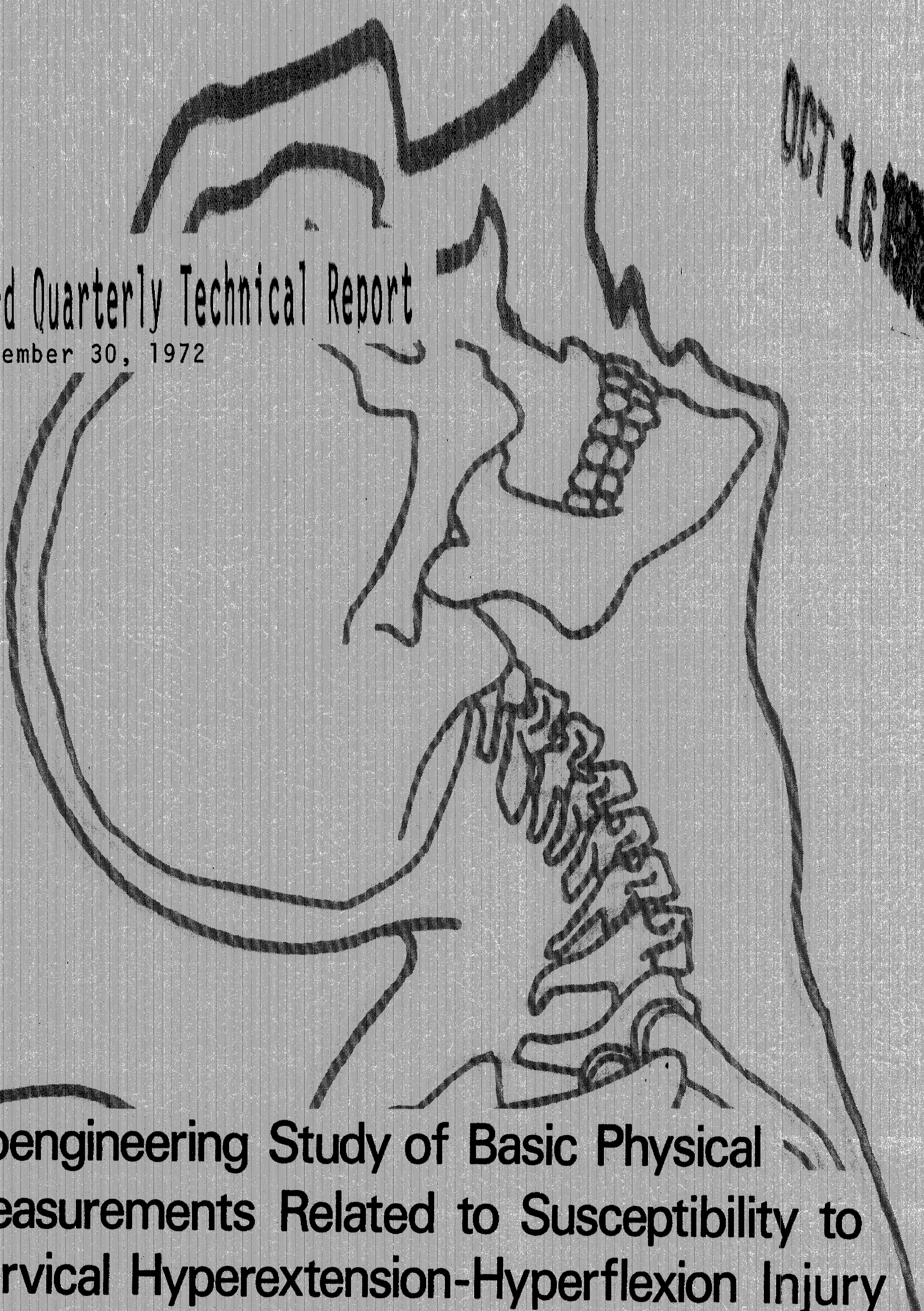

Third Quarterly Technical Report

September 30, 1972

Bioengineering Study of Basic Physical Measurements Related to Susceptibility to Cervical Hyperextension-Hyperflexion Injury

BIOENGINEERING STUDY OF BASIC PHYSICAL MEASUREMENTS RELATED TO SUSCEPTIBILITY TO CERVICAL HYPEREXTENSION-HYPERFLEXION INJURY

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SUMMARY

Despite substantial progress made during the past month, overall accomplishments during the period July 1st through September 30th have fallen behind our anticipated schedule for this period due to major difficulties encountered with equipment acquisition, measurement problems, and a personnel problem. All of these concerns, as detailed in our memorandum of August 23rd, have now been resolved. As is reflected in the work accomplished in September, we expect to collect data on more than half our subjects during the next quarter. Further, during periods of delay due to problems encountered in July and August, greater emphasis was placed on working on the analysis portion of the program. This has resulted to our benefit in development of a computer program designed concurrent with organization of data acquisition. This interaction will result in saving time in the highly complicated data analysis phase. We have confidence that the data analysis will be simpler, faster, and more efficient, since analysis procedures have already been established at an earlier point in the data collection phase than originally considered. Progress as of the end of the third quarter of this study may be summarized as follows:

1. A total of 400 new references have been added during this period, for a total of 1,810 relevant publications. No new studies providing useful data have been found since the last reporting period.
2. Anthropometry has been completed for 17 subjects. The procedures have now been standardized in the most efficient order. The anthropometry data form has been revised, and a detailed description for

each measurement completed. A total of 48 measurements are now being taken, with five measures added subsequent to the last report, and three measures dropped. Slight changes in several definitions were established, in particular inferior neck circumferences, where cervicale has been defined as the posterior level of measurement

3. Radiology of 43 subjects has been completed. Quality of films is excellent and to date only three subjects have been clinically disqualified from further participation after review of cervical X-rays. Statistical analysis of range of motion and soft-seat vs. hard seat neutral head positions was completed on 33 sets of X-rays. Results indicate that skull surface landmarks, rather than an external reference rod, will provide a more reliable measure of range of motion. Essentially no difference in head position was found between the soft seat and hard seat, so the soft-seat position is being eliminated. Instead, another lateral neutral X-ray will be taken with the shoulders dropped to achieve better definition of C-7 and T-1 vertebrae.

4. Photogrammetry was completed on 30 additional subjects during the quarter. Range-of-motion analysis was completed on a total of 27 subjects. Two independent reference axes were used to determine range of motion, and the results were compared statistically.

5. A two-fold technical problem was resolved during the quarter - that of insufficient loading forces and unacceptable levels of vibration in the loading system during the reaction time tests. Procedural changes resulting from the solution include the use of a lightweight, slightly elastic nylon cord to reduce vibration and a method of dropping the one-pound weight 4 to 6 inches to achieve acceleration forces nearer 1.0 g. Also used is a small pre-tensioning weight that removes slack from the cord and provides a striking surface for the falling weight. Equip-

ment modifications included establishment of a channel to control computerized data analysis, and a monitor console to increase data-taking efficiency.

6. Strength testing proceeded smoothly for the six subjects tested. Some "learning" trends have been observed, so future test subjects will be allowed one unrecorded maximum strength trial to become familiar with the effort involved.

7. A comprehensive automated data analysis program has been written for the Hewlett-Packard computer. The program is written to allow simultaneous sampling and analysis of up to five tape channels in a single pass. It is not necessary to start and stop the tape recorder for either the processing of all tests with a single subject or the sequential analysis of several subjects. A data record may be deleted after the fact, errors in proper testing sequence are detected and reported, all details of the analysis are recorded on digitized magnetic tape, and a one-line summary of test results is produced as the data is analyzed. The program is essentially debugged, and automatic data analysis has been demonstrated.

8. Statistical analysis was performed with the data obtained from 33 sets of X-rays and 30 sets of photogrammetry. Results indicated that there was no significant difference in neutral head angle between the soft seat and hard seat X-rays. The soft seat X-ray will be eliminated in favor of a dropped-shoulders view which allows better definition of C-7 and T-1 vertebrae. A statistical test of range of motion data from photographs using two independent reference axes revealed that, for many subjects, a reference rod attached to a headpiece was not stable enough to provide a reliable method of measuring head angles. A similar test of X-ray data using two independent reference axes

resulted in similar findings - the reference rod moved significantly in the extension position due to skin excursion. As a result of these statistical tests, the reference rod will be used only in neutral X-ray views, and only to establish the absolute neutral position of the head, with respect to horizontal. Body surface landmarks will be used to obtain range of motion data. A repeatability analysis was conducted using 19 sets of photogrammetric data, each set consisting of three views each of the neutral, flexion, and extension positions. The analysis indicates that each subject repeats his own body positions with little variation, but that individual subjects vary greatly in the absolute positions they achieve. A final analysis indicated that moving from one hard seat in the X-ray room to a similar one in the photogrammetry area did not significantly change the absolute position achieved by a given subject. The results of all the analysis completed to date indicates that X-ray and photographic data are comparable, and that either source provides reliable range of motion and absolute head position data.

9. Reaction time test data from six subjects indicate that dropping the weight is sufficient to produce a stretch reflex whenever g - levels of greater than approximately 0.4 are achieved. A greater head displacement is being observed (at a lower g - load) when the neck is extended than when it is flexed. Muscle reaction times tend to vary greatly, but initial indications are that the neck flexors are somewhat slower reacting.

10. Strength-testing of six subjects indicate good repeatability in some cases and a "learning" effect in others. However, the neck extensor muscles in back of the neck are consistently stronger than the neck flexors (40% stronger on the average).

I. INTRODUCTION

Occupants of motor vehicles involved in rear-end collisions commonly incur neck injuries. Such trauma has been characterized as "whiplash" or hyperextension-hyperflexion injuries. However, recent field and clinical investigations indicate that there is a significant preponderance of "whiplash" symptoms among females. Little information is known concerning variation in head mass or center of gravity of the seated occupant or variation of neck muscle strength as related to age, sex, and physique differences, and no previous study has related variation in neck muscle response time to external acceleration stimulus. Such information would appear to be of basic importance in consideration of sensitivity to hyperextension-hyperflexion injury.

The basic objective of this study is to determine the range of physical variation in function and structure of the human neck, with variables of age, sex, and stature, as a basis for improved head protection design in vehicular occupant hyperextension-hyperflexion accidents. Specific tests and measurements are being designed and will be conducted to result in several major types of information relating to the range of physical and sexual variation of the neck in a representative U.S. population. Neck measurements to be determined include anthropometry, radiography, photogrammetry, muscle strength, voluntary range of extension and flexion cervical motion, and muscle response time. Mathematical modeling is being used to predict dynamic sensitivity to changes in the parameters developed.

The following technical progress report provides a brief review of the third 90-day period of this investigation. Accomplishments during this period from July through August were behind our anticipated progress due to major difficulties encountered with equipment acquisition, measurement problems, and a personnel problem. All of these problems have now been resolved, as detailed in our memorandum of 23 August. During the past month substantial progress has been made. Emphasis was placed upon solving the major problems, and once this was accomplished we have been primarily concerned with data collection on subjects. Subject testing, including radiography, anthropometry, strength, photometrics, muscle reaction time, and range of motion is now proceeding as rapidly as possible. Due to changes in the scheduling in the early part of this period greater attention was paid to working on the analysis portion of the program, with the result that we are far ahead of schedule in this area and subsequent work should proceed with a minimum of programming and analysis problems. Individual task progress is detailed as follows.

II. TASK PROGRESS

1. Literature Survey

A continuing effort has been made to review and update the large body of literature related to the neck.

As in previous reports, the bibliography included in this report has been divided into five general categories; motion/mobility, mechanisms of injury, injuries/fractures, anatomy/radiography, and experimental strength and stress. The major portion of the literature consists of clinical reports not of particular use except to emphasize the nature and extent of cervical injuries and treatment aspects.

During the past three months we have located 400 additional references, bringing the total number of references found to date to 1,810. The bibliography lists only these new acquisitions, and it is planned to combine and possibly restructure the categories for the final report. Thus, each quarterly report reflects only the new references retrieved during that period, rather than the bulky total bibliography.

In the category "Motion/Mobility" 148 references were reported in the second quarterly report, and 34 additional reports are included at this time, bringing the total to 182 related to motion. To date, however, only 23 different studies of normal cervical motion have been located: No new studies of normal motion were located in this quarter. Many other motion studies in the literature were not considered because they utilized subjects with previous history of neck injury and could generate abnormal motion readings. Only two studies found in the "normal motion" literature use both male and female subjects over a wide age span, while the rest report measurements based upon a single sex, a limited age range and a selected sample. This confirms our previous findings of insufficient, inadequate, and/or unusual data from previous reports for application to this study.

As pointed out in earlier reports, it is difficult to compare results because of the different techniques, measurements, and endpoints employed by the various investigators. Extension and flexion limits have only been identified in ten studies although all studies listed a range of motion measured in the sagittal plane alone. Combining the 1958 total subjects for all previous studies identified to date results in a mean range of sagittal motion of 130^{0}. Examination of available previous work still indicates that no thorough study of the basic parameters outlined in this investigation has been conducted for a large number of subjects representative of the general population and including both sexes and a wide age-span.

During this period, a number of additional references in each category have been retrieved. To date, we have located 29 new reports, for a total of 91 in the category of mechanical injury, 48 new reports, for a total of 281, related to cervical anatomy or radiological studies, 71 new reports, for a total of 196 references in the area of experimental strength or stress of cervical structures, and 216 new reports totaling1068 clinical reports of injuries.

2. Subject Pool

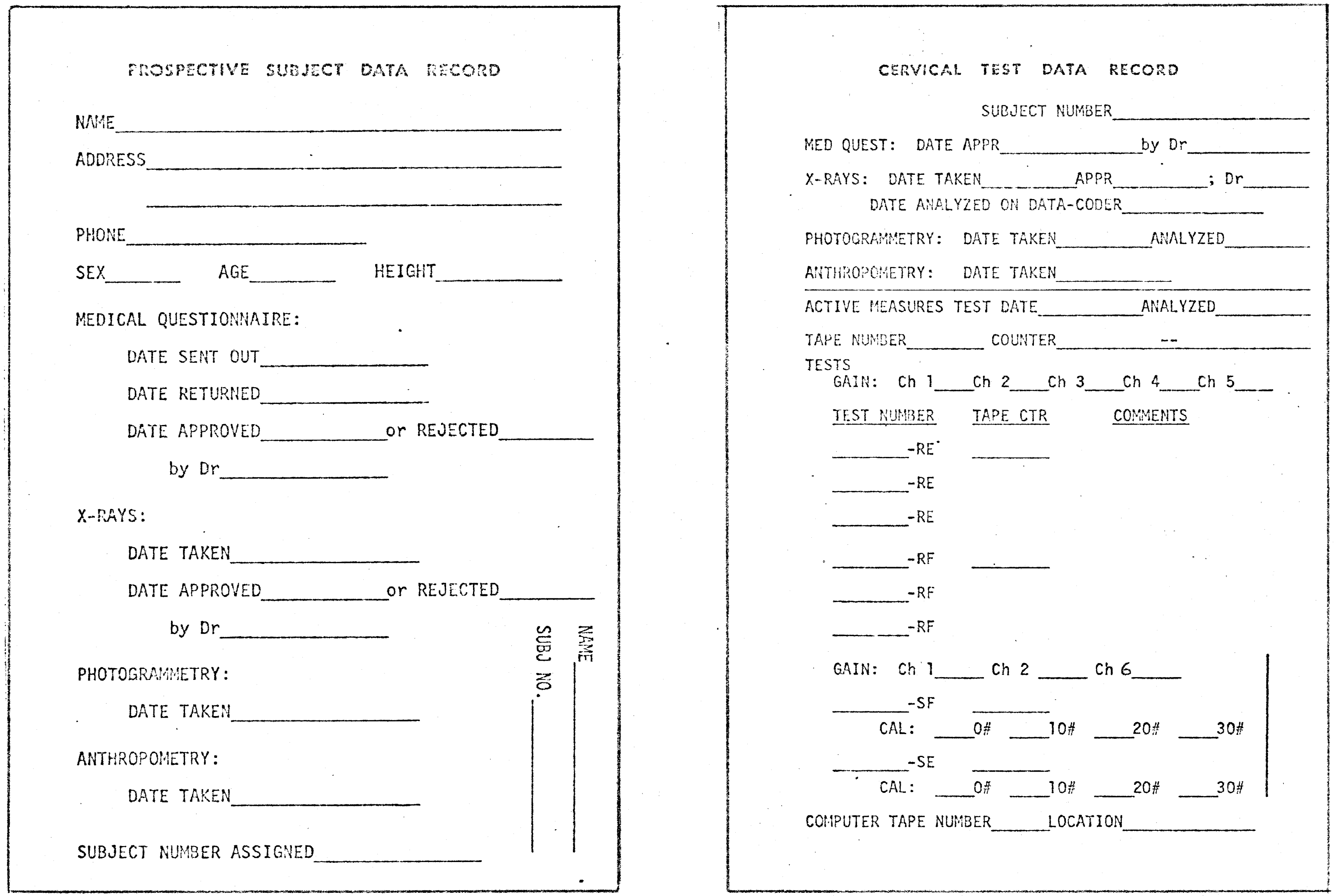
Organization of the subject pool selection criteria, together with an illustration of the subject's health questionnaire, and subject consent form have been detailed in the two previous quarterly reports. The majority of subjects to date have come from the

18 to 24 year old age group, primarily because they are easiest to obtain, usually more flexible concerning scheduling and more adaptable to the preliminary test requirements. However, we are now selecting subjects from the second age group, and during the next trimester expect to utilize subjects from the oldest group as well.

To facilitate record-keeping and coordinate subject scheduling activities, two card files have been developed. The forms used consist of two 5" by 8" cards, as shown in Figure 1. The "Prospective Subject Data Record" card is used to process a subject through the initial stages of the study. As previously detailed, before being medically cleared for the final tests, each subject is contacted several times and this card is updated for each step of the process.

After the medical questionnaire and X-rays have been approved by Dr. Baum, our radiologist consultant, pertinent information is transferred to the "Cervical Test Data Record" card. The subject is identified only by code number on this card, and it is the Cervical Test Data Record card that is used as the official record of testing for a subject. This card becomes a one-page source of information not only of the chronological progress of the subject in the study, but also when the data was analyzed, and where the raw and analyzed data are located.

The two-card system has been in use for approximately six weeks and has proven to aid considerably in keeping track of subjects through the several phases of approval, tests, and data analysis.



PROSPECTIVE SUBJECT DATA RECORD

NAME____________________

ADDRESS____________________

____

PHONE____________

SEX______ AGE______ HEIGHT________

MEDICAL QUESTIONNAIRE:

DATE SENT OUT__________

DATE RETURNED__________

DATE APPROVED________or REJECTED______

by Dr__________

X-RAYS:

DATE TAKEN__________

DATE APPROVED________or REJECTED______

by Dr__________

PHOTOGRAMMETRY:

DATE TAKEN__________

ANTHROPOMETRY:

DATE TAKEN__________

SUBJECT NUMBER ASSIGNED__________

NAME__________

SUBJ NO.__________

CERVICAL TEST DATA RECORD

SUBJECT NUMBER__________

MED QUEST: DATE APPR__________by Dr________

X-RAYS: DATE TAKEN________APPR_______; Dr_____

DATE ANALYZED ON DATA-CODER__________

PHOTOGRAMMETRY: DATE TAKEN________ANALYZED________

ANTHROPOMETRY: DATE TAKEN________

ACTIVE MEASURES TEST DATE________ANALYZED________

TAPE NUMBER______ COUNTER________ --

TESTS

GAIN: Ch 1___Ch 2___Ch 3___Ch 4___Ch 5___

TEST NUMBER	TAPE CTR	COMMENTS
______-RE	______	
______-RE		
______-RE		
______-RF	______	
______-RF		
______-RF		

GAIN: Ch 1____ Ch 2 ____ Ch 6____

______-SF ______

CAL: ____0# ____10# ____20# ____30#

______-SE ______

CAL: ____0# ____10# ____20# ____30#

COMPUTER TAPE NUMBER_____LOCATION__________

Figure 1. Samples of the Subject Data Record Cards. These forms were developed to facilitate tracking of subjects through scheduling, testing, and data analysis.

To date, some 150 medical questionnaires have been sent out and we estimate that about 400 will be necessary to obtain the selected subjects. 42 subjects have now had the X-ray and photogrammetry series completed, 17 of these have also had an anthropometry completed, and six subjects have had all data taken in final form and analyzed. In the younger, 18 to 24, age group rejections on the basis of the medical history alone have been running about 17%. However, several subjects who turned in questionnaires turned out to be too old or too young, and 14 could not be located at the address or phone number given on their questionnaire, giving a percentage of about 35% unusable questionnaires so far received. The medical questionnaire rejection rate is expected to markedly increase with older subjects and may become a real problem in obtaining a sufficient number of elderly subjects. To facilitate subject return of questionnaires, we are now providing self-addressed stamped envelopes, which the subject may forward directly in care of Dr. Baum.

Further procedural changes will probably be necessary to encourage older subjects. We have also been providing transportation to HSRI for any subjects in need of it. Travel is often a problem with both the youngest and oldest age groups. Our scheduling also has to remain flexible since we are finding that many subjects are only available during the evening or on weekends.

3. Anthropometry

Measurements taken on subjects have been changed somewhat in relation to both order and specific measurements during the past month. These changes provide for smoother progress of measurements with more efficient use of particular instruments, and should result in some reduction of the time needed to take the anthropometry.

At present, a total of 48 subject measurements are being taken. These include four in the standing erect posture, 15 in the seated erect posture, 22 in the seated relaxed position, and seven in the standing relaxed posture. A decision has been reached with respect to the eight measures considered as optional at the time of the last report. Three of these (seat surface to trochanterion, seat back to trochanterion, and buttock-knee length) will not be taken and the other five have been incorporated into the regular procedure. The three measures now omitted were felt to be useful measures for the purpose of eventual comparison of this population with other populations, particularly with regard to the leg-pelvic rotation point. However, since we can determine seat-reference points, and since taking these particular measures required changes in both procedure and degree of subject clothing, it was decided not to compromise obtaining the basic data needed for this study in order to obtain these additional measures.

The revised Subject Anthropometry Form is illustrated in Figure 2. Each measurement has been organized so that the succeeding measurement may be taken most efficiently, either as to instrument used or body location. Also, a notation has been added to the form

Figure 2. SUBJECT ANTHROPOMETRY FORM

DATE ______________

SUBJECT NO.____________

TIME OF DAY ______________

A. STANDING (ERECT)

	INSTRUMENT	
1. Weight	Scale	
2. Stature	WA	
3. Cervicale (C7) Height	WA	
4. Chin-Neck Intersect Height	WA	

B. SEATED (ERECT)

5. Sitting Height	A1	
6. Sitting Cervicale Height	A1	
7. Sitting Right Shoulder (Acromion) Height	A1	
8. Sitting Left Shoulder (Acromion) Height	A1	
9. Left Tragion Height	A1	
10. Right Tragion Height	A1	
11. Nasal Root Depression Height	A1	
12. Left Sitting Eye Height	A1	
13. Sitting Suprasternale Height	A1	
14. Biacromial Breadth	A2	
15. Shoulder Breadth (Bideltoid)	A2	
16. Lateral Neck Breadth (Mid)	A2	
17. Anterior-Posterior Neck Breadth (Mid)	A2	
18. Anterior Neck Length	SC	
19. Posterior Neck Length	SC	

C. SEATED (RELAXED)

20. Sitting Height (Slumped)	A1	
21. Left Sitting Eye Height (Slumped)	A1	

Subject No. ____________

22.	Superior Neck Circumference	T	
23.	Inferior Neck Circumference	T	
24.	Head Circumference	T	
25.	Head Ellipse Circumference (Bennett)	T	
26.	Head Breadth	HC	
27.	Head Length	HC	
28.	Head Height	A2	
29.	Sagittal Arc Length	T	
30.	Coronal Arc Length	T	
31.	Bitragion Diameter	HC	
32.	Minimum Frontal Diameter	HC	
33.	Minimum Frontal Arc Length	T	
34.	Bitragion Minimum Frontal Arc Length	T	
35.	Bitragion Inion Arc Length	T	
36.	Posterior Arc Length	T	
37.	Sitting Knee Height	A1	
38.	Sitting Knee Height (Maximal Clearance)	A1	
39.	Right Anterior Iliac Spine Height	A1	
40.	Hip Breadth	A2	
41.	Biceps Flexed Circumference (Right)	T	

D. STANDING (RELAXED)

42.	Calf Circumference (Right)	T	
43.	Femoral Biepicondylar Diameter (Right)	A2	
44.	Humerus Biepicondylar Diameter (Right)	A2	
45.	Right Triceps Skinfold	SF	
46.	Right Subscapular Skinfold	SF	
47.	Right Suprailiac Skinfold	SF	
48.	Right Posterior Mid-calf Skinfold	SF	

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to indicate which instrument is used for each measurement. This has proven useful for the assistant, who can now both record the measurements and hand the proper instrument to the measurer.

The subject is now initially marked with a grease pencil at the cervicale (C7), suprasternale, left and right acromions, and glabella landmarks. These landmarks are a reference for many measurements, and this procedural change has been found to improve the speed and accuracy of taking measurements at these body locations.

All anthropometry is being taken by a single individual, to avoid inter-measurer error. All subjects who completed anthropometry prior to the end of August, when Ann Desautels was hired to fill our personnel vacancy, are being remeasured. Ms. Desautels is responsible for recruiting and scheduling subjects, assisting with X-rays, and taking photometrics and anthropometry. She has been intensively trained by Dr. Snyder in the measurements to be taken and shows significant repeatability in her measurements. Subsequent to a training period, a number of subjects have been measured several times as a check. Also, unscheduled remeasures are selectively taken during the initial measurement period. All subject anthropometry measures were observed (and in some cases verified) for the first month by Dr. Snyder to double-check procedures and accuracy.

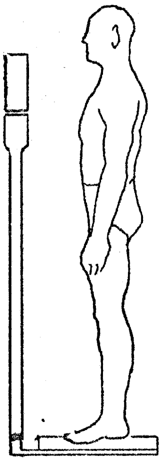
The detailed descriptions and illustrations of each measurement have been updated and reordered to agree with the latest measurement-taking sequence. These descriptions are included for reference as Table 1.

TABLE 1.

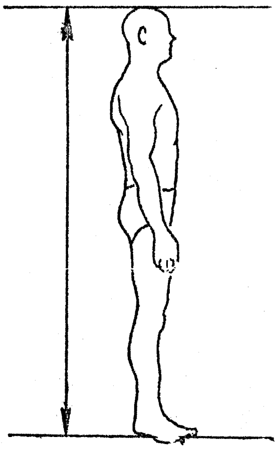
DESCRIPTION OF ANTHROPOMETRIC DIMENSIONS

A. SUBJECT IN STANDING POSITION (ERECT)

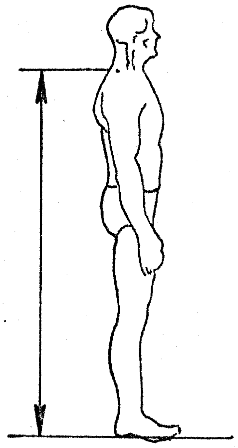
1. WEIGHT - Taken on standard medical type scale to nearest one-half pound. Subject unclothed except for shorts (plus halter for women).



2. STATURE - The subject maintains an erect standing posture, feet together, arms hanging at his side, looking straight ahead with head held in the Frankfurt Plane,* which is determined by lining up the infraorbital margins with tragion in the same horizontal plane. The vertical distance is measured with the wall-mounted anthropometer from the floor to the highest point on the subject's head with the anthropometer arm firmly contacting the scalp.



3. CERVICALE - The subject maintains an erect posture, feet together, arms hanging at his side, looking straight ahead with head held in the Frankfurt Plane. The vertical distance is measured with a wall-mounted anthropometer from the floor to the previously marked palpable spinous process of the seventh cervical vertebra.



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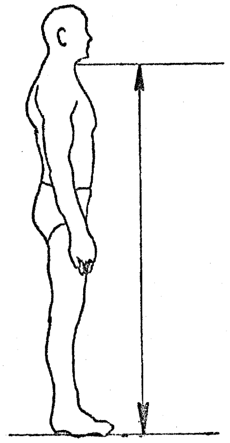
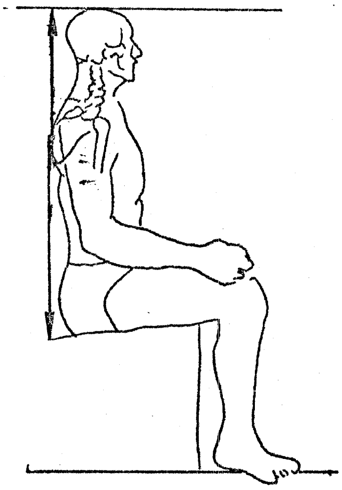
*Frankfurt Plane or horizontal (F.H.). The plane determined by the points on the infraorbital margins and the tragion.

4. CHIN-NECK INTERSECT - The subject maintains an erect posture, feet together, arms hanging at his side, looking straight ahead with head held in the Frankfurt Plane. The vertical distance is measured with a wall-mounted anthropometer from the floor to the point of intersection of the chin and neck at the mid-line. This intersection is located by observing the subject from the side and placing the point of the anthropometer arm at the highest point on the neck intersected by the chin.

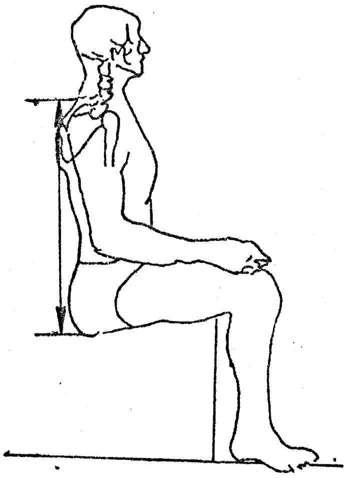


B. SUBJECT IN SEATED POSITION (ERECT)

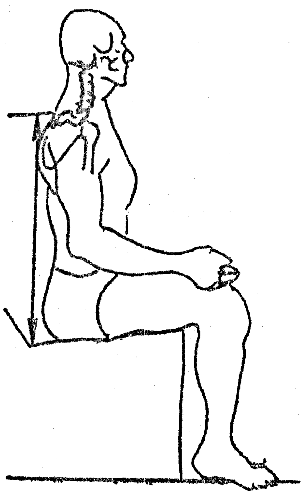


5. SITTING HEIGHT (erect) - The subject sits erect with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The head is held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the sitting surface to vertex with the anthropometer arm firmly touching the scalp.

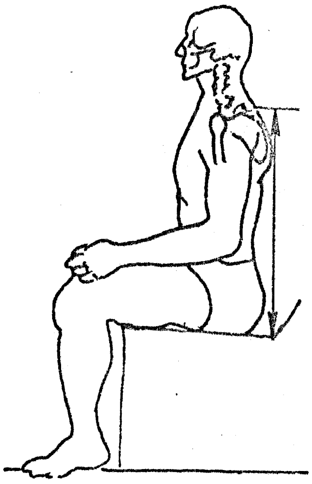
6. SITTING CERVICALE HEIGHT - The subject sits erect, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The head is held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the sitting surface to the palpable spinous process of the seventh cervical vertebra.



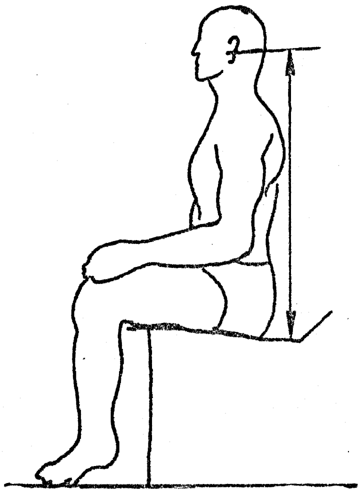
7. SITTING RIGHT SHOULDER (acromion) HEIGHT - The subject maintains an erect posture, with arms hanging at sides and resting on upper legs, feet together and resting on a surface so that the knees are bent at about right angles. The vertical distance is measured from behind the subject using an anthropometer from the sitting surface to the superior lateral border palpable on the margin of the acromion process of the right scapula (acromion).



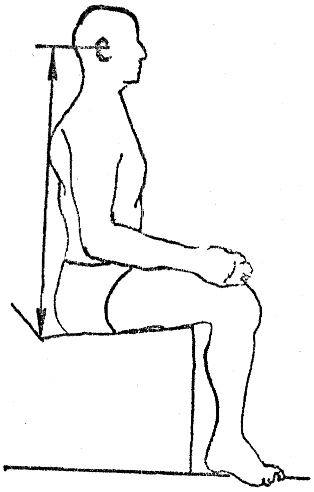
8. SITTING LEFT SHOULDER (acromion) HEIGHT - The subject maintains an erect posture, with arms hanging at sides and resting on upper legs, feet together and resting on a surface so that the knees are bent at about right angles. The vertical distance is measured from behind the subject using an anthropometer from the sitting surface to the superior lateral border palpable on the margin of the acromion process of the left scapula (acromion).



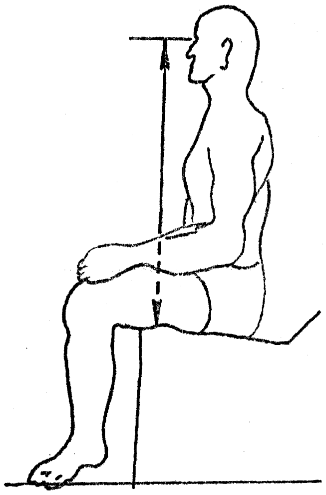
9. LEFT TRAGION - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. The vertical distance is measured with an anthropometer on the left side of the subject from the sitting surface to the anterior limit of the cartilaginous notch superior to the tragus of the left ear.



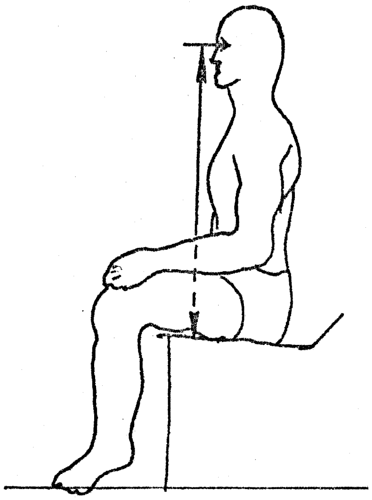
10. RIGHT TRAGION - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. The vertical distance is measured with an anthropometer on the right side of the subject from the sitting surface to the anterior limit of the cartilaginous notch superior to the tragus of the right ear.



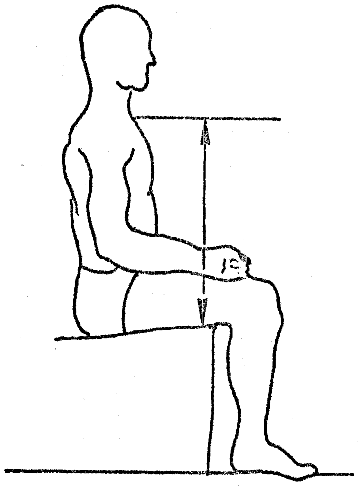
11. NASAL ROOT DEPRESSION - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. Facing the subject, the vertical distance is measured with an anthropometer from the sitting surface to the point of greatest indentation where the bridge of the nose joins the supraorbital ridge of the forehead.



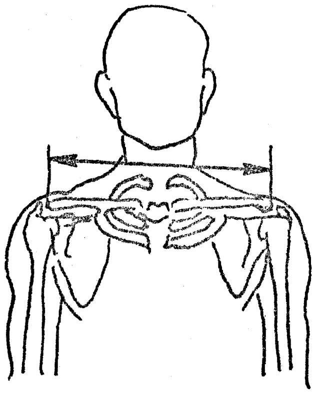
12. LEFT SITTING EYE HEIGHT (erect) - The subject sits erect, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The head is held in the Frankfurt Plane. The vertical distance is measured with an anthropometer from the sitting surface to the inner corner (internal canthus) of the right eye.



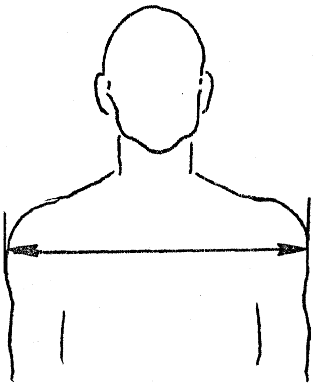
13. SITTING SUPRASTERNALE HEIGHT - The subject sits erect with buttocks against seat back, arms resting on upper legs, legs spread slightly, and head held in the Frankfurt Plane. Facing the subject, the vertical distance is measured with an anthropometer from the sitting surface to the superior margin of the jugular notch of the manubrium.



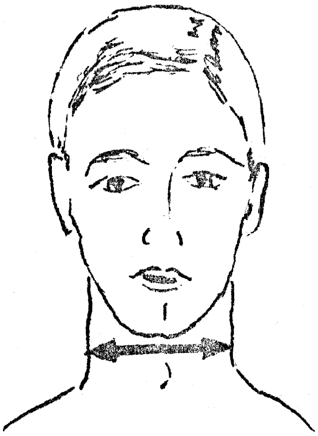
14. BIACROMIAL BREADTH - The subject maintains an erect posture, with arms hanging at side and resting on upper legs, looking straight ahead. Facing the subject, the horizontal distance is measured with an anthropometer between the superior lateral border of the acromial processes of the left and right scapula.



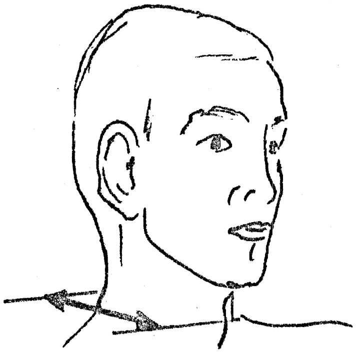
15. SHOULDER BREADTH (bideltoid) - The subject sits erect, his upper arms hanging at his sides, and his forearms extended horizontally. Using the anthropometer, the distance is measured horizontally across the deltoid muscles.



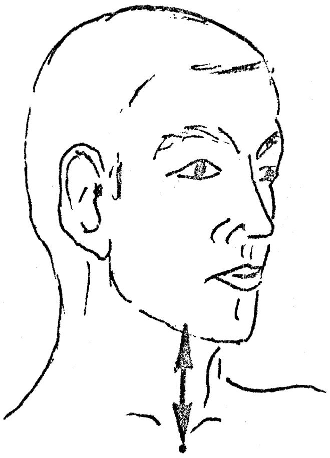
16. LATERAL NECK BREADTH (mid) - The subject is seated in erect posture. Diameter is measured with anthropometer at mid-point of neck from left to right side.



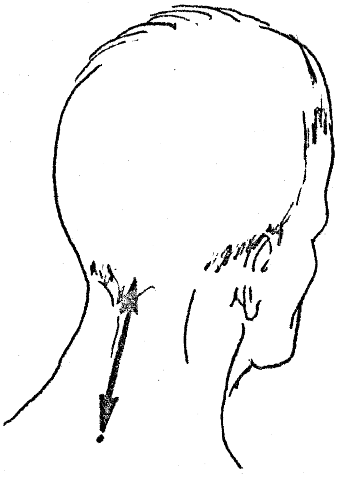
17. ANTERIOR-POSTERIOR NECK BREADTH (mid) - The subject is seated in erect posture. Diameter is measured with anthropometer at mid-point of neck from front to rear.



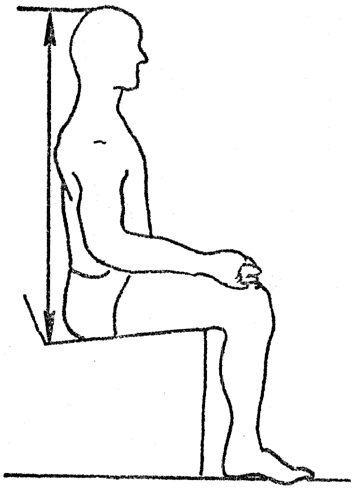
18. ANTERIOR NECK LENGTH - The subject is seated in erect posture. Surface distance from suprasternale to the juncture of the chin and neck is measured with sliding calipers.



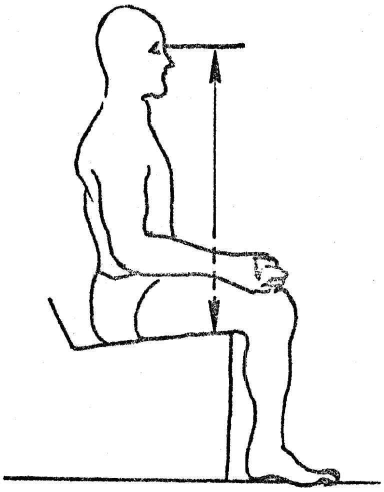
19. POSTERIOR NECK LENGTH - The subject is seated in erect posture. Surface distance is measured from cervicale to the lowest point of occipital region (at or below inion) with sliding calipers.



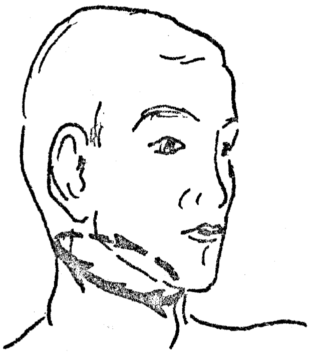
C. SUBJECT IN SEATED (RELAXED) POSITION



20. SITTING HEIGHT (slumped) - The seated subject is allowed to assume normal slumped posture, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The vertical distance is measured from the sitting surface to top of head (vertex).

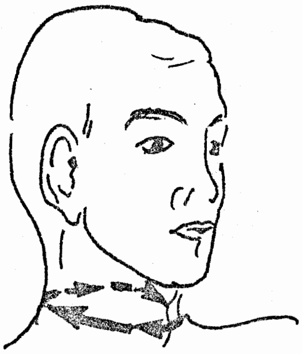


21. LEFT SITTING EYE HEIGHT (slumped) - The seated subject is allowed to assume normal slumped sitting posture, with arms resting on upper legs, feet together and lower legs at right angles to upper legs. The vertical distance is measured from the sitting surface to the inner corner (internal canthus) of the left eye.

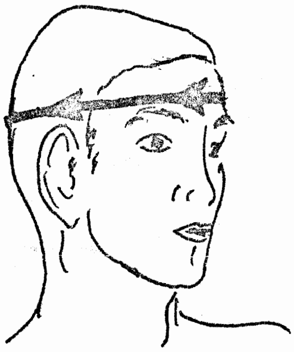


22. SUPERIOR NECK CIRCUMFERENCE - The subject is seated in erect posture. The horizontal circumference from juncture of chin and neck to lowest point of occipital region (at or below inion) is measured with tape.

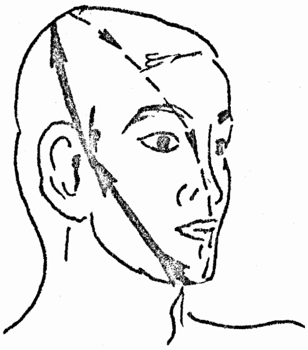
23. <u>INFERIOR NECK CIRCUMFERENCE</u> - The subject is seated in erect posture. The horizontal circumference from lowest anterior neck level to cervicale on dorsal aspect is measured with tape.



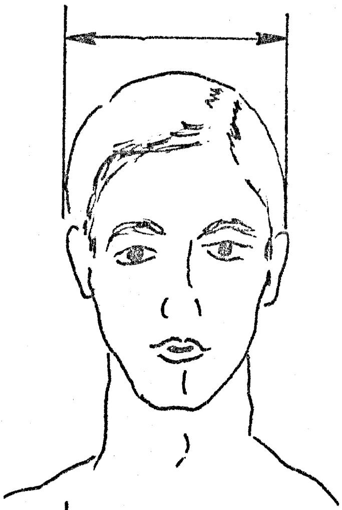
24. <u>HEAD CIRCUMFERENCE</u> - The subject is seated in erect posture. The maximum circumference of the head is measured with a steel tape passing over the brow ridges and held perpendicular to the mid-sagittal plane (but not necessarily horizontally).



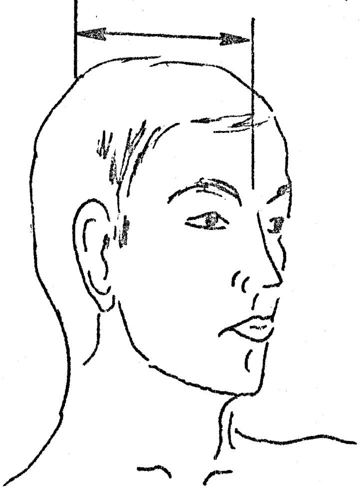
25. <u>HEAD ELLIPSE CIRCUMFERENCE (BENNETT)</u>
The subject is seated in erect posture. The head circumference from menton (chin) to point on back of head at maximum distance is measured with a steel tape.



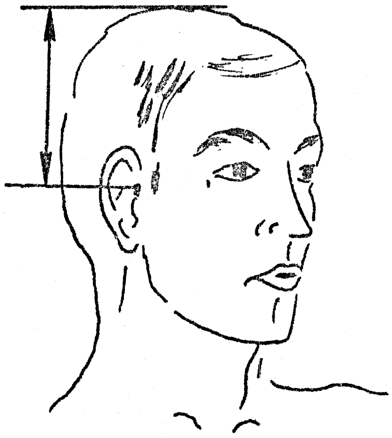
26. HEAD BREADTH - The subject is seated in an erect posture. The maximum breadth of the head is measured with the spreading calipers perpendicular to the mid-saggital plane of the head.



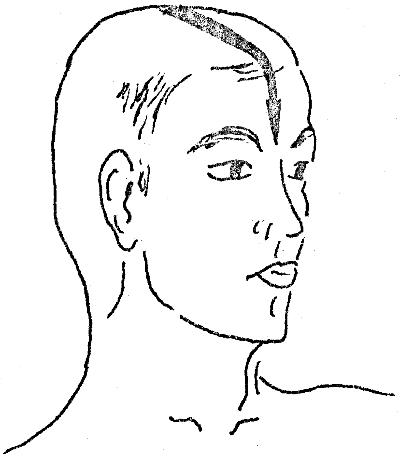
27. HEAD LENGTH - The subject is seated in an erect posture. The maximum length of the head is measured from glabella to the occipital region in the mid-saggital plane of the head with the spreading calipers.



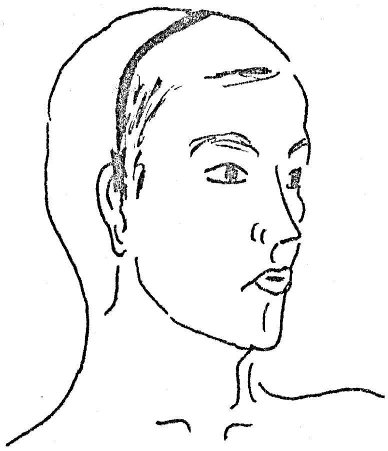
28. HEAD HEIGHT - The subject is seated in an erect posture. The vertical distance is measured from tragion to the highest point of the skull with the anthropometer.



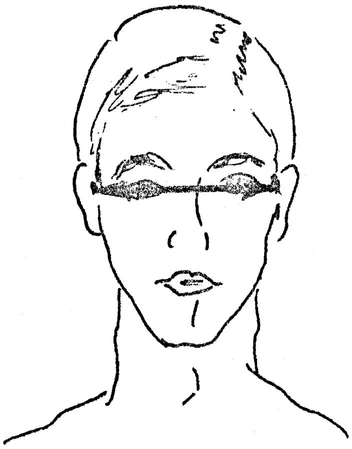
29. SAGITTAL ARC - The subject is seated in an erect posture. The arc measured with the tape in the mid-sagittal plane of the head, from glabella to the lowest point on the base of the skull that can be felt by a firm touch amid the nuchal musculature (at inion or below).



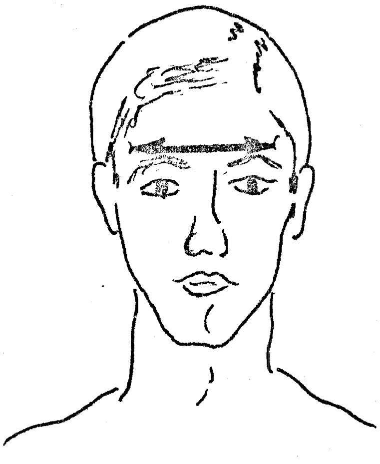
30. CORONAL ARC - The subject is seated in an erect posture looking straight ahead. The arc is measured from right to left tragion over the top of the skull with the steel tape in a vertical plane.



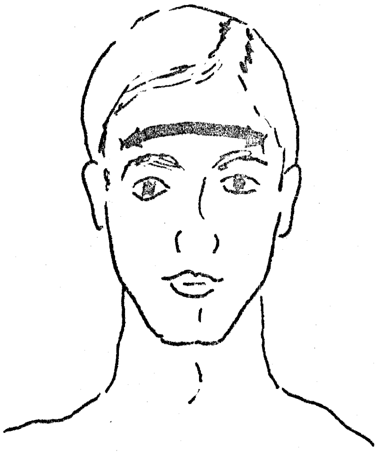
31. BITRAGION DIAMETER - The subject is seated in an erect posture. The diameter between right and left tragion is measured with light contact and holding the spreading caliper in a horizontal plane.



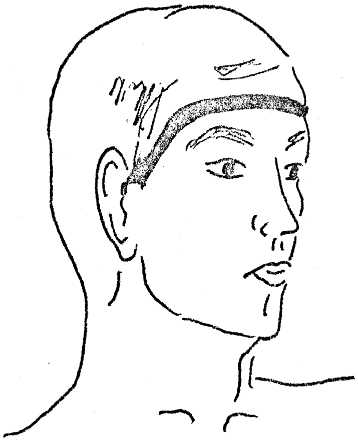
32. MINIMUM FRONTAL DIAMETER - The subject is seated in an erect posture. The minimum diameter is measured with the spreading caliper across the temporal crests at their point of greatest indentation. Care must be taken that the measurement is made on the crests and not over the temporal muscles.



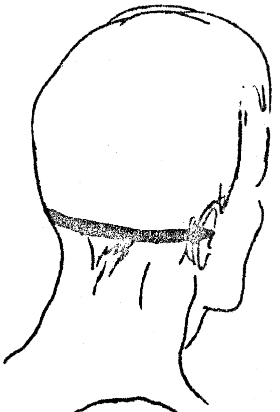
33. MINIMUM-FRONTAL ARC - The subject is seated in an erect posture. The arc is measured across the forehead, above the brow ridges, with the tape passing across the crests of the temporal muscles at their points of greatest indentation toward the mid-saggital plane of the head.



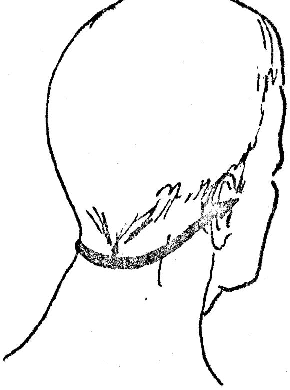
34. BITRAGION-MINIMUM FRONTAL ARC - The subject is seated in an erect posture. The arc is measured from right to left tragion with a steel tape over the region of the minimum frontal arc.



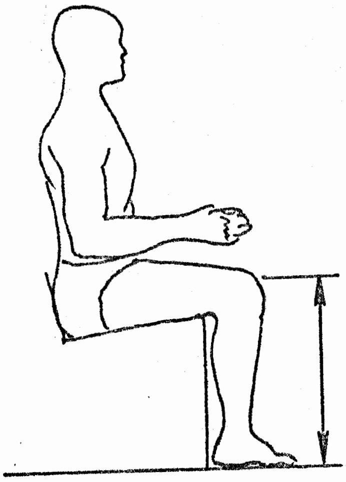
35. BITRAGION-INION ARC - The subject is seated in an erect posture. The arc is measured from right to left tragion with the steel tape passing over inion.

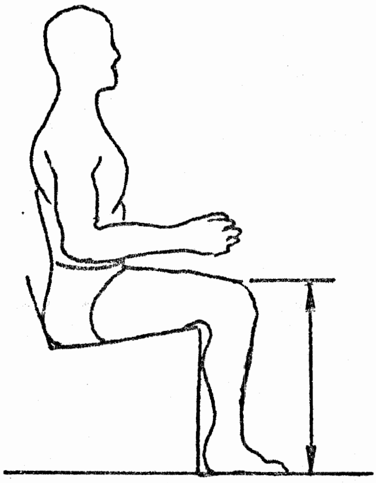


36. POSTERIOR ARC - The subject is seated in an erect posture. The arc is measured from right to left tragion with the steel tape passing over the lowest point of the skull where the nuchal musculature attaches.



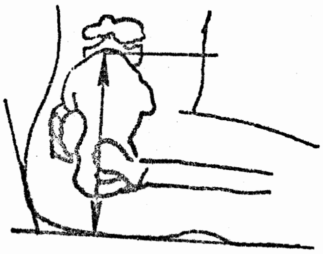
37. SITTING KNEE-HEIGHT - The subject sits erect, arms resting on upper legs, and lower legs together at a 90° angle to upper legs. The vertical distance is measured with an anthropometer from the floor to the superior point of the patella.



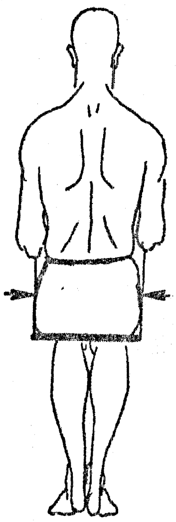


38. SITTING KNEE-HEIGHT (maximal clearance) - The subject sits erect, arms resting on upper legs, and lower legs together and at a 90° angle to upper legs. The vertical distance is measured with an anthropometer from the floor to the highest point of the right knee. This point will be superior to the preceding measurement and provides maximum knee clearance distance.

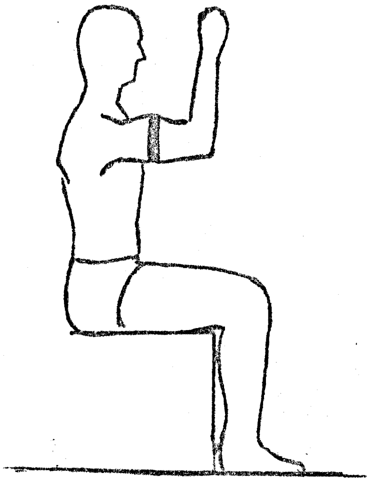
39. SEATED HEIGHT OF RIGHT ANTERIOR ILIAC SPINE - The subject is seated in an erect posture. The vertical distance is measured with an anthropometer from the sitting surface to the anterior superior iliac spine of the right il um.



40. SEATED HIP BREADTH - The subject is seated in an erect posture. The horizontal distance is measured with an anthropometer across the maximum breadth of the hips, applying only light contact pressure. Subject is lightly clothed.

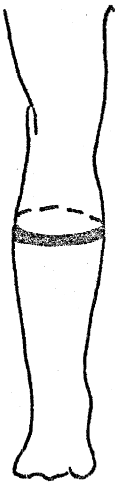


41. BICEPS FLEXED CIRCUMFERENCE (right) - The seated subject maintains an erect posture with his arms hanging freely at the side. The subject flexes his right arm at least 90°, makes a fist while holding his upper arm horizontal to the floor, and flexes his biceps to the maximum. The measurement is made with a steel tape at the maximum circumference of the upper right arm.

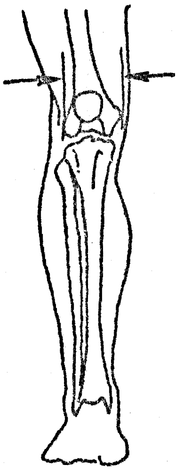


D. STANDING POSITION

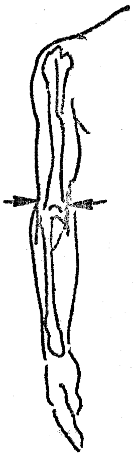
42. CALF CIRCUMFERENCE - The standing subject maintains an erect posture with his weight equally distributed and legs slightly apart. The maximum circumference of the right calf is measured with a steel tape.



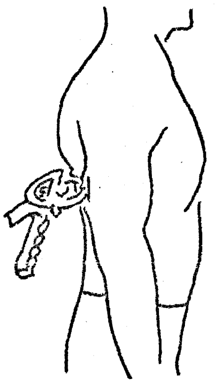
43. FEMORAL BIEPICONDYLAR DIAMETER - The subject maintains an erect posture with feet spread slightly apart. Using an anthropometer the horizontal distance is measured between the medial and lateral epicondyles of the right femur.



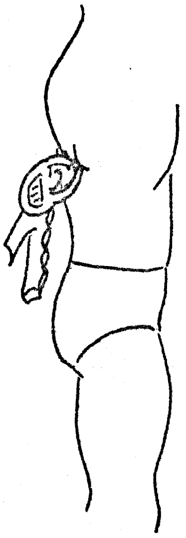
44. HUMERUS BIEPICONDYLAR DIAMETER - The distance between the lateral and medial epicondyles of the right humerus is measured with a sliding caliper with the arm hanging freely at the side.



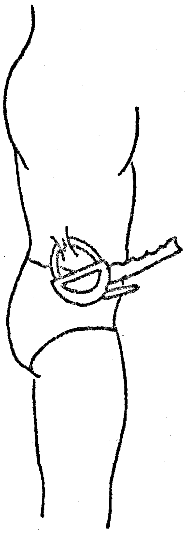
45. RIGHT TRICEPS SKINFOLD - The point of measurement is located on the dorsal aspect of the right arm of the standing subject, midway between the acromion and tip of the elbow (olecranon) when the forearm is flexed at 90°. The subject's arm is then extended to hang freely, the skinfold is lifted parallel to the long axis of the arm by firmly grasping a fold between the thumb and forefinger about one centimeter from the point to which the Lange caliper is applied. A reading is made within three seconds after application of the caliper, and the average is taken of several readings.



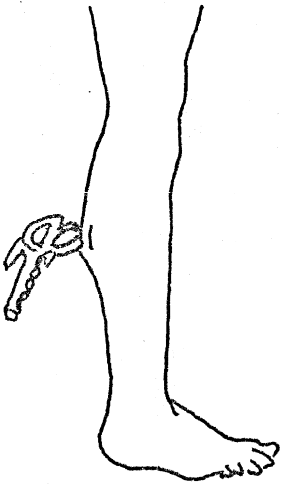
46. RIGHT SUBSCAPULAR SKINFOLD - This site is located on the standing subject below the inferior angle of the right scapula. The skinfold is lifted in a direction parallel to the ribs, with the skinfold angled upward medially and downward laterally at about 45° from the horizontal. A reading is made with the Lange caliper within three seconds after application of the caliper, and the average is taken of several readings.



47. RIGHT SUPRAILIAC SKINFOLD - This site is located on the standing subject superior to the lateral aspect of the iliac crest on the right side. The skinfold is lifted parallel to the pelvis and angled slightly upward medially. A reading is made with the Lange caliper within three seconds after application of the caliper, and the average is taken of several readings.



48. RIGHT POSTERIOR MID-CALF - This site is located on the standing subject half-way between the popliteal and lateral malleolus of the dorsal aspect of the lower leg, midway between the ankle and knee. The skinfold is lifted parallel to the leg, and a tight skin adhesion is most commonly found here. A reading is made with the Lange caliper within three seconds after application of the caliper, and the average is taken of several readings.



4. Radiography

During the quarter, thirty additional subjects completed the X-ray portion of the study, for a total of 43 subjects completed to date. Three subjects were clinically disqualified from further participation in the study after a review of the X-rays. Useful range of motion data is available from all of the 40 approved sets of X-rays. However, due to the lack of appropriate markers on the films, six of the early X-rays will not provide information on dimensions of the bony structures and/or the angle between the nasion-tragion line and horizontal.

It was noted in the Second Quarterly Report that a reference rod attached to a headpiece was being exposed in each X-ray. The rod is intended to define the angle of the head as the subject moves through his range of motion. More than 30 subjects were tested in which the rod was exposed in all views. Typical of the results are the X-rays from subject MAZ-08. Figure 3 is the neutral position view with the subject on the hard seat. The rod, body landmark indicators, and verticality indicator are all shown, as are the reference lines used to establish angles for the data analysis phase. During data analysis, head position relative to horizontal was established by using the rod and the verticality indicator. As a check, head angle with respect to horizontal was also established by using a line drawn from the occipital protuberance tangent to the base of the skull. The angle difference between the reference rod line and the skull line was also checked. Figure 4 illustrates the position of the head at maximum voluntary flexion. Again, the reference rod and skull points were both used to establish the number of degrees of flexion achieved, and the angle between the rod and skull lines was checked. The same subject in the maximum voluntary

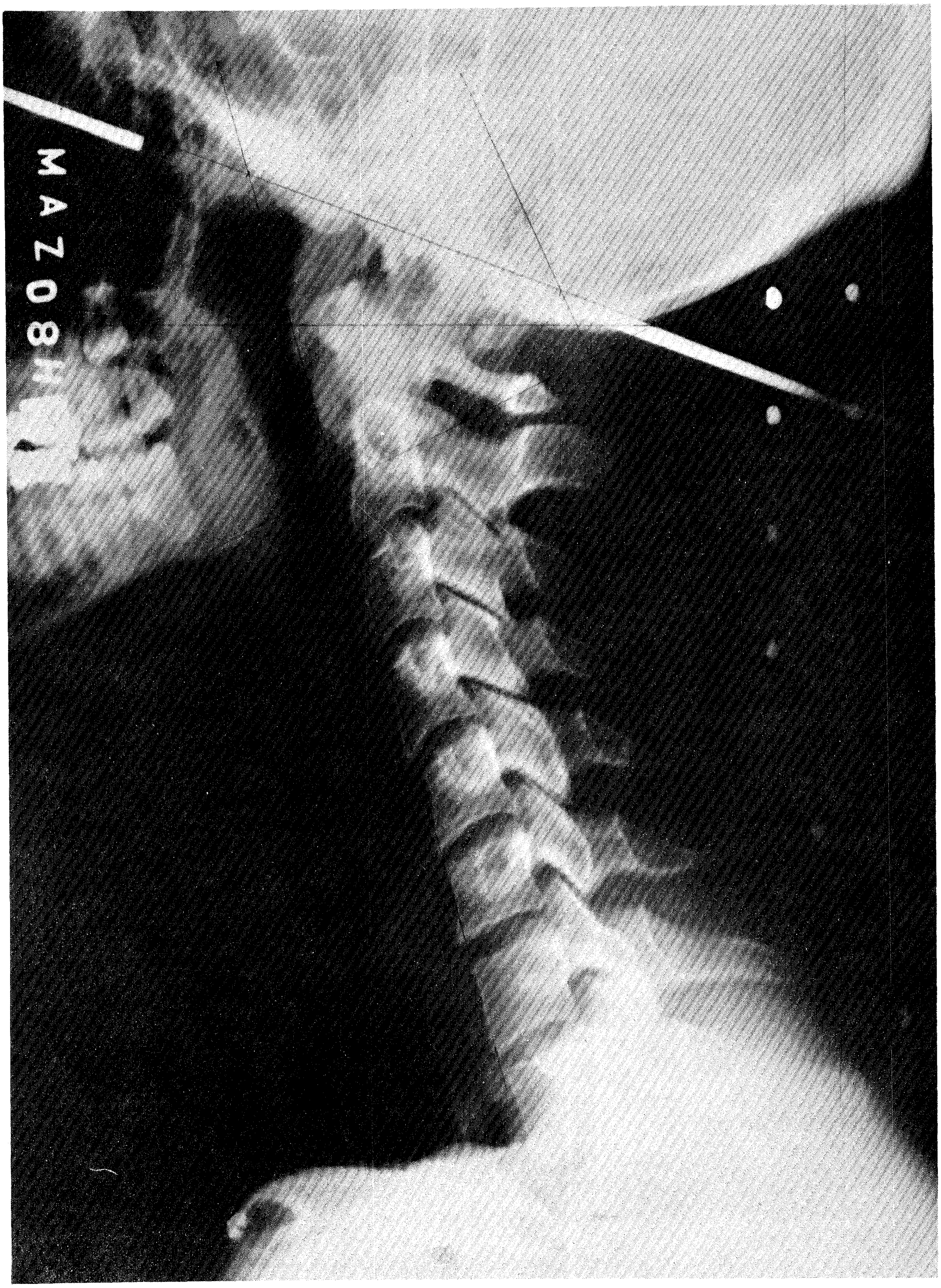


Figure 3. Lateral X-ray of Subject in Neutral Position (Hard Seat). Note Lead Markers at C-5 and C-7, Rod Positioned on Nasion-tragion Line, and Verticality Marker. Head Position can be Established by the Angle Between the Rod and Horizontal and also by the Angle Between Horizontal and a Line Drawn from the Occipital Protuberance Tangent to the Base of the Skull.

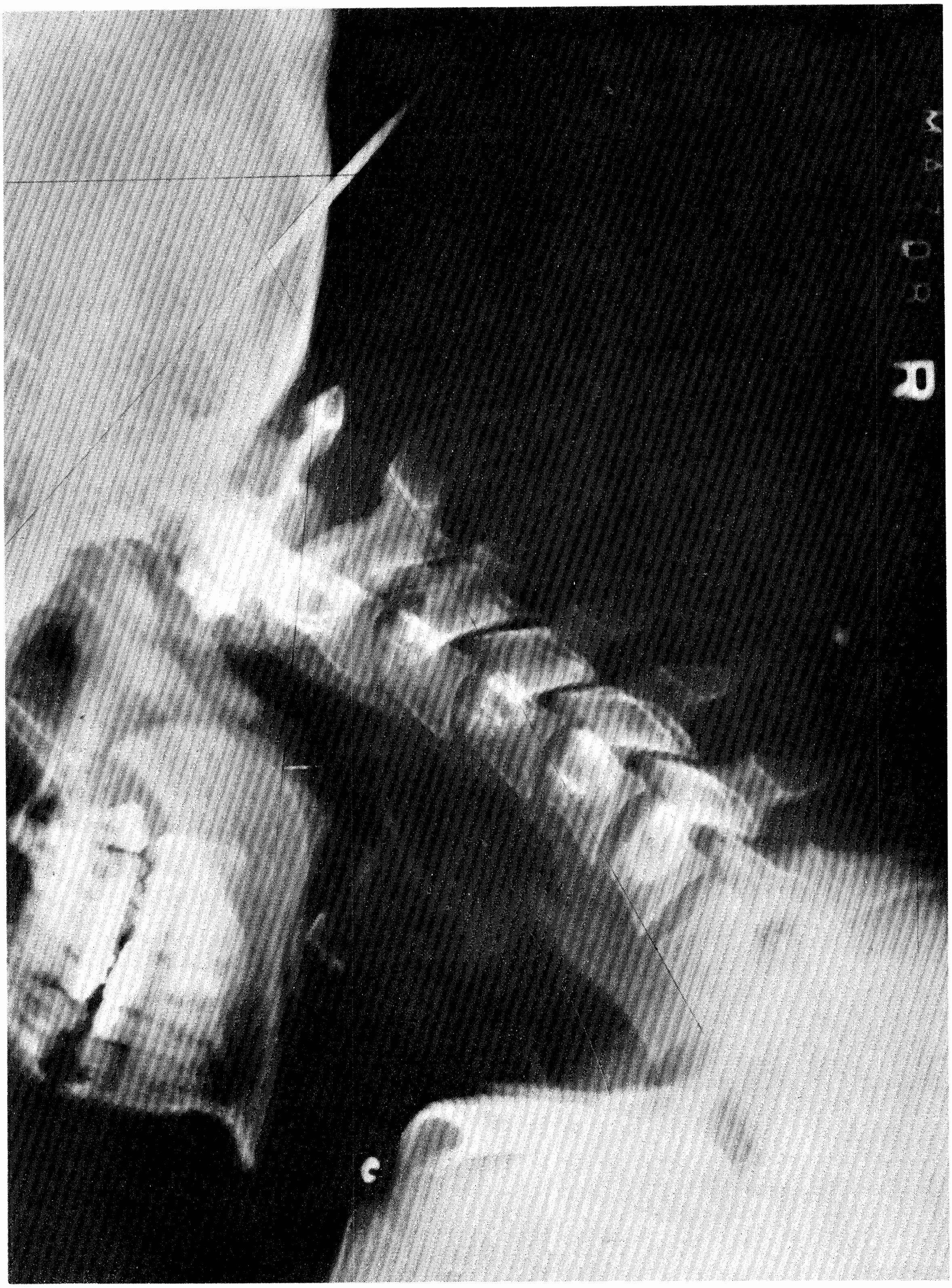


Figure 4. Lateral X-ray of Subject in Flexion. Note the Movement of the Rod to Indicate Amount of Flexion, and the Positioning of the Verticality Marker in the Mid-sagittal Plane to give a Magnification Correction Factor.

extension position is shown in Figure 5. Head position with respect to horizontal was again established by two methods.

Typically, the angle between the rod and skull reference lines remained unchanged when the subject moved from neutral to flexion position. However, the angle often did change as the subject assumed the extended position, indicating that the reference rod was moving with respect to the skull. Apparently, in many subjects, skin excursion at the back of the skull during extension could cause the headpiece to move in relation to the skull. A statistical analysis (reported in detail in Section III) revealed a significant amount of movement. As a consequence, a procedural change is being made. In the future, the headpiece and rod will be used only in the neutral view to establish the subject's absolute head orientation to horizontal. This orientation will still be defined as the angle between the reference rod (which is aligned with nagion and tragion markers) and the horizontal. The reference line established by the skull landmarks has proved to be a reliable basis for measurement and will be used to establish subject range of motion.

Also during this quarter, sufficient X-rays were completed to perform a statistical comparison of the neutral position assumed by subjects in the soft automobile seat vs. that on the hard seat of similar design. The results of the analysis indicated not enough difference to be statistically significant. We were able to conclude that the "soft seat" X-ray was not necessary and that the positions achieved by a subject in the laboratory hard seat could be correlated with those in a production auto seat with similar cushion and back angles.

Coincidentally, our radiologist consultant, Dr. Baum, has encoun-

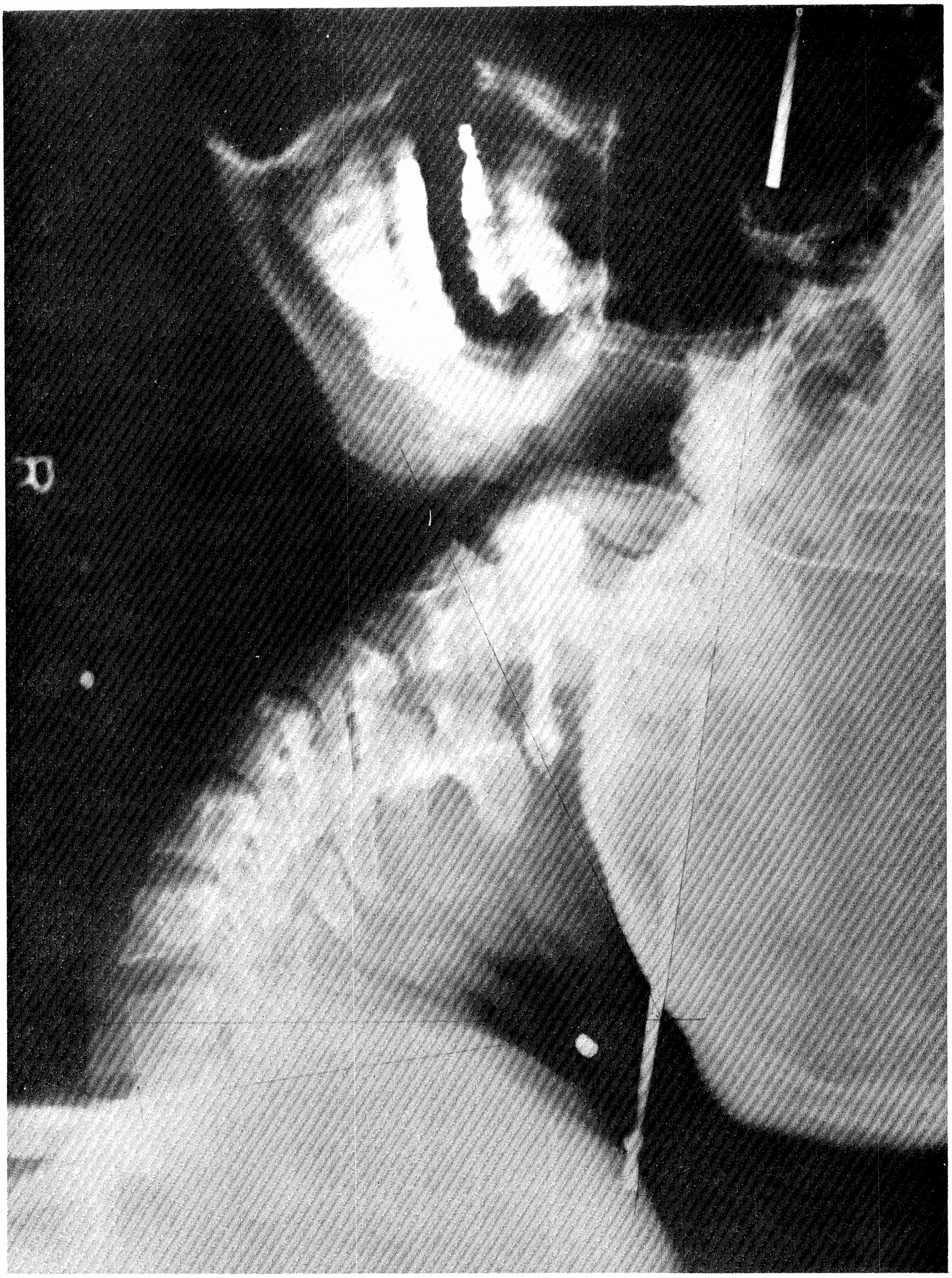


Figure 5. Lateral X-ray of Subject in Extension. Note Position of Rod and Amount of Skin Compression as Indicated by C-5 and C7 Markers. It is this Skin Excursion Which is Thought to Cause the Headpiece, and Hence the Rod, to Shift Occasionally in Relation to the Skull.

tered difficulty in evaluating the X-rays of certain subjects because of obstruction of the seventh cervical vertebra by the subject's shoulders. A clearer view of C-7, and often a good exposure of T-1, can be achieved if the subject's shoulders are forced down.

In light of the results of the hard seat vs. soft seat analysis, another procedural change is being instituted. For the remainder of the subjects, the following X-rays will be taken, each with the subject seated on the hard seat: a) for clinical evaluation, one anterior-posterior view and one lateral view with the shoulder dropped; b) for both clinical evaluation and project data analysis, lateral views in relaxed neutral, maximum voluntary flexion and maximum voluntary extension positions.

5. Photogrammetry

During this quarter, photogrammetry was taken with 30 subjects. Two sets of photographs are not suitable for analysis because of clinical rejection of the corresponding X-rays.

Procedures used in the photogrammetry phase of the project have not materially changed from those reported earlier. The subject repeats the three basic positions - neutral, flexion and extension - in sequence and repeats each sequence three times. Simultaneous photographs of each position are taken with cameras beside and in front of the subject.

Sufficient data were obtained during the quarter to allow a repeatability analysis of the positions. The results are reported in Section III, and they showed a high degree of repeatability. In the neutral view, where the subject is allowed to assume his own body position, then is asked to look at the camera in front, the mean head angle from 19 subjects varied over a range of only one-half degree for the three replications of the position.

The photographic data were analyzed for range of motion in a manner similar to that used for the X-ray data. Two different reference axes were used: the reference rod aligned with nasion and tragion, and two surface landmarks (in this case, the bottom of the tragus of the right ear and the right nostril). Statistical analysis supported the conclusions reached from X-ray analysis. The rod was found to move in relation to the skull for a large number of subjects. This result led to a procedural change in photogrammetry methods. Remaining subjects will not wear the headpiece for photogrammetry. Instead, photographic bullseyes will be placed directly on nasion and tragion landmarks and these will be used to establish both absolute head position and ranges of motion. We will continue to take three replicationsof each position.

6. Reaction Time Measurements

The most serious technical problems encountered during the quarter were concerned with the reaction time portion of the project. The problem was two-fold: it was necessary to increase g-loading to the head to nearer the design goal of 1.0 g (so that a stretch reflex would be assured), while at the same time reducing the undesirable amount of vibration that was transmitted to the head through the weight releasing system. After some considerable experimentation with several approaches, a satisfactory solution seems to have been found without the necessity of major redesign of the entire system. It was not necessary to change either the headpiece or the weight-release and pulley system. Instead, the forces are applied through a self-damping cord - a 25-pound-test woven nylon fishing line. Using this slightly elastic line, the amount of vibration was reduced to an acceptable level for accurate computerized analysis. Forces are still applied by the one-pound weight developed earlier, but the weight is now dropped several inches to achieve adequate loading. A two-ounce pre-tensioning weight, adjusted on the cord below the weight, takes the slack out of the nylon cord as it passes from the headpiece over the pulley. When the one-pound weight is released, it drops 4 to 6 inches, striking a foam pad and the pretensioning weight and applying a force to the head. The current method of loading is illustrated in Figure 6a, and the effect of the new method on the acceleration profile is shown in Figure 6b.

Since the pre-tensioning weight takes all of the slack out of the cord, the displacement transducer attached to the pulley has now become a highly accurate measure of head movement. Repeated tests have shown that the pulley starts to turn at exactly the same moment as head acceleration begins. Displacement, therefore, may be measured directly, without need for either double integration of acceleration or correction factors to account for slack.

Other important equipment modifications were made during the quarter. Most important was the activation of Channel 7, the control channel for computerized data analysis. This channel provides a constant dc level signal which is changed as a subject progresses through the reaction time and strength tests. Also provided is a Data Strobe pulse which signals the computer that a test event is occurring. A detailed description of control channel functions and their effect on computer analysis is contained in the description of computerized data analysis.

A large number of monitoring and control functions are necessary to insure that reaction time and strength measurement data are being recorded properly and in a manner compatible with computerized analysis. During the quarter, a consolidated monitoring system and console was con-

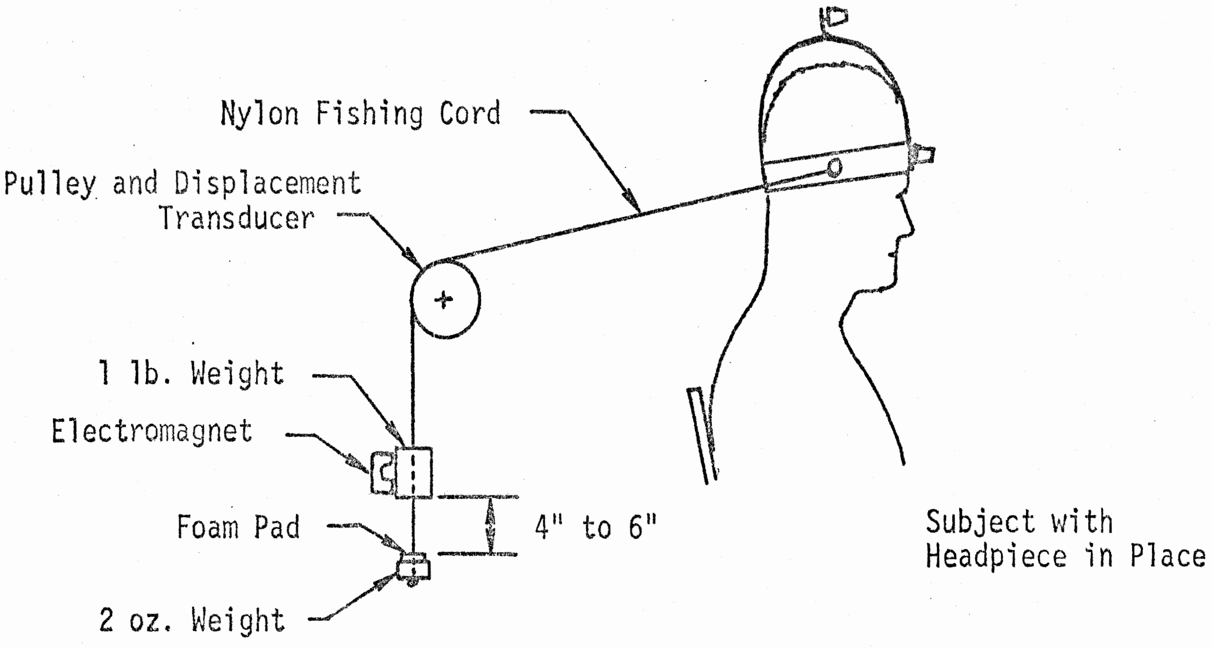


Figure 6a. Method of Applying Force for Reaction Time Experiment

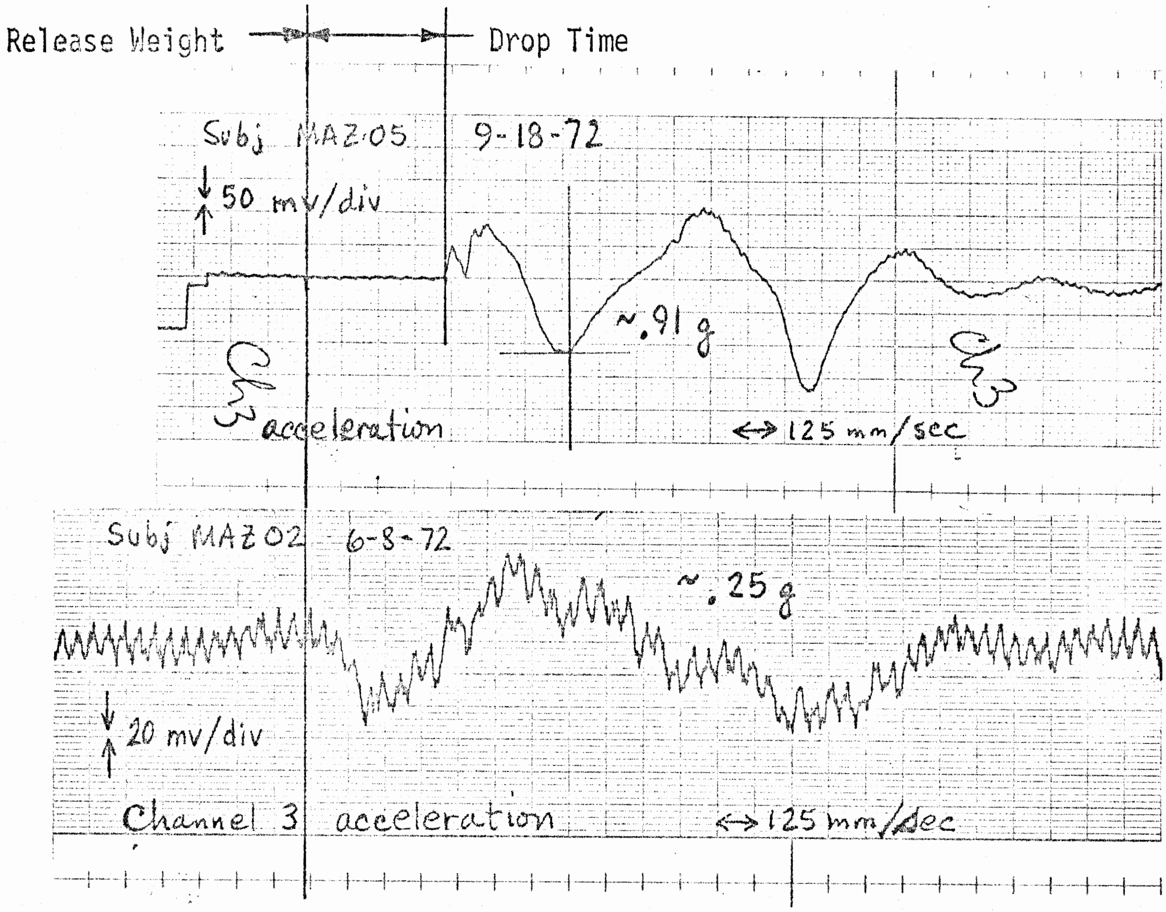


Figure 6b. Comparison of Acceleration Data

Figure 6. Changes to Reaction Time Experiment to Improve Force Loading and Reduce Vibration

structed which placed all controls for channel amplifiers, control channel functions, timing, and tape recording on a single console panel. This consolidation of functions is increasing the efficiency of the data-taking procedures and, at the same time, reducing the chance for errors.

The technical problems and modifications were resolved in time to allow six subjects to be measured for reaction time and strength during the latter part of the quarter. The data analysis for those subjects is contained in Section III, and it reflects considerable improvement in the reliability of our data-gathering procedures and techniques. A problem still remains, however, in the placement of electrodes to achieve reliable EMG measures. Several corrective approaches are being considered, including using an electrode probe on the surface of the skin to locate the point of strongest signal before the regular surface electrode is fixed in place.

The data analyzed to date verify the need for three replications of each reaction time test (flexion and extension), since repeatability of reaction times for a given subject has not yet been adequately demonstrated, and since we are still experiencing a rather high percentage of data loss.

7. Strength Measurements

Neck flexor and extensor strength was measured for six subjects during the quarter, and the test results are detailed in Section III. The procedures run very smoothly, with the subject first "calibrating" his neck muscle strength by applying a known amount of force, then pulling with a maximum voluntary effort for three trials. The procedure is repeated for both flexor and extensor muscles. Test-retest checks of several subjects did reveal a "learning" trend. In certain cases, the subject either overcame his initial reservations about pulling hard or became more motivated, because force applied increased with each trial. It is desirable to reduce this effect, so we will now incorporate one non-recorded maximum exertion in each direction to allow the subject to get a "feel" for the test. We will continue to record three trials for each test.

8. Computerized Data Analysis

The Hewlett-Packard 2115 mini-computer has now been programmed to handle the initial analysis of tape-recorded data in a completely automatic fashion. The tape recorder is connected to the computer through an analog-to-digital converter. To analyze data, all the operator need do is load the program, start the tape recorder, and occasionally answer prompting questions at the Teletype. The computer program requirements have been coordinated with data-taking procedures so that data from tests of many subjects may be analyzed sequentially without any need to stop and restart either the tape recorder or the computer program. In addition, many desirable editing, deletion, error, prompting, and real time data summary features have been built into the program.

The following is a somewhat detailed description of the computer program and its salient features. It was prepared by Robert J. Wolters, the programmer who designed and wrote the program.

SOFTWARE ORGANIZATION

It was desirable for our data acquisition package to be modular for ease of implementation, efficient in space due to a limitation of 8000 words of computer memory, and efficient in speed due to real time processing requirements. In addition, it must have certain productive capabilities. The hardware elements used in data processing are indicated in Figure 7. A primary function is that of Analog to Digital (A-D) converter control and sampling. There may be up to six simultaneous tracks of data on tape and so to allow "one pass" analysis, the software must be able to control independent (possibly simultaneous) sample processes on the six data channels with possibly different start times, sample rates, and block sizes for each channel. The software must contain label and parameter input, data logging, and real time print out capabilities (to adjust analysis parameters in real time). And perhaps more important than even the various data reduction algorithms are error detecting and/or correcting features to ensure reliable operation of the system. The software system described herein was designed to meet all of these objectives.

An overview of the software system is illustrated in Figure 8. The heart of the system is the TICS (Time Interupt Control System) multiprogramming monitor and some associated background modules which constitute the

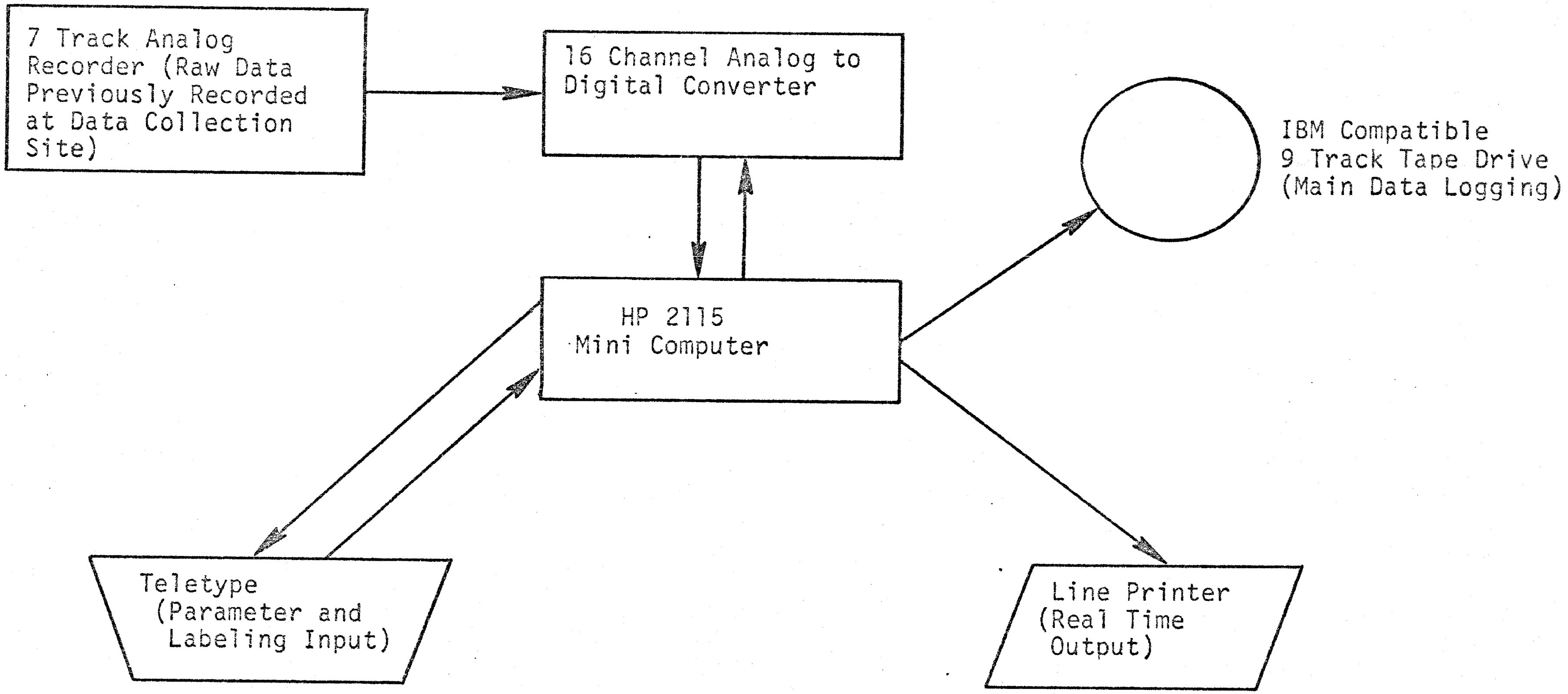


Figure 7. Computer Hardware Configuration.

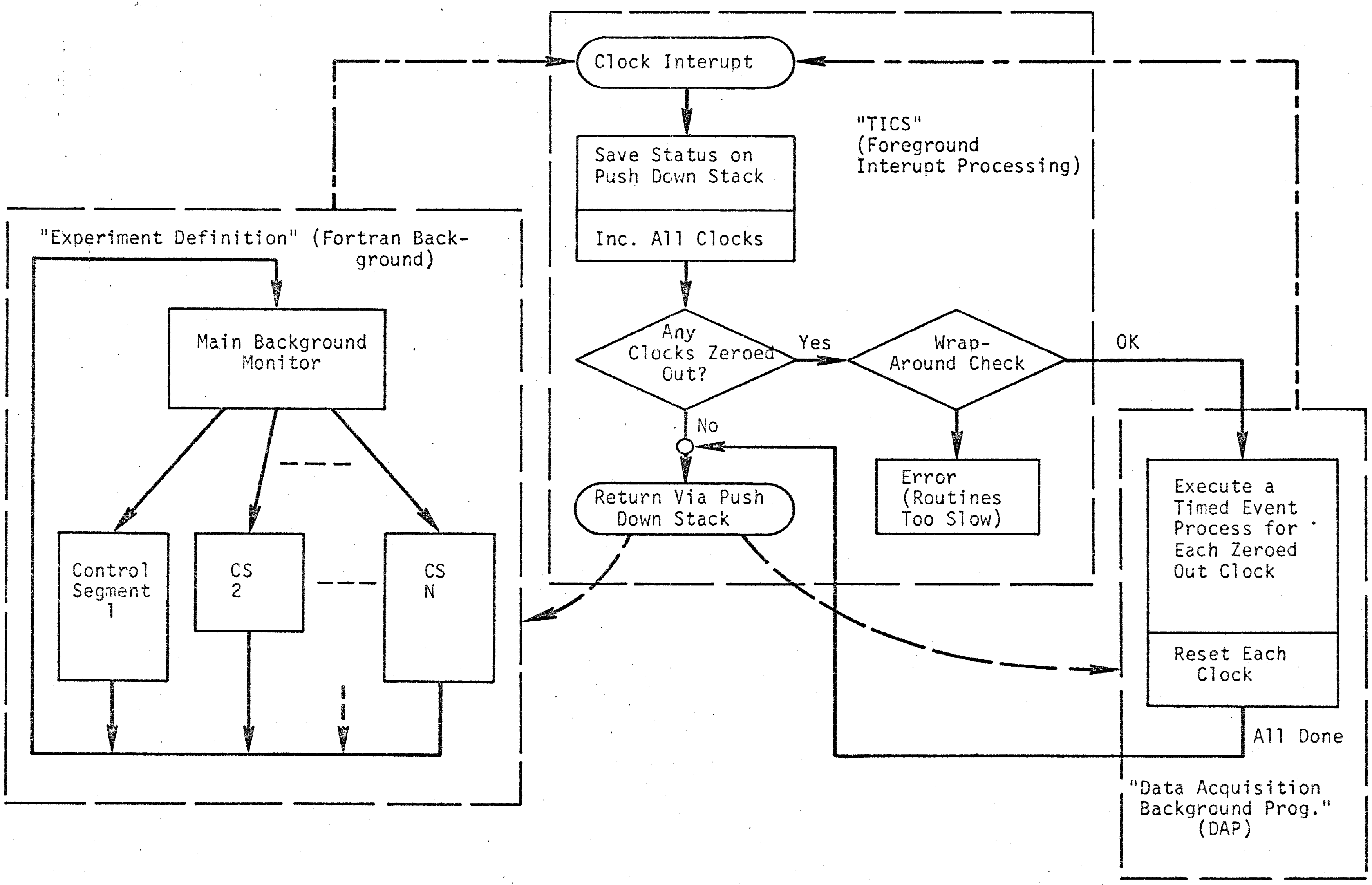


Figure 8. Foreground/Background Processing.

Data Acquisition Package (DAP). The overall operation of the data analysis is controlled by the Fortran background programming.

TICS

The HP2115A computer contains a Time Base Generator (TBG) which can be set to interrupt every millisecond. TICS, as sole controller of all timed events, services each of these interupts. An important feature of TICS is the Task Execution Queue (Figure 9). Each Task Control Block (TCB) on this queue has a clock, program address, status word, clock rate value, and an optional parameter block used by various routines. On each TBG interupt, TICS scans through this queue and increments every TCB clock (all clocks count from negative to zero). If no clocks are zeroed out, TICS simply returns to the background programming, otherwise it checks a global A-D sample request flag. If this flag is non-zero, TICS calls for a high speed (28 μs/channel) sequential (psuedo simultaneous) sample of all A-D channels 0 to 6. The 7 data values are stored in a temporary local buffer. TICS will then initiate an execute scan of the queue (if not already in progress).

During the execute scan, for each TCB, if the TCB's clock is zero or positive TICS will execute a service program for it. The address of this execution program is the one defined in the TCB. Each of these programs is a module of DAP and typically controls a timer, A-D sample process, control channel monitoring, etc.

When a subroutine returns to TICS, it can request to be removed from the execute queue (otherwise left on) by

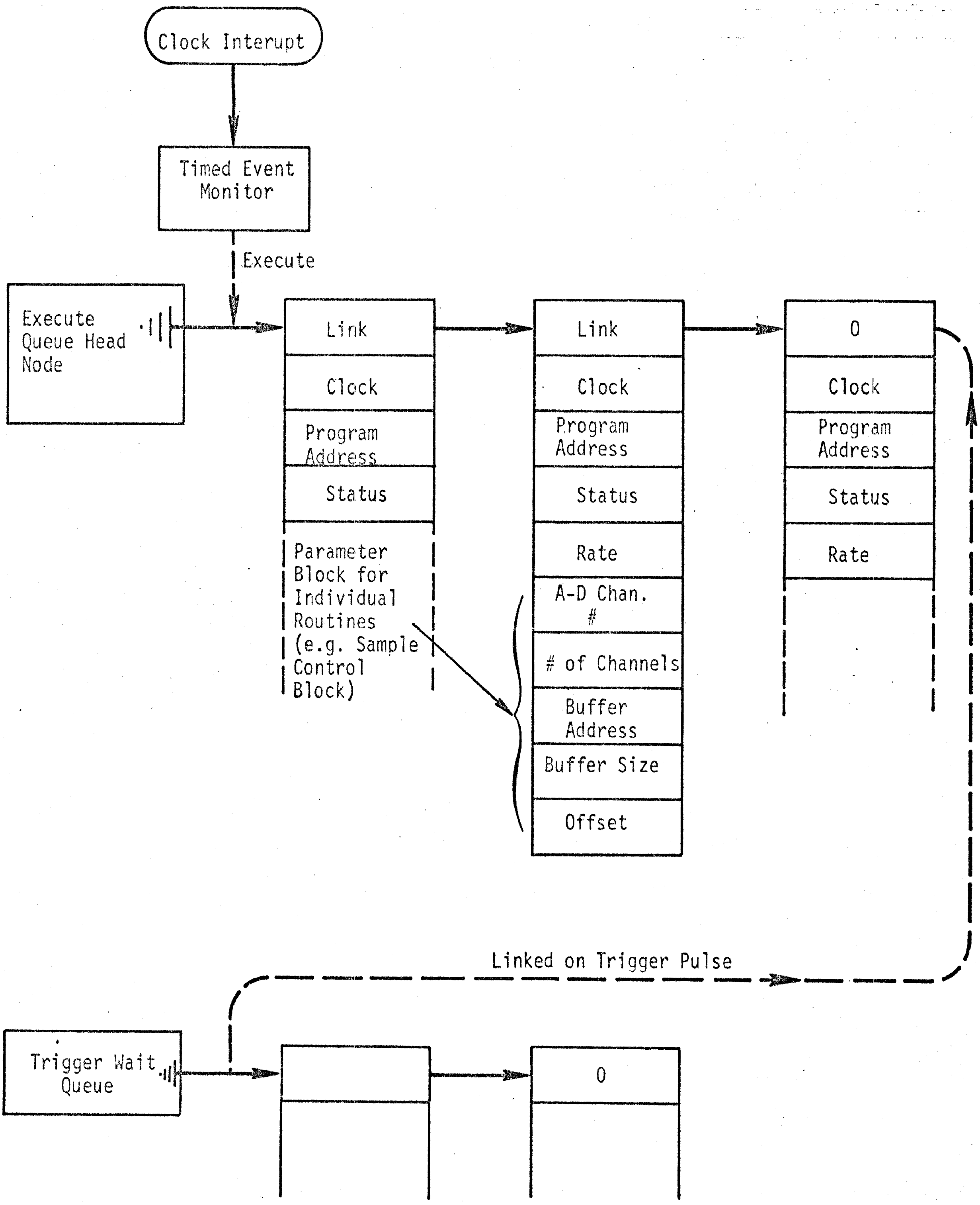


Figure 9. Execution Task Queuing.

setting a bit in its TCB status word. For example, the A-D sample routine will request this when its sample buffer is full. When TICS deletes a TCB from the execute queue, it sets a completion bit in the TCB status word. This status word (and in fact the entire TCB) is available to the background Fortran program for monitoring. This allows a Fortran program to initiate a task and wait for its completion. When all TCB's in the queue have been processed, TICS returns to the background program.

A pushdown stack is used to save Background Status upon interupt entry to TICS and to restore that status when TICS returns. This allows interupt processing to interlace with the execution of the DAP modules. Without this feature, all the task control routines (DAP) would have to execute in a single millisecond on each interupt cycle (a near impossibility with execution queues of any length and duration). However, with this feature, the total execution time of a cycle is determined only by the fastest clock on the queue. For example, if the fastest clock zeroes out every 3 ms., then there will be 3 ms. minimum in which to execute the entire queue, which is a 200% increase over 1 ms.

The main thing to observe from the above discussion is that TICS allows several different time independent tasks to run concurrently.

AUTOMATIC DATA ANALYSIS - The Control Channel

In the past, typical computer analyses of recorded analog data have required a human operator to manually direct the program through the various data collection phases. In order to determine what is happening on the tape, the operator will listen for voice track recorded queues and/or watch an oscilloscope tracing of the data. The operator manually tells the computer when to start sampling what and how by typing in simple commands on a teletype console. He must sort out bad data from good and apply corrective procedures when necessary (some times very often). The large amount of data to be analyzed for this project prohibited such a manual approach. Consequently, an automated control function was devised to allow less time consuming and more reliable methods of initial data analysis.

The hardware/software system used in this project enables the total automatic computer analysis of the recorded data. A human operator is required only in a supervisory capability and to enter occasional computer requested parameters and labels. In order to adequately control the data collection without human intervention, a control channel must be encoded on the recorded data tape. This signal consists of various DC levels which identify the different phases of the experiment and certain timing conditions. For example, using the 11 equally spaced DC levels from -1 volt to +1 volt, we can assign -1 volt as a data strobe, -.8 v during tape calibration procedures, -.6 volts during reaction time testing, etc.

In order for the software to be able to reliably and efficiently detect the control channel information, certain anomalies such as tape recorder start/stop transient noise pulses and control level sequencing errors must be accounted for. Many of these errors are either prevented or "tagged" by special formatting and control electronics that buffer the operator from the real tape transport controls and recorded control level signals (Figure 10).

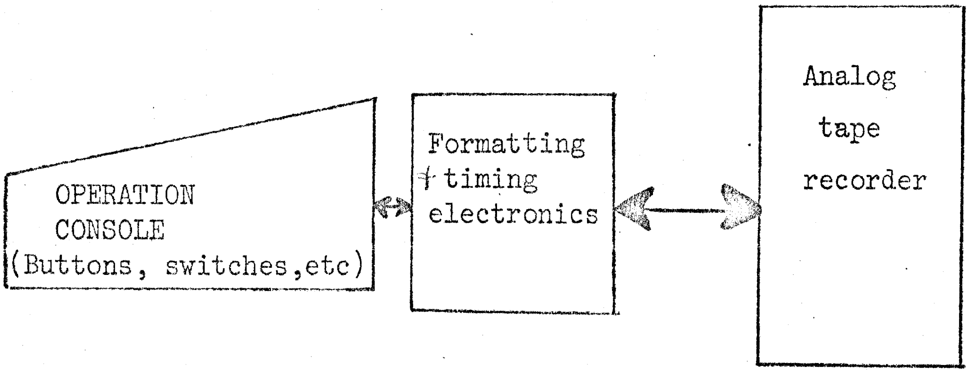
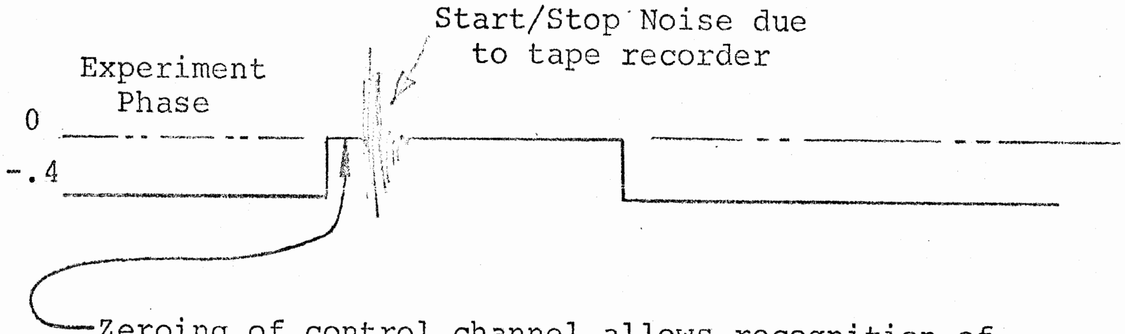


FIG 10 Buffering of tape transport controls.

Thus the operator through remote buttons and switches requests certain things to be done by the hardware. Ideally, the complete sequencing and timing of the experiment should be controlled by hardware (or computer), but this total system automation has not yet been achieved in this project. In any case, we may still expect certain types of errors to occur during data collection. Skin electrodes may loosen, switches may be incorrectly set, the experiment controller may forget to press a data strobe button, etc. In our implemented system, if the operator discovers a mistake or realizes bad data, he can "delete" past data blocks using a special control level on the control channel. This records an "edit pulse" which, when detected by the computer at analysis time, will cause it to delete the last data block. The convenience here is that the data collection operator need not stop the recorder and manually back up and search for the start of the bad data and start again. The software will also automatically detect illegal control level sequencing, saturation of analog data channels, etc.



Zeroing of control channel allows recognition of stop/start noise transients (Level zero is never used to identify an active phase)

FIG 11 Illustration of Noise "Tagging"

A significant portion of the Data Acquisition package is concerned with the control channel processing. The DAP module, CNTRL, is initiated by and used to "drive" the Fortran Background monitor. Its primary function (Fig. 11) is the detection of level changes on the control channel. Using a noise filtering technique, the analog levels on tape are converted to a digital index number by consulting a level definition table. When a legal level change is detected, a completion bit of the control channel TCB (this module runs as a task under TICS) is set to inform the background Fortran program of the event. The background Fortran monitor will then normally branch into a specified mode of operation.

The Data Strobe. Typically, the control channel level is used to indicate which "mode" of operation the program should be running under (i.e., calibration, EMG reaction time, average neck muscle strength). A convenient, additional feature is the ability to mark or strobe the beginning of an event within a mode of operation during data collection, and during later analysis have the computer automatically "trigger" a task to analyze this event. This is all accomplished with the Data Strobe pulse. Referring to the execution task queue in Figure 9, note the additional trigger wait queue. Background programs can initialize tasks and link their TCB's to this queue. When a trigger pulse is detected by the control channel module, it will link the TCB's on the trigger queue to the end of the execution queue. Note that this feature allows the syncronization of a number of different tasks created sequentially in background programming. That is, a complex task can be "assembled" from basic primary tasks and be executed as a package.

ANALOG TO DIGITAL CONVERSION

Conversion of analog tape data to digital form is of course a primary function in the analysis of the data. Subroutine TAKE can be called from Fortran Background programs to initiate a task which will convert an analog tape signal into an array of amplitude vs. time values in the computer memory. This created task can sample from 1 to 16 sequential channels at a specified initial channel, sampling rate, and total array size. In addition, there are options which can be selected to allow the following:

a. Start the sample on a trigger pulse (i.e., put TCB on wait queue.)

b. Turn control channel processing off during the sample period. (This leaves more execution time to allow a greater number of other high priority tasks to execute concurrently - for example, additional A-D sample tasks).

c. Completion Wait Option:

   If not requested, control returns to calling program immediately after the task has been initiated. If this option is selected, control will return to the calling program only after the total sample is complete. This option allows coding of the form:

```
CALL TAKE (TRIG. OPT.....NOWAIT.....PAR1......)
CALL TAKE (TRIG. OPT.....NOWAIT.....PAR2......)
CALL TAKE (TRIG. OPT......WAIT......PAR3......)
```

> This assembles a complex sample task from syncronized primary tasks. (The calls are ordered so that all tasks will be complete by or at the time the last task is.)

A fine point to note is that a task may not execute at exactly the same time after each clock interupt (see TICS discussion) due to the fact that on some cycles, there may be more tasks requiring execution than on others due to different clock rates. And on any particular cycle, some tasks are near the beginning of the queue and some near the end. Therefore, if each task sampled the A-D converter when its execution time came up, there could be excessive time jitter and/or delay in the sampling process. However, this is not the case due to the use of a buffered sampling technique. Recalling from the discussion of TICS, that at the end of the clock incrementing scan of the execute queue, all A-D channels were sampled simultaneously and the data values stored in a temporary local buffer. Now, when the task's own program finally begins to execute, it simply retrieves its A-D channel value from the temporary buffer and inserts it into the appropriate data array. Thus, all channels are sampled at syncronized intervals and the individual data points distributed over the interval.

FORTRAN BACKGROUND PROGRAM - EXPERIMENT DEFINITION

When examining the Fortran background programming, the value and power of TICS becomes apparent. The TICS (and DAP) modules isolate from the Fortran programmer all of the intricate details of interupt processing, task switching and queue management and control channel processing. The Fortran programmer is much freer to concentrate on the work at hand - writing code to process the experimental data.

The different control channel levels that encode the data allow a modular approach in the design of the Fortran Background program. There is in fact, a separate module for each distinct process (data collection phase). There is a simple monitor loop which checks the control channel status as returned by the DAP control channel module. When a legal level change is detected, the monitor simply branches to the appropriate section of code. Thus in Figure 8, each CS1,...CSN corresponds to a different phase of the experiment. When a control segment finishes, it simply returns to the monitor loop. Coding of each segment is pleasantly straightforward.

A special error routine (ISER) sets up sufficient communication between the Fortran program and the TICS and DAP modules so that asyncronous errors can be referred back to the Fortran program for error processing. This is similar to the ON "Condition" features of PL/1. For example, suppose a control level change from zero to level

N initiates the execution of a Fortran control segment. This segment may initiate several A-D sample tasks that will activate on a Data Strobe pulse, and then the segment goes into a wait loop. Now suppose that due to some data collection error, no Data Strobe pulse is present during this control phase. The program would be in a loop waiting for this pulse and would not free itself until a strobe pulse occurred in some later control phase. This of course would mean that the next control phase would be out of sequence.

However, with error processing turned on, the effect of a missing strobe pulse is less drastic.

A Fortran control segment can turn on an error control switch before it goes into a data strobe wait mode. It will turn the switch off only after it has received all of its data. If the control channel prematurely goes to zero during this period, an error routine will switch control to a Fortran entry point. The Fortran program can then emit an appropriate error comment and resyncronize itself with the control channel. Thus only data during the offending control phase is lost.

I TRIG SUBROUTINE

The final algorithm described in this subsection is the one used to detect the onset of significant activity in the EMG signal during the drop test. A representative set of tape signals can be seen in Figure 12a. Data are sampled from the tape and distributed to the proper memory locations by the A-D converter as shown in Figure 12b. If, for example, the reaction time (from A to B in Figure 12a) is to be determined, statistical analysis is used. Consider a random process as shown in Figure 13a. Starting at T_o we can compute the mean and the standard deviation of the process. One detection criterion is illustrated at point T_x where the process increases to above the old mean plus the standard deviation. Figure 13b illustrates the implemented algorithm using the same approach. Figure 13b represents a sample period of .9 sec. containing N1 (300) data points. The array is divided into blocks of size N2. First the absolute value of the EMG is taken so that we now deal with a signal similar to that in Figure 13a. The process is implemented by computing the mean and standard deviation for the first four blocks (as one block), and the mean is computed for the fifth block. We then test the fifth mean against the mean of the first four plus portions of the standard deviation. We have a "trigger" condition which passes when

$$\text{Avg. 5th blk.} \geq \text{Avg. 1st 4} + T^* \text{ (Std. Dev. 1st four blks)}$$

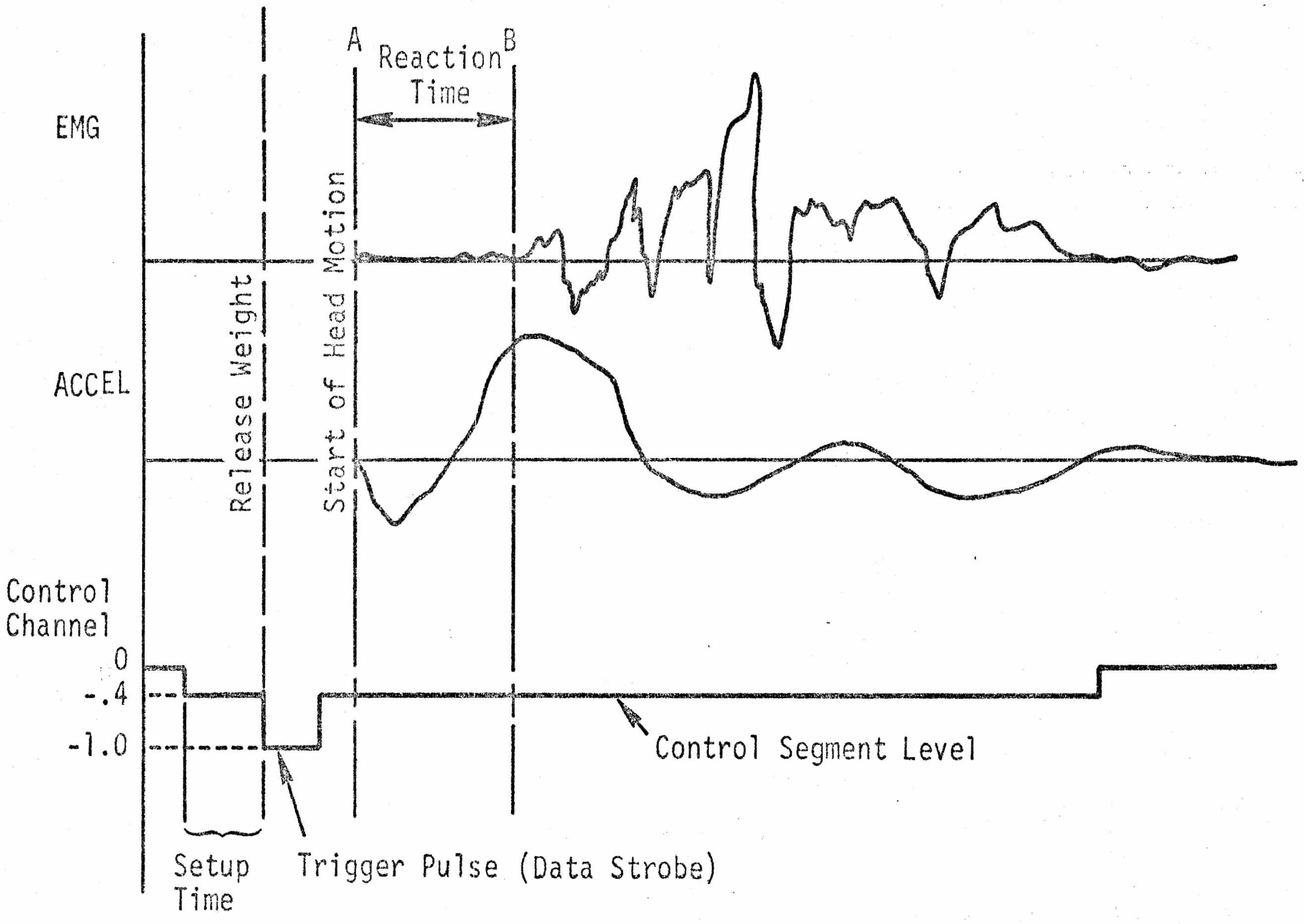


Figure 12a. Representative Analog Signals.

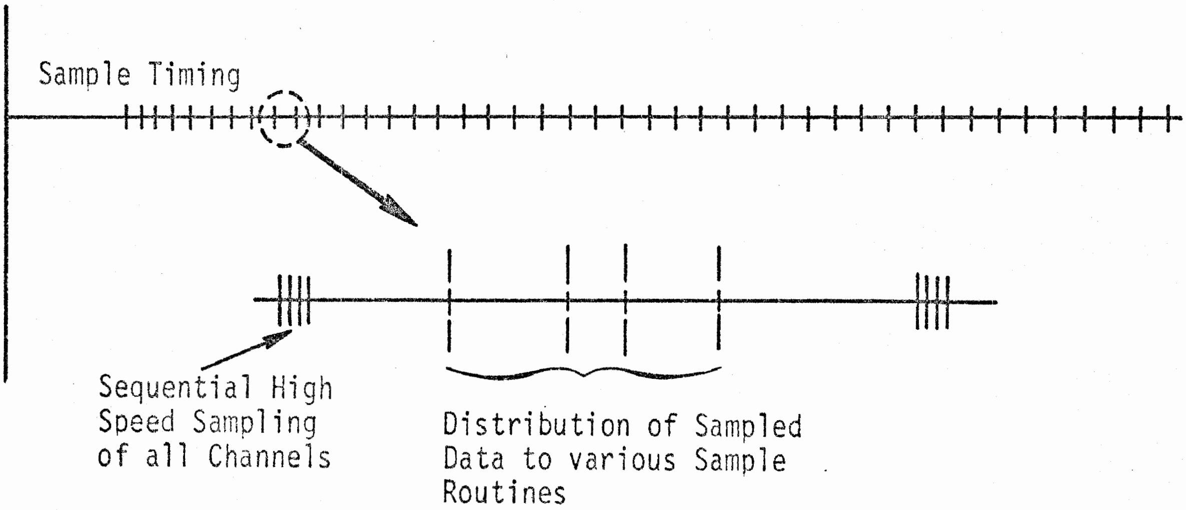


Figure 12b. Distribution of Data Samples.

Figure 12. Tape-recorded Signals and A-D Sampling Technique.

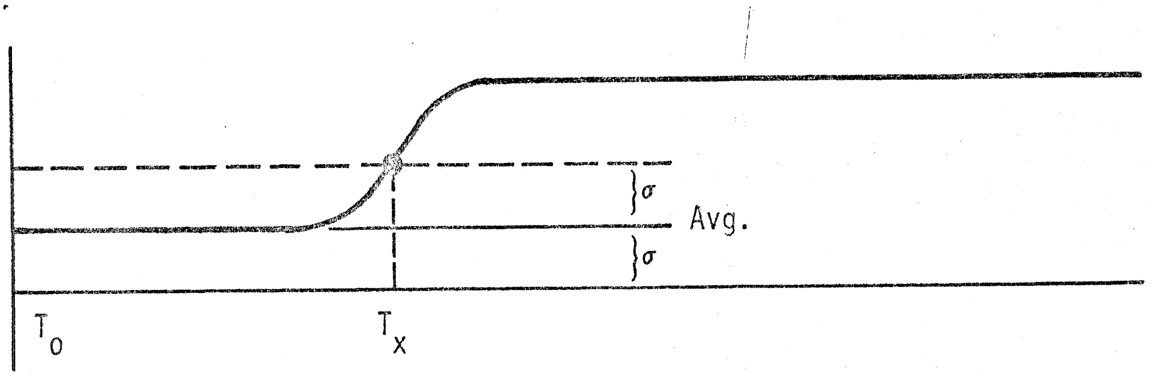
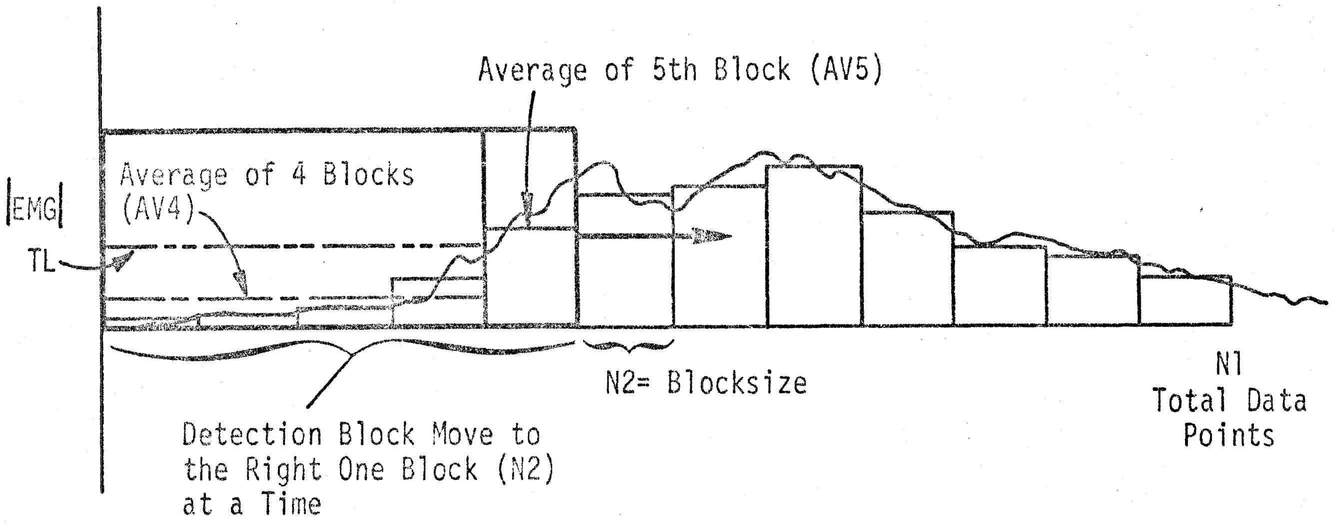


Figure 13a. Detection of Signal Level Change



TL = Trigger Level

Trigger Condition True When:

AV5 ≥ AV4 + T*(Standard Deviation of 1st 4 Blocks)

<u>Adjustable Parameters:</u>

T - used to adjust threshold.
IRT - sample rate used in sampling.
N2 - block size
N1 - total sample size.

Figure 13b. Detection of Increased EMG Activity

Figure 13. Method Used to Determine Increased Signal Strength.

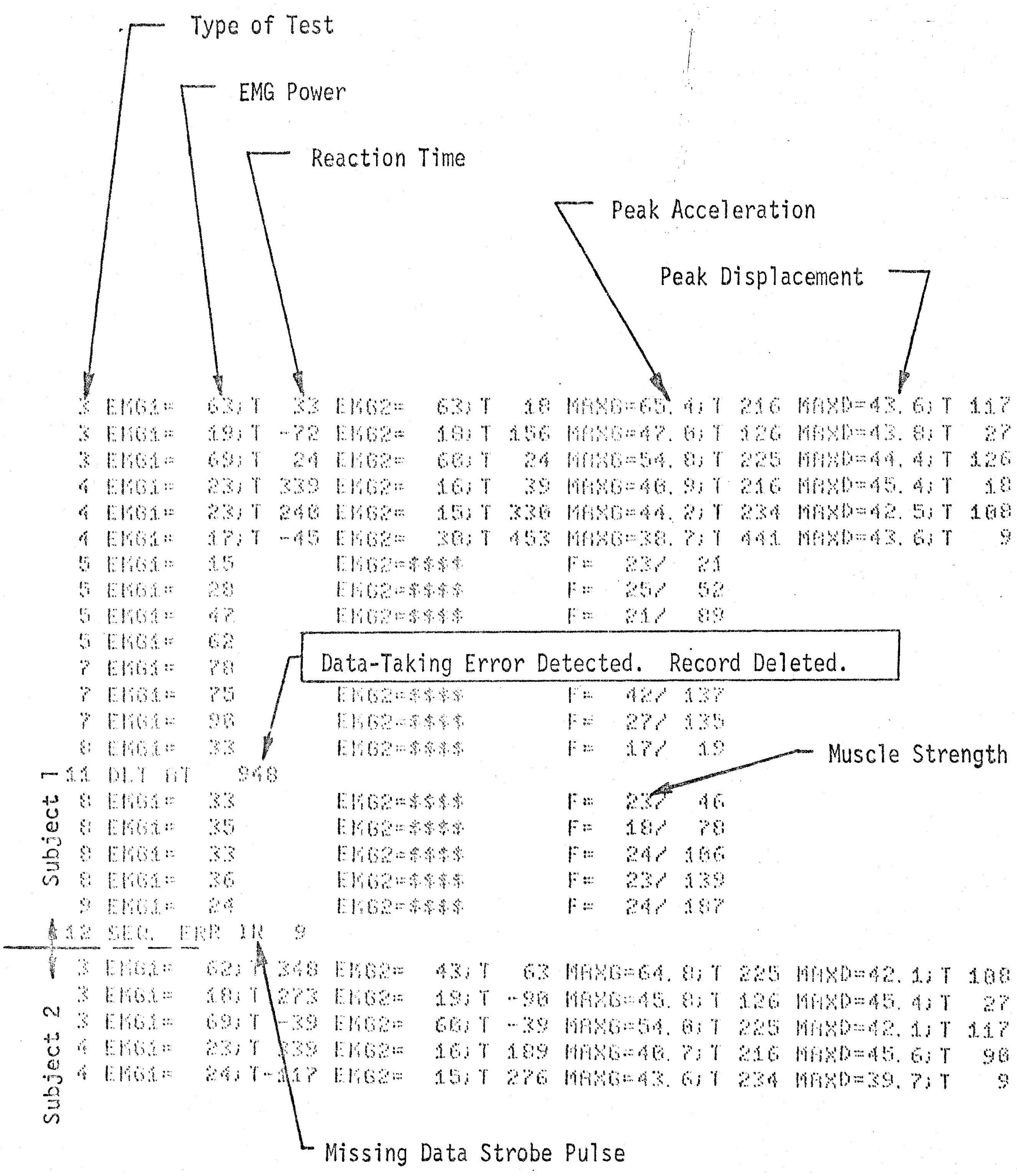
where T is a parameter used to adjust the threshold. If the test fails, we shift computation right one block and test again, etc. Thus we are always comparing a block against its previous 4 blocks. If and when detection occurs, the array index of the 5th block is returned as the breakaway time.

This of course is not the only detection algorithm possible. Conveniently, as the data is analyzed the first time, all the digitized raw analog data is stored on digital magnetic tape. Thus, if any modifications or improvements are made to this algorithm or if a better one is found, it can easily be applied to the original data sets.

Demonstration of Computerized Analysis

The computer program is written and almost completely debugged at this time. Daily contact between the programmer and the investigators has provided a dynamic environment for rapid response to both data-taking and data-analyzing requirements. This has also shortened the debugging and check-out cycle considerably.

Figure 14 is included as an illustration of the output from the automated data analysis program. This is an example of the types of information to be printed out by the line printer on a real-time basis. As the computer analyzes each trial of each test, the data summary shown will be printed out at the same time more detailed information is transferred to a digitized magnetic tape unit. Note that Figure 14 is for demonstration purposes only. Scaling and correction factors are being implemented to print immediately usable numbers. The numbers appearing in Figure 14 can be interpreted, but only after applying necessary scale factors. Actual analysis of these data is reported in Section III.



```
 3 EMG1=  63; T  33 EMG2=  63; T  18 MAXG=65. 4; T 216 MAXD=43. 6; T 117
 3 EMG1=  19; T -72 EMG2=  10; T 156 MAXG=47. 6; T 126 MAXD=43. 8; T  27
 3 EMG1=  69; T  24 EMG2=  60; T  24 MAXG=54. 8; T 225 MAXD=44. 4; T 126
 4 EMG1=  23; T 339 EMG2=  16; T  39 MAXG=40. 9; T 216 MAXD=45. 4; T  18
 4 EMG1=  23; T 240 EMG2=  15; T 330 MAXG=44. 2; T 234 MAXD=42. 5; T 108
 4 EMG1=  17; T -45 EMG2=  30; T 453 MAXG=38. 7; T 441 MAXD=43. 6; T   9
 5 EMG1=  15        EMG2=$$$$          F=  23/  21
 5 EMG1=  28        EMG2=$$$$          F=  25/  52
 5 EMG1=  47        EMG2=$$$$          F=  21/  89
 5 EMG1=  62
 7 EMG1=  78
 7 EMG1=  75        EMG2=$$$$          F=  42/ 137
 7 EMG1=  96        EMG2=$$$$          F=  27/ 135
 8 EMG1=  33        EMG2=$$$$          F=  17/  19
11 DLT GT    948
 8 EMG1=  33        EMG2=$$$$          F=  23/  46
 8 EMG1=  35        EMG2=$$$$          F=  18/  78
 8 EMG1=  33        EMG2=$$$$          F=  24/ 106
 8 EMG1=  36        EMG2=$$$$          F=  23/ 139
 9 EMG1=  24        EMG2=$$$$          F=  24/ 187
12 SEQ. ERR IR   9
 3 EMG1=  62; T 348 EMG2=  43; T  63 MAXG=64. 8; T 225 MAXD=42. 1; T 108
 3 EMG1=  10; T 273 EMG2=  19; T -90 MAXG=45. 8; T 126 MAXD=45. 4; T  27
 3 EMG1=  69; T -39 EMG2=  60; T -39 MAXG=54. 6; T 225 MAXD=42. 1; T 117
 4 EMG1=  23; T 339 EMG2=  16; T 189 MAXG=40. 7; T 216 MAXD=45. 6; T  90
 4 EMG1=  24; T-117 EMG2=  15; T 276 MAXG=43. 6; T 234 MAXD=39. 7; T   9
```

Figure 14. Line Printer Summary of Test Data

III. DATA ANALYSIS

Presently, 33 subjects have been tested in one or another phases of the project. The intent of the analysis of the data thus far has been to determine if the measurement procedures are both sensitive and repeatable enough to be standardized for the remainder of the testing phase of the project. Also, the data have been used to debug the computer analysis programs described earlier.

Radiography and Photogrammetry for Neck/Head Alignments. Five questions have been evaluated this quarter. Each will be presented and discussed separately in the following sections.

A. Does the neutral head position change when seated in the hard seat as opposed to the soft seat? This question was evaluated by comparing the head alignment axis positions (relative to horizontal) for 27 subjects seated in each seat. The seated subjects were asked to look straight ahead at a sighting target approximately 60 inches in front of them. The mean difference in head-neck orientation between the soft and hard seats was 1.2 degrees, which is not significantly different than zero, at an α significance level of one percent.

B. Does a reference rod attached to a headpiece (this is a rod aligned over both tragion and nasal root depression) remain in a constant orientation to the head as defined by external landmarks for all three positions attempted? This question was evaluated by comparing the rod's angular position to a second reference axis drawn on the photos (i.e. an axis connecting two well defined landmarks - the right tragus of the ear and the right nostril), for each of the three trials in each position. Data from twenty subjects were analyzed. The difference between the two axes for each position are summarized in Table 2. An F test disclosed that though the rod-to-

TABLE 2

ANGULAR DIFFERENCES BETWEEN REFERENCE ROD AND PHOTO LANDMARK REFERENCE AXIS

	NEUTRAL POSITION			FLEXION			EXTENSION		
SUBJECT	I	II	III	I	II	III	I	II	III
1	12.0	11.0	10.0	11.5	11.5	11.5	11.5	8.0	8.0
2	10.5	8.0	7.0	10.5	8.0	10.0	8.0	8.0	5.5
3	12.5	12.0	11.0	13.0	13.5	12.5	9.5	15.5	9.0
4	11.5	11.5	11.0	11.5	9.5	11.5	13.0	13.5	13.5
5	14.0	15.5	14.5	13.5	15.5	14.0	13.5	15.0	15.0
6	20.0	17.5	16.0	14.0	14.0	12.5	15.0	16.5	13.5
7	17.0	16.5	16.0	18.0	17.0	16.5	16.5	16.0	16.0
8	12.0	12.0	17.5	11.0	8.5	9.0	17.0	13.0	14.5
9	13.0	12.0	11.5	15.5	11.0	12.0	11.0	11.0	10.5
10	21.5	20.5	20.0	23.0	23.5	21.5	24.0	21.0	22.5
11	13.5	18.5	19.0	11.5	17.5	17.0	16.5	23.5	23.0
12	19.0	16.5	17.5	18.5	19.5	18.5	12.0	14.5	13.5
13	18.0	17.5	17.5	19.5	20.0	20.0	20.0	17.5	19.0
14	17.0	18.5	17.5	18.5	20.0	19.0	19.0	19.5	30.5
15	17.5	17.0	17.5	15.5	16.5	16.0	17.5	16.5	16.0
16	15.5	14.5	15.5	15.0	16.0	16.5	14.0	15.0	15.0
17	16.0	17.0	15.5	18.0	17.5	17.0	13.5	12.5	11.5
18	9.5	10.0	9.5	7.5	6.5	6.5	9.0	8.5	9.5
19	10.0	10.5	10.5	11.0	10.0	10.5	10.5	10.5	11.0
20	9.5	11.0	9.0	13.5	13.5	11.0	11.0	9.0	10.0
MEAN	14.48	14.38	14.18	14.5	14.45	14.15	14.1	14.23	14.35
SD	3.64	3.54	3.85	3.81	4.64	4.05	4.10	4.32	5.88

surface landmark alignments were different between subjects (due to anatomical differences) the rod did not consistently change for all people when in the three positions ($\alpha \leq 0.01$) but did significantly change for some (interaction of subjects and positions significant at $\alpha \leq 0.01$).

C. Does the reference rod and its headpiece remain in a constant orientation with regard to an axis defined by two X-ray bone points for all three positions? This question was evaluated by comparing the difference between the reference rod and a second axis drawn on the X-rays from the occipital protuberance tangent to the surface of the base of the skull. This line is illustrated in Figures 3, 4, and 5. The data for 26 subjects are summarized in Table 3. An F test disclosed that the angular difference between the two axes did change significantly at the $\alpha \leq 0.025$ level. Because of this shift and the earlier result which showed the reference rod was found to shift in some people with respect to surface landmarks, a procedure has been adopted where-in surface landmarks will be used to measure neck ROM.

D. Does the subject vary his absolute neutral position or the amount of flexion, extension and full range of motion (ROM) he can achieve for three successive trials? This question was evaluated by comparing either the external reference rod, or the external landmark reference axis (i.e. bottom of tragus of ear to nostril) on the photos of each person in three repeated positions. Data from nineteen subjects were available for this evaluation, and are summarized in Table 4. F-tests of the angles from the neutral position in both flexion and extension disclosed no significant differences between trials ($\alpha \leq 0.01$), though individual subjects varied by a great amount. The same result was true when using the total ROM data. It was also disclosed that the subjects repeatedly assumed their neutral positions, though each subject's neutral position varied greatly. Note in Table 4 that the mean

TABLE 3

ANGULAR DIFFERENCES BETWEEN REFERENCE ROD AND X-RAY HEAD ALIGNMENT AXIS

SUBJECT	NEUTRAL	FLEXION	EXTENSION
1	58.0	57.5	53.0
2	57.0	54.5	57.0
3	66.0	67.0	60.5
4	38.0	38.0	32.0
5	58.0	45.0	45.0
6	44.0	44.0	64.0
7	51.5	54.0	43.0
8	39.5	40.0	36.0
9	48.0	47.5	45.5
10	39.0	36.5	35.0
11	50.5	50.0	47.5
12	44.5	45.0	47.5
13	48.0	49.5	42.5
14	56.0	56.5	54.0
15	31.5	32.0	34.0
16	39.5	38.5	33.0
17	47.0	40.5	41.5
18	47.5	49.0	45.5
19	37.0	35.0	37.0
20	42.5	42.0	40.0
21	50.0	49.0	50.5
22	29.0	26.0	23.5
23	47.0	52.5	39.0
24	61.5	59.5	57.5
25	39.5	39.5	40.5
26	44.0	39.5	35.0
MEAN	46.69	45.69	43.83
SD	9.07	9.36	9.80

TABLE 4

SUBJECT HEAD POSITION DATA FROM PHOTOGRAPHS

	FLEXION*			EXTENSION*			RANGE OF MOTION*			NEUTRAL POSITION**		
SUBJECT	I	II	III	I	II	III	I	II	III	I	II	III
1	66.5	63.0	69.0	53.0	70.5	70.5	119.5	133.5	139.5	22.0	18.5	20.5
2	47.0	73.0	57.0	110.0	99.5	101.0	157.0	172.5	158.0	5.0	10.0	4.5
3	65.5	62.0	69.0	71.5	63.5	73.5	137.0	125.5	142.5	14.5	9.0	17.5
4	34.0	39.5	38.5	91.5	85.0	85.5	125.5	124.5	124.0	4.0	5.0	3.0
5	62.5	67.0	69.5	81.5	80.5	85.5	144.0	147.5	155.0	6.5	15.0	11.0
6	51.0	60.5	53.0	117.5	109.5	108.0	168.5	170.0	161.0	1.5	6.0	4.0
7	56.5	66.5	75.0	68.5	76.0	83.5	125.0	142.5	158.5	21.5	21.5	18.5
8	71.0	80.0	81.5	87.0	83.0	82.0	158.0	163.0	163.5	1.0	2.0	1.5
9	70.5	71.5	70.0	75.0	65.0	67.0	145.5	136.5	137.0	15.5	18.5	15.5
10	55.0	66.5	60.0	78.5	68.0	68.5	133.5	134.5	128.5	21.5	25.5	24.5
11	69.5	64.5	65.0	63.5	65.5	65.5	133.0	130.0	130.5	18.0	11.0	9.5
12	64.0	63.5	68.0	68.0	66.0	72.0	132.0	129.5	140.0	14.0	15.0	16.0
13	42.5	52.5	53.5	86.0	76.0	82.0	128.5	128.5	135.5	5.0	7.5	9.0
14	48.5	60.0	71.5	67.0	74.0	61.0	115.5	134.0	132.5	20.0	25.0	30.0
15	68.0	69.0	70.5	77.5	71.0	73.0	145.5	140.0	143.5	27.0	27.5	25.0
16	57.0	53.5	53.0	87.5	88.5	89.0	144.5	142.0	142.0	16.0	14.5	14.5
17	47.5	43.5	46.5	80.0	91.5	86.5	127.5	135.0	133.0	10.5	7.5	9.0
18	63.0	66.0	64.5	60.0	63.5	61.5	123.0	129.5	126.0	21.5	20.5	17.5
19	60.0	54.5	54.0	75.0	85.0	81.0	135.0	139.5	135.0	15.5	11.0	12.0
MEAN	57.9	61.9	62.6	78.9	78.0	78.8	136.7	139.9	141.3	13.7	14.2	13.8
SD	10.46	9.86	10.79	15.87	12.90	12.61	14.03	14.13	12.26	7.88	7.48	7.93

*Degrees of flexion, extension and total range of motion. Range of motion is extension degrees plus flexion degrees. Reference axis used: line connecting right nostril and bottom of tragus of right ear.

**Degrees above horizontal. Reference rod used to establish angle between nasion-tragion line and horizontal.

absolute neutral position for the 19 subjects varied by not more than one-half degree in the three replications of the position.

E. Does the reference rod angle measured from both the X-rays and the first photograph taken change consistently, i.e. did the fact that the subject got up from one hard seat and sat down in another similar one alter his head orientation? This question was evaluated by comparing the data obtained from 28 subjects. The data are summarized in Table 5. A Student's t test of means from each procedure disclosed that there is no statistically significant difference when using either procedure across the three positions, at $\alpha \leq 0.01$. It is therefore concluded that comparable head position data could be gathered from either X-ray or photogrammetry phases of the project.

In summary, it is now believed that procedures have been developed and tested which result in reliable measures of head position and neck range of motion. In specific, the following initial hypotheses have been tested and accepted as a basis for future test procedures:

1. Comparable X-ray and photographic positional data could be obtained.
2. Hard and soft seats with similar seat cushion and back angles did not affect head positions or ROM.
3. Subjects could be requested to demonstrate repeatable head positions for both neutral and extremes of voluntary motion.
4. Subjects would achieve a wide range of head positions and ranges of motion.

Also, the measurement of head position using an external reference rod and head piece was found to be not as reliable as the use of surface landmarks, and the measurement procedures have been modified accordingly.

Head Acceleration and Displacement Repeatability: A concern this Quarter has been to develop a test procedure which would result in a peak head

TABLE 5

REFERENCE ROD ANGLES FROM BOTH X-RAYS AND FIRST PHOTOGRAPHS*

	NEUTRAL		FLEXION		EXTENSION	
SUBJECT	X-RAY	PHOTO	X-RAY	PHOTO	X-RAY	PHOTO
1	16.0	17.0	-54.5	-53.5	93.0	88.0
2	14.5	ND	-50.0	ND	69.5	ND
3	14.5	22.0	-52.5	-45.0	78.0	74.5
4	14.5	9.0	-60.5	-71.0	95.0	79.0
5	24.0	18.0	-53.5	-50.5	88.0	90.0
6	10.0	16.0	-34.0	-25.0	77.0	95.5
7	11.5	5.0	-61.0	-42.0	110.5	112.5
8	17.5	15.5	-48.0	-49.5	83.0	84.0
9	2.0	4.0	-50.5	-30.0	96.0	97.0
10	18.0	16.0	-53.0	-47.0	104.0	103.0
11	10.0	6.5	-56.0	-55.5	117.5	88.5
12	5.0	1.5	-52.0	-55.5	113.0	114.0
13	16.0	21.5	-58.0	-34.0	76.5	89.5
14	3.0	1.0	ND	-49.0	102.0	83.0
15	20.0	15.5	-40.0	-32.0	101.0	102.5
16	19.0	21.5	-59.5	-52.5	81.0	91.5
17	15.0	ND	-48.0	ND	106.5	ND
18	25.5	18.0	-57.0	-49.5	92.5	78.5
19	13.0	14.0	-39.5	-50.5	80.0	75.0
20	21.5	17.0	-33.5	-43.0	86.5	70.0
21	15.5	5.0	-44.0	-37.5	90.5	91.0
22	21.5	20.0	-41.0	-27.0	111.5	89.0
23	ND	16.0	ND	-50.5	ND	95.0
24	13.5	29.5	-52.0	-41.5	102.0	121.0
25	19.0	27.0	-45.0	-42.0	88.5	71.0
26	0.5	10.5	-38.5	-35.0	94.0	91.5
27	21.5	21.5	ND	-42.5	91.0	81.0
28	19.0	15.5	-45.5	-40.5	99.0	92.0
MEAN	14.9	14.7	-49.1	-44.3	93.5	89.9
SD	6.51	7.51	8.03	10.24	12.23	12.78

*Angles measured as defined in <u>Second Quarterly Report</u>, Figure 13.

acceleration (as measured by horizontal motion at the top of head) that would assure enough head motion to instigate a measurable stretch-reflex time, but not exceed our chosen upper acceleration limit of 1.0 g. The procedure adopted has been explained earlier. The data to test it were gathered on four male and two female subjects. The data are summarized in Table 6. What is evident is that a peak acceleration of about 0.55 g is being achieved when the head/neck is extended by the weight-drop, while about 0.66 g is accomplished in flexion. Also there is great variability between people (compare subject MAZ05 with MAX02). As to repeatability between trials, it must be acknowledged that test-retest variability is present, and in one subject (FAX02) is larger than desired. It is maintained, however, that the test results obtained to date do not warrant changing the test procedures, since stretch-reflex data have been gathered in an acceptable form from the tests when g loads of greater than approximately 0.4 were achieved. (Note: some data were lost due to electrical noise in a particular test.) It is apparent, though, that continued retesting of each subject three times will be necessary to assure the existence of useful data on stretch-reflex times. This retesting, plus the use of multiple subjects for each population stratification of age, height, and sex should assure statistically valid results.

The horizontal head displacement measures disclosed that the motion backward (extending) appears to be larger than foward (flexing) for the group (see Table 6), even though the peak g load indicated a higher acceleration in flexing. Thus the head motion was stopped faster when jerked forward than when jerked backward. The stretch-reflex times (see below) indicate that the neck muscles may be the basis for this difference. A large individual subject difference in head displacement was also documented, though more data are necessary to statistically discuss this effect.

TABLE 6

SUMMARY OF MUSCLE REACTION TIMES, PEAK HORIZONTAL HEAD ACCELERATIONS AND PEAK HORIZONTAL HEAD DISPLACEMENTS

SUBJECT NUMBER	DIRECTION OF NECK MOTION DUE TO FORCE APPLIED	REACTION TIME TO SIGNIFICANT EMG (msec)				PEAK HORIZONTAL HEAD ACCELERATIONS (g)				PEAK HORIZONTAL HEAD DISPLACEMENTS (cm)			
		I	II	III	MEAN	I	II	III	MEAN	I	II	III	MEAN
MAZ 05	Extending	240	134	180	184.7	.67	.67	.79	.71	5.8	3.9	4.4	4.7
	Flexing	48	32	48	42.7	.91	.92	.65	.826	5.8	3.1	3.2	4.03
MAY 04	Extending	ND	ND	ND	ND	.36	.39	ND	.375	3.4	3.9	5.0	4.1
	Flexing	160	114	100	124.7	.41	.60	.67	.56	5.8	4.5	3.7	4.7
MAZ 03	Extending	ND	184	108	146.0	ND	.79	.60	.695	9.7	5.8	5.2	6.9
	Flexing	136	148	156	146.7	.73	.60	.66	.663	4.5	5.5	5.8	5.27
MAX 02	Extending	ND	ND	112	112.0	.26	.27	.27	.267	4.6	ND	5.8	5.2
	Flexing	184	152	136	157.3	.36	.52	.32	.40	6.1	7.3	5.0	6.13
FAZ 06	Extending	ND	72	148	110.0	ND	.37	.27	.32	ND	3.6	3.2	3.4
	Flexing	34	52	64	50.0	.76	.95	.73	.813	3.9	3.9	3.5	3.77
FAX 02	Extending	ND	72	ND	72.0	1.03	.63	.82	.827	6.5	ND	ND	6.5
	Flexing	88	52	48	68.0	.76	.69	.55	.667	5.2	4.0	6.5	5.23
Means	Extending	240	115.5	137	138.9	.58	.52	.55	.546	6.0	4.3	4.72	5.06
	Flexing	108.3	91.7	92	97.3	.655	.713	.597	.655	5.22	4.72	4.62	4.85

ND = No Data

Again, like peak accelerations, the displacement data varied between trials to the degree that repeated measures will continue to be necessary.

Neck Muscle Reaction Time Repeatability: The most difficult measurement and analysis procedure in this project is the determination of muscle reaction time, as determined by EMG latency after initiation of head movement. The analysis has been accomplished for this report by the procedures described in the Second Quarterly Report, i.e., by strip charting all data and measuring the parameters of interest. The computer analysis described earlier has been used to evaluate some of the data, but since the program has not been completely checked-out, the strip chart analysis scheme has been used for this report.

The six subjects were all tested as described previously. The EMG's were obtained from both neck flexor and extensor muscles during three tests each of extension and flexion. The data are presented in Table 6. Though an analysis of variance again did not appear to be warranted on such sparse data, some interesting trends are apparent. First, the flexor muscles of the neck (those stretched during extension) appear to react slower than the extensor muscles by more than 40 msec. This difference is consistent with the previous head displacement data that disclosed greater head motion during extension of the neck.

It is also apparent that the retests of each subject are justified, since a high (20%) data loss is still present. This data loss is greatest in the extending type jerk, primarily due to the EMG signal from the sternomastoid flexor muscle being of low amplitude. More care in locating the electrodes to enhance the signal-to-noise ratio is to be used in future tests.

Isometric Strength Tests of Neck Muscles: As in the other tests, three repeated strength tests were performed on each subject. The data are four second average forces (in pounds) exerted against a wide strap around the head (see Second Quarterly Report). The data are presented in Table 7. Test-retest variability is reported as a coefficient of variation (CV) computed by dividing the sample standard deviation by the sample mean for the three trials. A CV of below 10 percent is judged to be good, so long as a reasonable learning trend is not evident in the three trials. As can be seen, with the exception of two subjects who had a consistent trend, an acceptable repeatability was accomplished. Thus the procedure in general is deemed adequate. However, an additional pretrial maximum exertion will be requested in an attempt to reduce the "learning" aspect of the strength test.

It is interesting to also note that the strength of the neck flexors is about 69% of the neck extensor strength. This fact, coupled with the slower reaction times of the flexor muscles (as reported in the preceding subsection) indicates that a differential risk level may exist in flexion and extension type loading of the head/neck complex. As more data is gathered on all of these parameters, this potential major effect will be evaluated.

TABLE 7

SUMMARY OF NECK MUSCLE ISOMETRIC STRENGTH TESTS

SUBJECT NUMBER	TYPE OF MUSCLE ACTION	FOUR SECOND MEAN STRENGTH (Pounds)					
		I	II	III	MEAN	S.D.	C.V.*
MAZ 05	Extensors	40.9	44.5	45.5	43.6	2.42	5.5%
	Flexors	30.0	30.0	36.4	32.1	3.69	11.5%
MAY 04	Extensors	39.8	42.5	48.9	43.7	Trend	Trend
	Flexors	30.0	31.8	30.0	30.6	1.04	3.4%
MAZ 03	Extensors	33.2	34.5	36.8	34.8	1.82	5.2%
	Flexors	34.5	27.2	25.4	29.0	4.82	16.6%
MAX 02	Extensors	24.5	36.4	40.9	33.9	Trend	Trend
	Flexors	25.0	24.5	23.1	24.2	0.98	4.0%
FAZ 06	Extensors	38.2	33.6	32.7	34.8	2.95	8.5%
	Flexors	19.1	19.5	22.7	20.4	1.97	9.7%
FAX 02	Extensors	30.0	33.6	33.6	32.4	2.24	6.9%
	Flexors	18.2	15.9	18.6	17.6	1.46	8.3%
Means	Extensors	34.40	37.52	39.73	37.22	2.36	6.53%
	Flexors	26.13	24.82	26.03	25.65	2.33	8.92%

*Coefficient of Variation (CV) = $\frac{\text{S.D.}}{\text{Mean}}$

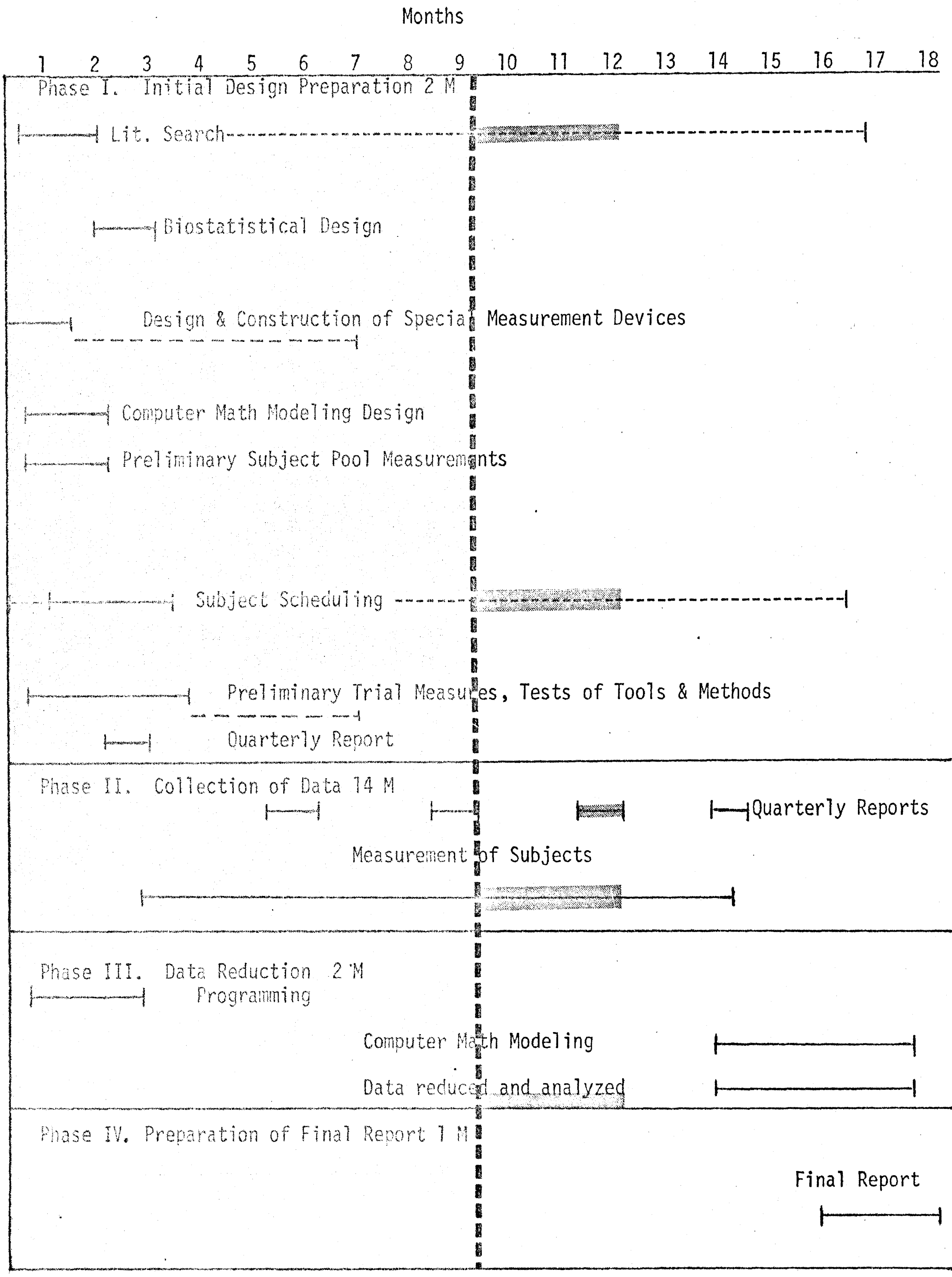
IV. WORK TO BE ACCOMPLISHED DURING THE NEXT REPORTING PERIOD, OCTOBER 1 THROUGH DECEMBER 30.

Now that major instrumentation, measurement, and personnel problems have been resolved, emphasis during the fourth period of this study will be upon collection of the data, with concurrent analysis. The computer data data analysis portion of the study has been refined to allow more efficient utilization than expected at this phase of the study, and this should result in a considerable time saving in the final phases. Our goal is to average 10 new subjects a week, or 120 additional subjects by the end of December. Although this will be difficult to do, especially since it involves continual night and weekend work for the study team, and can be adversely affected by sickness, unforseen problems, or equipment failures, major emphasis will be given to this goal. We believe that the earlier delays resulting from obtaining the Ampex Recorder and checking out the experimental instrumentation and procedures will now result in our obtaining more and better information than projected in our original experimental design.

Projected program accomplishments for the period through December 30 are reflected in Table 8.

TABLE 8

PROGRAM SCHEDULE



▨ Indicates activities projected for Period 1 Oct. - 30 Dec.

Portion of Program completed.

V. BIBLIOGRAPHY

I. MOTION/MOBILITY

Adams, C.B., et al. "Studies in Cervical Spondylotic Myelopathy. II. The Movement and Contour of the Spine in Relation to the Neural Complications of Cervical Spondylosis." *Brain* 94:568-586, 1971.

Alvik, I. "[Biomechanics of the Spine]" *T. Norsk Laegeforen* 89:1340-1344, September 1969. (Nor)

Belen'kii, B.E. "[Method and Initial Results of Study of Spinal Mobility During Locomotion]" *Ortop Travm Protez* 29:25-31, October 1968. (Rus)

Brechner, V.L. "Unusual Problems in the Management of Airways. I. Flexion-Extension Mobility of the Cervical Vertebrae." *Anesth Analg* (Cleveland) 47:362-73, July-August 1968.

Chaffin, D.B. "A Computerized Biomechanical Model-Development and Use in Studying Gross Body Actions." *J Biomech* 2:429-441, 1969.

Chudacek, Z. "[Teleradiography of the Entire Spine]" *Cesk Radiol* 21:17-9, January 1967. (Cz)

Eshougues, J.R., et al. "[The Spinal Mobile Segment]" *Rhumatologie* 23:193-198, 1971. (French)

Gaizler, G. "[New Aspects of the Radiological Examination of Spinal Posture and Movements]" *Fortschr Roentgenstr* 111:280-5, August 1969. (Ger)

Garner, J.H. "Body Mechanics - A Short Course for Active People." *J. Ass. Phys Ment Rehab* 21:18-20, January-February 1967.

Harvey, V.P., et al. "Reliability of a Measure of Forward Flexibility and Its Relation to Physical Dimensions of College Women." *Res. Quart Amer Ass Health Phys Educ* 38:28-33, March 1967.

Hjortsjo, C.H. "[Pattern of Movement and Degenerative Changes in the Cervical Spine]" *Nord Med* 82:1247-8, October 1969. (Swe)

Hoshikawa, M. "[Roentgenological Study on the Rotational Movement of the Spine, with Reference to Lukas' Method and Cross-Rotatory Tomography]" *J Jap Orthop Ass* 41:141-56, May 1967. (Jap)

Karelin, V.A. "[Goniometry as a Method of Determining the Function of the Spine]" *Voennomed Zh* 4:63-7, April 1966. (Rus)

Khelimskii, M.A., et al. "[Certain Biomechanical Properties of Individual Vertebral Fragments and Vertebrae as a Whole]" *Eksp Khir Anest* 13:51-6, May-June 1968. (Rus)

Lanik, V. "[Kinetics and Dynamics of the Spine]" *Acta Chir Orthop Traumatol Cech* 38:67-72, 1971. (Czech)

Lindahl, O. "Determination of the Sagittal Mobility of the Lumbar Spine." Acta Orthop Scand 37:241-254, 1966.

Lucas, D.B. "Mechanics of the Spine." Bull Hosp Joint Dis 31:115-131, 1970.

Macrae, I.F., et al. "Measurement of Back Movement." Ann Rheum Dis 28:584-9, November 1969.

Moll, J.M., et al. "Normal Range of Spinal Mobility. An Objective Clinical Study." Ann Rheum Dis 30:381-386, 1971.

Nakalsuka, T., et al. "Dynamical Considerations on Whiplash Motion of an Occupant Caused by Rear-end Collision." Report from Vehicle Dynamics and Safety Lab, Isuzu Motors, Ltd., 1969.

Nickerson, J.L. and Coermann, R.R. "Internal Body Movements Resulting from Externally Applied Sinusoidal Forces." Aerospace Medical Laboratories, Wright-Patterson AFB, Ohio, Rept. AMRL-TDR-62-81, 1962.

Panjabi, M. and White, A.A. "A Mathematical Approach for Three-Dimensional Analysis of the Mechanics of the Spine." J Biomech 4:203-212, 1971.

Papastavrou, N., et al. "[Measurement of Spinal Movement]" Monatsschr Unfallheilkd 74:495-503, 1971. (German)

Paris, S.V. "Gross Spinal Movements and Their Restriction as the Basis of Joint Manipulation." Prog Phys Ther 1:208-213, 1970.

Pavelka, K. "[Measurement of Vertebral Column Rotation]" Z Rheumaforsch 29:366-370, 1970. (German)

Przybylski, J. "[Behavior of the Anterior-Posterior Curvatures Among Young People in the Sitting Position]" Chir Narzadow Ruchu Ortop Pol 36:71-75, 1971. (Pol)

Reichmann, S. "Motion of the Lumbar Articular Processes in Flexion-Extension and Lateral Flexions of the Spine." Acta Morphol Neerl Scand 8:261-272, May 1971.

Roy, S. "Bio-engineering in Relation to Spinal Mechanism." J Indian Med Assoc 54:566-568, 1970.

Schultz, A.B. and Galante, J.O. "A Mathematical Model for the Study of the Mechanics of the Human Vertebral Column." J Biomech 3:405-416, 1970.

Seno, S. "The Motion of the Spine and the Related Electromyogram of the Patient Suffering from Lumbago." Electromyography 8:185-6, May-July 1968.

Stricker, H.F. "[Mechanical Statistical and Roentgenological Aspects of the Spine]" Nederl T Geneesk 111:1643-4, September 1967. (Dut)

Tiul'kin, E.P. "[A Method of Spine Rotation Measurement]" Ortop Travm. Protez 26:79-81, October 1965. (Rus)

White, A.A. "The Significance of the Vertebral Posterior Elements in the Mechanics of the Thoracic Spine." Clin Orthop 81:2-14, 1971.

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

II. MECHANISM/INJURY

Aikawa, Y. "[Experimental Study on Spinal Cord Injuries]" Iryo 21: 542-549, May, 1967.

Akasaka, K. "[Experimental Study on Etiological Mechanism of So-called Cervical Syndrome--On the Development of Cervical Spondylosis Caused by Cervical Intervertebral Disc Injuries]" J Jap Orthop Ass 40: 1-21, April, 1966. (Jap)

Bosee, R.A. and Payne, C.F. "Theory on the Mechanism of Vertebral Injuries Sustained on Ejections from Aircraft." A paper presented to Advisory Group for Aeronautical Research and Development, NATO, ASTIA catalog 256 378, Air Crew Equipment Laboratory, U.S. Naval Air Materiel Center, Philadelphia, April, 1961.

Code, C.F., Williams, M.D., Baldes, E.J. and Ghormley, R.K. "Are the Intervertebral Discs Displaced During Positive Acceleration?" J Aviation Med 18:231-236, 296, 1947.

Friedman, M.M., et al. "Seat Belt Spinal Fractures." Amer Surg 35:617-618, September, 1969.

Gosch, H.H. et al. "Mechanism and Pathophysiology of Experimentally Induced Cervical Spinal Cord Injuries in Adult Rhesus Monkeys." Surg. Forum 21:455-457, 1970.

Higgens, L.S., et al. "Pathomorphology of Experimental Head Injury Due to Rotational Acceleration." Acta Neuropath (Berlin) 12:200-204, January, 1969.

Hiranuma, H. "[Experimental Study on the Arteries of the Head and Neck Regions in Whiplash Injuries]" J Jap Orthop Assoc 45:161-172, 1971. (Jap)

Italiano, P. "[Interpretation of Mechanisms of Fracture in Jet Pilots, Ejected with Their Seats, with Special Reference to the F 104 G Aircraft]" Riv Med Aero 29:193-228, April-June, 1966. (Ital)

Italiano, P. "[Interpretation of the Mechanism of Fractures in Jet Plane Pilots Ejected with Their Seats, with Special Reference to F 104 G Planes]" Riv Med Aero 29:407-410, Dec. 1966 (Ital.)

Kihlberg, J.K. "Flexion-torsion Neck Injuries in Rear Impacts." CAL Report No. VJ-2721-R2, April, 1969.

Klement, M. "[On Mechanical Problems of Wedge Fractures of Vertebral Bodies of the Thoracolumbal Transition]" Rozhl Chir 47:433-440, July, 1968. (Cze)

Latham, F. and Howard, P. "Mechanism of Injury During Whole Body Linear Deceleration." RAF Institute of Aviation Medicine, Farnborough. FPRC memo. Report No. 100. September, 1958.

Marsh, H.O., et al. "Seat Belt Fractures. Chance Fractures Caused by Seat Belts: Presentation of Three Cases." J Kansas Med Soc 71:361-365, September, 1970.

Martinez, J.L. and Garcia, D.J. "A Model for Whiplash." J Biomech 1:23-32, 1968.

Maurer, H.J., et al. "[Accident Mechanism and Vertebral Injuries--Catamnestic Radiographic Study]" Hefte Unfallheilkd. 108:13-29, 1971. (Ger)

Mayer, E.T., et al. "[Medullary Lesions Caused by Hyperextension of the Spine]" Acta Neurol (Napoli) 23:679-687, July-August, 1968. (Ital)

McKenzie, J.A. "An Analysis of Automobile Rear-end Accident Induced Injuries to the Head and Neck." M. Sc. Thesis, University of Melbourne, Australia, 1971.

McKenzie, J.A. and Williams, J.F. "The Dynamic Behavior of the Head and Cervical Spine During Whiplash." J Biomech 4:477-490, 1971.

Mohr, G.C., et al. "Variations of Spinal Alignment in Egress Systems and Their Effect." Aerospace Medicine 40:983-988, September, 1969.

Ogienko, F.F. "[The Relationship of the Genesis of Lumbosacral Pain to the Biomechanics of the Spine]" Zh Nevropat Psikhiat Korsakov 69:496-499, 1969. (Rus)

Orne, D., et al. "A Mathematical Model of Spinal Response to Impact." J Biomech 4:49-71, 1971.

Roberts, V.L. "Biomechanics of Snowmobile Spine Injuries." J Biomech 4:569-577, 1971.

Rudy, K. "[Etiology and Results of Injuries of the Spinal Column]" Schweiz. Med Wschr 99:1433-1438, October, 1969 (Ger)

Schneider, R., et al. "Lap Seat Belt Injuries; The Treatment of the Fortunate Survivor." Michigan Medicine 67:171-186, 1968.

Schwartz, M. "Comparative Study of Body Displacements in Both Humans and Anthropomorphic Dummies when Simultaneously Subjected to Controlled Vertical Impact Type Decelerations." Department of the Navy, Naval Air Development Center, Johnsville, Pennsylvania, Report No. NADC-AC-6808, April, 1968.

Smith, W.S. and Kaufer, H. "A New Pattern of Spine Injuries Associated with Lap Type Seat Belt." Univ Mich Med Center J 33:99-104, 1967.

Tanabe, M. "[Experimental Studies on the Etiological Mechanism of So-called Cervical Syndrome--Cervical Spondylosis Caused by Repeated Movement]" J Jap Orthop Ass 40:175-194, May, 1966. (Jap)

Terry, C.T. and Roberts, V.L. "A Viscoelastic Model of the Human Spine Subjected to $+G_Z$ Accelerations." J Biomech 1:161-168, July, 1968.

III. ANATOMY/RADIOLOGY

Asai, H. "[Experiemntal Study on the Pathology of So-called Whiplash Injuries, with Special Reference to the Histopathological Examination]" J. Jap. Orthop. Assoc. 45:431-439, June, 1971. (Jap)

Badoux, D.M. "Some Notes on the Curvature of the Vertebral Column in Vertebrates with Special Reference to Mammals." Acta Morph. Neerl. Scand. 7:29-40, 1968.

Balau, J., et al. "[Radiography of Traumatic and Nontraumatic Changes of the Occipito-Cervical Transition Area]" Hefte Unfallheilkd. 108:37-39, 1971. (Ger)

Bazilevskaia, Z.B. "[Roentgendiagnosis of Injuries of Ligaments and Intervertebral Joints in Injuries of the Spine and Spinal Cord]" Vestn. Rentgenol. Radiol. 45:99-100, September, 1970. (Russian)

Beck, E. ["Radiographic Measuring Methods in Vertebral Fractures]" Hefte Unfallheilkd. 108:36-37, 1971. (Ger)

Bohler, J. "[Morphology of Cervical Vertebral Injuries According to Etiology]" Hefte Unfallheilkd. 108:10-13, 1971 (Ger)

Bricolo, A, et al. "[Cervical Disk Radiography: Diagnostic Value and Indications]" Fracastoro 59:731-739, November-December, 1966. (Ital)

Cicala, A. "[Importance of Clinico-Radiological Studies of the Spinal Column in Selection of Flight Personnel]" Riv. Med. Aero. 29: Suppl. 293-305, December, 1966. (Ital)

Cossette, J.W. "The Instantaneous Center of Rotation of the Third Lumbar Intervertebral Joint." J. Biomech. 4:149-153, 1971.

Davidson, C. "Pathology of the Spinal Cord as a Result of Trauma." Res. Publ. Assoc. Res. Nerv. Ment. Dis. 24:151, 1945.

Delahaye, R.P., et al. "[Radiography of the Spine in a Sitting Position. Its Importance in Aviation Medicine]" Rev. Corps. Sante Armees 10:571-574, 1969. (French)

Delahaye, R.P., et al. "[Radiology of Fractures and Injuries of the Spine]" Presse Med. 78:1365, June, 1970. (French)

Delahaye, R.P., et al. "[Systematic Radiologic Examination of the Spine During the Admission Examination of Flight Personnel]" Rev. Corps Sante Armees 11:667-683, 1970. (French)

Diaconescu, N., et al. "[Comparative Studies of the Development of Dynamics of the Thoracolumbar Vertebrae and the Division of Lobes of the Liver in Primates and Humans]" Anat. Anz. 118:185-191, 1966. (Ger)

Diaconescu, N., et al. "[The Spinal Column as a Form Building Factor]" Acta. Anat. (Basel) 73:210-241, 1969. (Ger)

Djian, A., et al. "[Anatomo-radiologic and Physiologic Review of the Cervical Spine]" Presse Therm Climat. 104:199-204, 1967. (Fre)

Exner, G. "[Pathologic Anatomy and Clinical Evaluation of the Cervical Syndrome]" Beitr. Orthop. Traumatol. 17:620-623, 1970. (Ger)

Fait, M., et al. "[Apparatus for Spinal Measurements]" Acta Chir. Orthop. Traum. Cech. 35:356-358, August, 1968. (Cze)

Gordon, E.E. "Natural History of the Intervertebral Disk." Arch. Phys. Med. 42:750-763, 1961.

Happey, F., McRae, T.P. and Naylor, A. "X-ray Chrystallographic Investigation on the Change with Age in the Structure of the Human Intervertebral Disc. In Nature and Structure of Collagen." p. 65. Editor: Randall, J.T. Butterworth's Scientific Publications, London, 1953.

Hatt, M.U. "[Segmental Localisation of Cervical Herniated Discs By Clinical Diagnosis, Electromyography (EMG) and Myelography]" Deutsch. Z. Nervenheilk. 197:56-65, December, 1969. (Ger)

Hewitt, W. "The Intervertebral Foramen." Physiotherapy 56:332-336, 1970.

Houston, C.S., et al. "The Shape of Vertebral Bodies and Femoral Necks in Relation to Activity." Radiology 89:59-66, July, 1967.

Jostes, F.A. "The Laminagraph as an Aid to the Diagnosis of Atlanto-Axial Lesions." JAMA 118:353, 1942.

Klausen, K., et al. "On the Location of the Line of Gravity in Relation to L5 in Standing." Acta Physiol. Scand. 72:45-52, January-February, 1968.

Koneczny, O. "[Interpretation and Documentation of Traumatic Injuries of the Spine]" Hefte Unfallheilk 90:33-72, 1967. (Ger)

Lindbom, A. "The Roentgenographic Appearance of Injuries to the Intervertebral Discs." Acta. Radiol. 45:129, 1956.

Lippert, H. "[Anatomy of the Spine from the Viewpoints of Development and Function]" Med. Klin. 61:41-46, January, 1966. (Ger)

Lowrance, E.W., et al. "Weights and Variability of Components of the Human Vertebral Column." Anat. Rec. 159:83-88, September, 1967.

Lutz, G. "[The Development of the Little Vertebral Joints]" Z. Orthop. 104:19-28, December, 1967. (Ger)

Naylor, A., Happey, F. & MacRae, T. "Changes in the Human Intervertebral Disc with Age: A Biophysical Study." J. Amer. Geriat. Soc. 3:964, 1955.

Naylor, A. "The Biophysical and Biochemical Aspects of Intervertebral Disc Herniation and Degeneration." Ann. Roy. Coll. Surg. Eng. 31:91, 1962.

Orlov, N.V. "[Significance of Roentgeneologic Studies of the Spine in the Practice of the Aviation-Medical Expertise]" Voennomed. Zh. 10:67-70, October, 1966. (Rus)

Pieper, K.S., et al. "[Exact Demonstration of Differences in the Curvatures of the Spine in Very Small Children, Children and Adults by Quadratic Regression Analysis]" Gegenbaur. Morph. Jahrb. 108:451-475, 1966. (Ger)

Ponova, L.I. "[X-ray Changes in the Spine of Workers with Concrete Exposed to the Action of Combined Vibration]" Vestn. Rentgen. Radiol. 41:78-80, May-June, 1966. (Rus)

Rogers, L.F. "The Roentgenographic Appearance of Transverse or Chance Fractures of the Spine: The Seat Belt Fracture. " Amer. J. Roentgen. 111:844-849, 1971.

Rosen, J.S., et al. "Electromyography in Spinal Cord Injury." Arch. Phys. Med. 50:271-273, May, 1969.

Roth, M. "Models of Vertebro-neural Relations." Acta Radiol [Diagn] (Stockholm) 9:746-753, 1969.

Sauli, M. "[Problems of Clinical Physiopathology and Therapy in Acute Spinal Cord Injuries]" Friuli Med. 25:291-304, 1970. (Ital)

Schoberth, H. "[The Vertebral Column of School Children--Orthopedic Requirements of School Sitting]" Ergonomics 12:212-225, March, 1969. (Ger)

Seyss, R. "[Radiation Exposure in Roentgenography of the Spine]" Med. Mschr. 22:304-305, July, 1968. (Ger)

Sibirskaia, P.V. et al. "[X-ray Diagnosis of Compression Fractures of the Spine in Children]" Ortop. Traum. Protez. 31:59-61, November, 1970. (Russian)

Stofft, E., et al. "[Flaval Ligaments of the Human Spine]" Verh. Anat. Ges. 63:363-371, 1969. (Ger)

Swezey, R.L. et al. "Radiographic Demonstration of Induced Vertebral Facet Displacement." Arch. Phys. Med. 52:244-249, 1971.

Uehlinger, E. "[Anatomy and Pathologic Anatomy of the Spine]" Bibl. Tuberc. 23:25-45, 1967. (Ger)

Weinbren, M. "The Value of Tomography in the Examination of Fractured Vertebra." Acta Radiol. Suppl. 116 p., 184, 1954.

Zatzkin, H.R. The Roentgen Diagnosis of Trauma: The Whiplash Injury. Year Book Publishers, Chicago, 1965.

Zinchenko, A.P. et al. "[Neurologic Syndromes in Pathology of the Cervical Spine and Structures of the Neck in Acute Cranio-cerebral Injuries]" Vopr. Neirokhir. 35:46-49, March, 1971. (Russian)

IV. EXPER. STRENGTH/STRESS

Albin, M.S. et al. "Funtional and Electrophysiological Limitations of Delayed Spinal Cord Cooling After Impact Injury." Surg. Forum 19:423-424, 1968.

Albin, M.S. et al. "Study of Functional Recovery Produced by Delayed Localized Cooling After Spinal Cord Injury in Primates." J. Neurosurg. 29:113-120, 1968.

Albin, M.S. et al. "Effects of Localized Cooling on Spinal Cord Trauma." J. Trauma 9(12):1000-1007, 1969.

Ames, W.H. "Tolerance to Acceleration in the Automatic Pilot Ejection Seat." Bull. U.S. Army Med. Dept. 7(9):776, September, 1947.

Aquino, C.F. "A Dynamic Model of the Lumbar Spine." J. Biomechanics 3:473-486, 1970.

Barcikowski, W. "[Effect of Acceleration on the Bones and Joints of the Spine]" Chir Narzad Ruchu Ortop Pol 33:137-144, 1967. (Pol)

Bechtoldt, W. "[On the Problem of Damage to the Spine Due to Excessive Stress in Degeneration of the Intervertebral Disc]" Z. Orthop. 106:5-32, March, 1969 (Ger)

Beeding, E.L. Jr. "Daisy Track and Supporting System." HADC Technical Note, June, 1957.

Beeding, E.L. Jr. "Daisy Track Tests 156-270, June 13-December 17, 1957." USAF Missile Development Center, Holloman AirForce Base, New Mexico, Project No. 7850, Test Report No. 7, March 1958.

Beeding, E.L. Jr. and Hessberg, R. Jr. "Daisy Track Tests 271-337." Report AFMDC TR 28-8, Runs 4 Feb.-9May 1958.

Beeding, E.L. Jr. "Daisy Track Tests. Test Numbers: 338-519, May 22, 1958-July 9, 1959." USAF Missile Development Center, Holloman Air Force Base, New Mexico. Project No. 7850, Task No.78503 Test Report No. 59-14. December, 1959.

Beeding, E.L. Jr. "Daisy Decelerator Tests 520-707. July 13, 1959-April 13, 1960." USAF Missile Development Center, Holloman Air Force Base, New Mexico. MDW Test Report 60-4, July, 1960.

Beeding, E.L. Jr. and Mosely, J.D. "Human Deceleration Tests." USAF Missile Development Center, Holloman Air Force Base, New Mexico. AFMDC-TN-60-2. January, 1960.

Beeding, E.L. Jr. "Human Forward Facing Impact Tolerance." Aerospace Medicine 32(3):220, March 1961.

Beeding, E.L. Jr. and Cook, J.E. "Correlation Tests of Animals and Humans." 5th Stapp Automotive Crash Field Demonstration Conference, p. 125 (1961), 1962.

Bierman, H.R. "The Protection of the Human Body from Impact Forces of Fatal Magnitude." The Military Surgeon. 100:125-135, February, 1947.

Breig, A. "Overstretching of and Circumscribed Pathological Tension in the Spinal Cord--A Basic Cause of Symptoms in Cord Disorders." J. Biomechanics 3:7-9, 1970.

Chaffin, D.B. and Maulis, E.J. "An Empirical Investigation of Low Back Strains and Vertebrae Geometry." J. Biomechanics 2:89-96, 1969.

Charles, J.P. "Fractured Vertebrae in U.S. Navy Aircraft Accidents." J. Aviation Med. 24:483-490, 1953.

Chubb, R.M., Dietrick, W.R. and R.H. Shannon "Compression Fracture of the Spine During USAF Ejections." Aerospace Med. 36:968-972, 1965.

Cook, J.E. and Mosely, J.D. "Visceral Displacement in Black Bears Subjected to Abrupt Deceleration." Aerospace Med. 31(1):1-8, 1960.

David, H. et al. "Electromyographic and Cinematographic Analysis of Spinal Extension Under Stress." J. Physiol. (London) 200:4P-6P, January, 1969.

Ducros, E. and Grégoire, R. "[Spine Injuries in Flight Accidents of the French Air Force]" Médecine Aeronautique (Paris) 9(4):483-487, 1954 (French)

Ewing, C.L. "Vertebral Fracture in Jet Aircraft Accidents: A Statistical Analysis for the Period 1959 through 1963." U.S. Navy, Aerospace Med. 37(5):505-508, May, 1966.

Fabricius, B. "[Abrupt Acceleration of Auto Occupants as a Result of Rear-end Collision]" Dissertation for Doktor-Ingenieur, Technischen Universität, Berlin, 1969. (German)

Fairholm, D. et al. "Microangiographic Study of Experimental Spinal Injuries in Dogs and Rabbits." Surg. Forum 21:453-455, 1970.

Feder, H.C. and Root, E.H. "Dynamic Response Analysis of $+G_X$ Impact on Man, 6571st Aeromedical Research Laboratories, Holloman AFB, New Mexico, Rept. ARL-TR-64-11, November, 1964.

Furusho, H. et al. "Analysis of Occupant Movements in Rear-end Collisions. Parts I and II. Paper No. 13-14, JSAE Safety Research Tour, 1969.

Fuse, K. "[Study on Tensile Strength of the Vertebral Arch in the Spinal Supporting System, with Special Reference to the Isolated Arch of the Vertebrae in Spondylolysis]" Nippon Ika Daig Z. 36:132-159, 1969. (Jap)

Garcia, D.J. "Investigation of Nonlinearities in the Whiplash Problem." Ph.D. thesis, Tulane University, U.S.A., 1966.

Groh, H. et al. "[The Static Load of the Spinal Column Through the Sagittal Curvature]" Int. Z. Angew Physiol. 24:129-149, 1967. (Ger)

Gurdjian, E.S. et al. "Repeated Loading Tests of the Lumbar Spine." Surg. Forum 9: 1959.

Gurdjian, E.S., Lissner, H.R., Evans F.G., Patrick, L.M. and Hardy, W.G. "Intracranial Pressure and Acceleration Accompanying Head Impacts in Human Cadavers." Surgery, Gynecology and Obstetrics 113:185-190, 1961.

Hanson, P.G. "Maximum Voluntary Ventilation after $+G_x$ Impact in Humans." 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico, Rept. ARL-TR-65-22, November, 1965.

Henzel, J.H., Clarke, N.P., Mohr, G.C. and Weis, E.B. Jr. "Compression Fractures of Thoracic Vertebrae Apparently Resulting from Experimental Impact, A Case Report." Aerospace Medical Laboratories, Wright-Patterson AFB, Ohio, Rept. AMRL-TR-65-134, August, 1965.

Hinz, P. "[Morphological Findings in Experimentally Induced Whiplash Injuries]" Hefte Unfallheikld. 108:29-31, 1971.

Italiano, P. "[Vertebral Fractures of Pilots in Helicopter Accidents]" Riv. Med. Aero. 29:577-602, Oct-Dec,1966 (Ital.)

Klopfenstein, H.W. "Compression Fracture of the Seventh Thoracic Vertebra Caused by Experimental Impact: A Case Report." Paper presented at the 40th Annual Scientific Meeting, Aerospace Medical Association, San Francisco, May 5-8, 1969.

Lewis, S.T. and Stapp, J.P. "Experiments Conducted on a Swing Device for Determining Human Tolerance to Lap Belt Type Decelerations." 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico, Report ARMDC TN-57-1, 1957.

Liu, Y.K. "Towards a Stress Criterion of Injury--An Example in Caudocephalad Acceleration." J. Biomechanics 2:145-149, 1969.

Lombard, C.F., Close, P. Theide, F.C. and Larmie, F. "Impact Tolerance of Guinea Pigs Related to Orientation and Containment." Aerospace Medicine 35(1):1-6, January, 1964.

Lombard, C.F., Bronson, S.D., Theide, F.C. , P. Close and Larmie, F.M. "Pathology and Physiology of Guinea Pigs Under Selected Conditions of Impact and Support Restraint." Aerospace Medicine 35(9):860-866, 1964.

Lovelace, W.R., Baldes, E. and Wulff, V.J. "The Ejection Seat for Emergency Escape from High Speed Aircraft." ASTIA ATI-7245, 1945.

Nachemson, A. and Morris, J. "Lumbar Discometry, Lumbar Intradiscal Pressure Measurements in Vivo." Lancet pp. 1140-1142, May 25, 1963.

Neely, S.E. and Shannon, R.H. "Vertebral Fractures in Survivors of Military Aircraft Accidents." J. Aviation Med. 29:750-753, 1958.

Ommaya, A.K. "Trauma to the Nervous System. A Clinical and Experimental Study." Annuals of the Royal College of Surgeons 39:317-347, 1966.

Ommaya, A.K. and Hirsch, A.E. "Tolerances for Cerebral Concussion from Head Impact and Whiplash in Primates." J. Biomechanics 4:13-22, 1971.

Provost, E.L. and Schrum, D.J. "Dynamic Research of Upper Torso Restraints." Proceedings, 9th Stapp Car Crash Conference, pp. 83-92, University of Minnesota Press, 1966.

Reader, D.C. "The Restraint Afforded by the USAF and Proposed RAF-IAM Seat Harnesses for the F-111 Under High Forward and Lateral Decelerations." IAM Report No. 421, September, 1967.

Rushmer, R.F. "Comparsion of Experimental Injuries Resulting from Decelerative Forces Applied to the Ventral and Dorsal Aspects of Rabbits During Simulated Aircraft Accidents." ASTIA AD 135 555, 1944.

Rushmer, R.F., Green, E.L. and Kingsley, H.D. "Internal Injuries Produced by Abrupt Deceleration of Experimental Animals." J. Aviation Med. 17:511,December, 1946.

Savely, H.E., Ames, W.H. and Sweeney, H.M. "Laboratory Tests of Catapult Ejection Seat Using Human Subjects." ASTIA ATI-119947, 1946.

Severy, D.M., Mathewson, J.H. and Bechtol. C.O. "Controlled Automobile Rear-end Collisions: An Investigation of Related Engineering and Medical Phenomena." Chapt. 5, pp. 152-184, In, Medical Aspects of Traffic Accidents, Ed. by H. Elliott, Montreal, Sun Life Assurance Co. of Canada, 1955.

Shaw, Robert S. "Ruptured Intervertebral Disk from Positive Acceleration." J. Aviation Medicine 19:276-278, 1948.

Singer, J.M. et al. "Changes in Evoked Potentials After Experimental Cervical Spinal Cord Injury in the Monkey." Exp. Neurol. 29:449-461, December, 1970.

Slattenschek, A. "[Behavior of Motor Vehicle Windshields in Impact Tests with a Phantom Head]" Automobiltechnische Zeit 70(7):233-241, July, 1968.

Snyder, R.G., Snow, C.C., Young, J.W., Crosby, W.M. and Price, G.T. "Pathology of Trauma Attributed to Restraint Systems in Crash Impacts." Aerospace Medicine 39(8):812-829, 1968.

Snyder, R.G. "A Survey of Automotive Occupant Restraint Systems: Where We've Been, Where We are and Our Current Problems." Society of Automotive Engineers, Inc., New York. International Automotive Engineering Congress, Detroit, Michigan, Paper No. 690243, January, 1969.

Snyder, R.G. "Occupant Restraint Systems of Automotive, Aircraft, and Manned Space Vehicles: An Evaluation of the State-of-the-Art and Future Concepts." Impact Injury and Crash Protection (E.S. Gurdjian, W.A.Lange, L.M. Patrick, and L.M. Thomas, eds.), Charles C.Thomas, Springfield, Illinois, pp. 496-563, 1970.

Stapp, J.P. "Human Exposure to Linear Deceleration. Part I, Preliminary Survey of Aft-Facing Seated Position." AF Tech. Rept. 5915, June, 1949.

Stapp, J.P. "Human Exposure to Linear Decelerative Forces in the Background Facing Seated Position." Military Surgeon 109:106-108, 1951.

Stapp, J.P. "Tolerance to Abrupt Deceleration." Collected Papers on Aviation Medicine, AGARD, Butterworths Scientific Publications, London, pp. 122-139, 1955.

Swaim, S.F. "Injury to the Cervical Spinal Cord in the Dog." J. Amer. Vet. Med. Assoc. 158:462-467, February, 1971.

Swearingen, J.J., Garner, J.D., McFadden, E.B. and Blethrow, J.G. "Human Voluntary Tolerance to Vertical Impact." Aerospace Medicine 31(12):989, 1960.

Taylor, E.R. "Biodynamics: Past, Present and Future." 6571st Aeromedical Research Laboratory, Holloman Air Force Base, New Mexico, Report ARL-TDR-63-10, March, 1963.

Tursunov, B.S. "[Effect of Experimental Partial Excision of the Intervertebral Disk and Adjacent Surfaces of the Vertebral Bodies on the Growth and Formation of the Spine]" Ortop. Traumatol. Protez. 31: 60-64, 1970. (Russian)

Unterharnscheidt, F., et al. "Traumatic Lesions of Brain and Spinal Cord Due to Nondeforming Angular Acceleration of the Head." Texas Rep. Biol. Med. 27:127-166, 1969.

von Gierke, H.E. and Steinmetz, E. "Motion Devices for Linear and Angular Oscillation and for Abrupt Acceleration Studies on Human Subjects (Impact)." National Academy of Sciences -- National Research Council, Washington, D.C., Publication 903, 1961.

Wassilev, W. "[Changes in the Neck Part of the Spine in Vertical Load]" Anat. Anz. 121:453-467, 1967. (Ger)

Watts, D.T., Mendelson, E.S. and Hunter, H.N. "Evaluation of Face Curtain and Arm Rest for Use on Ejection Seats." Naval Air Experiment Station, Philadelphia, Pa., TED No. NAM 256005, Rept. No. 4, March, 1947.

Watts, D.T., Mendelson, E.S. and Kornfield, A.T. "Human Tolerance to Accelerations Applied from Seat to Head During Ejection Seat Tests; Pilot's Escape from High Performance Aircraft Mechanism for Development and Test of." ASTIA ATI 206-052, 1947.

V. INJURIES/ FRACTURES

Abell, J.M. "Evaluating Spine Injury Claims." Amer. J. Orthop. Surg. 10:128-131, May, 1968.

Adams, A.E. "[Basic Principles and Clinical Evaluation of Blunt Spinal Cord Injuries]" Nervenarzt. 40:579-585, Dec. 1969 (Ger)

Alexander, E., et al. "Anterior Dislocation of the First Cervical Vertebra Simulating Cerebral Birth Injury in Infancy." Amer. J. Dis. Child. 85:173-181, 1953.

Anchelevich, V.D. "[Remote Complications After Closed Trauma to the Spine and Spinal Cord]" Vop. Neirokhir. 32:6-10, March-April, 1968. (Rus)

Anchelevich, V.D. "[Some Factors Determining Prognosis in Closed Injury of the Spine and Spinal Cord"] Klin. Khir. (Kiev) 5:45-9, May 1968. (Rus)

Andersen, P.T., et al. "Fracture of the Spine. Follow-up on a Material Treated by Early Mobilization." Acta. Orthop. Scand. 40:653-663, 1969.

Anderson, L.D. "Injuries of the Cervical Spine." J. Trauma 11:537-539, 1971.

Ashworth, J. "Spinal Injuries and Fractures." Brit. Med. J. 4:414-415, November 15, 1969.

Aston, J.N. and Perkins, T.A. "The Clinical Pattern of Injury in Road Accidents." Brit. Med. J. 2:200, 1954.

Baab, O.D. and Howorth, M.D. "Fractures of the Dorsal and Lumbar Vertebrae." JAMA 146:97-100, 1951.

Babichenki, E.I. "[Open Reduction of Fracture-Dislocations of the Thoracic and Lumbar Portions of the Spine with Injury of the Spinal Cord]" Ortop. Travm. Protez.28:9-13, July, 1967. (Rus)

Babin-Chevaye "[Injuries of the Cervical Spine]" J. Presse Med. 74:2747-8, December 10, 1966. (French)

Barnes, R. "Paraplegia in Cervical Spine Injuries." Proceedings of the Royal Society of Medicine (Section of Orthopaedics), 54:365, 1961.

Barnett, I. and Moss, B. "Whiplash Injuries." Gen. Pract., October, 1957.

Barraquer-Bordas, L., et al. "[5 Further Cases of Acute Central Cervical Medullary Syndrome Caused by Hyperextension]" Acta Neurol. Belg. 66: 99-105, February, 1966. (French)

Bastron, J.A. and Henderson, E.D. "Answer to Question, Pain After Whiplash Injury." JAMA 184:609-610, May 18, 1963.

Bazilevskaia, Z.B. "[Clinical Aspects and Therapy of Ligamental Injuries in Injuries of the Spine and Spinal Cord]" Ortop. Traumatol. Protez. 31:16-19, June, 1970. (Russian)

Bentley, G., et al. "Multiple Spinal Injuries." Brit. J. Surg. 55:565-570, August, 1968.

Berezina, I.N. "[Vestibular Disorders in Lesions of the Cervical Portion of the Spinal Cord and Spine]" Vestn. Otorinolaring. 29:50-54, Jan-Feb, 1967. (Rus)

Berryman, J.S. "Diagnosis of Whiplash Injuries." Int. Rec. Med. 169:26-27, 1956.

Bertrand, G. "Management of Spinal Injuries with Associated Cord Damage." Postgrad. Med. 37:249-262, 1965.

Blikra, G., et al. "Fractures of the Spine with Cord Lesions." Acta. Orthop. Scand. 40:666, 1969.

Blikra, G., et al. "[Fractures of the Spine with Lesions of the Spinal Cord]" Nord. Med. 81:207-210, February 13, 1969. (Nor)

Bogdanov, F.R., et al. "[Work Capacity After Vertebral Fracture Without Spinal Cord Injury]" Ortop. Traum. Protez. 29(4):15-22, 1968. (Rus)

Bogdanov, F.R., et al. "[Some Objective Methods of Evaluation of the Functional Capacity of the Spine Following Compression Fracture]" Ortop. Travm. Protez. 30:20-5, April, 1969. (Rus)

Bohler, J. "[Operative Treatment of Fractures of the Dorsal and Lumbar Spine." J. Trauma 10:1119-1122, 1970.

Boling, D.S. "Spine Fractures Involving the Trunk." J. Florida Med. Ass. 54:960-961, October, 1967.

Botton, J.E. "Athletic Head and Spinal Injuries." Virginia Med. Monthly 96:79-84, passim, Feb. 1969.

Braunstein, P.W., et al. "Preliminary Findings of the Effect of Automotive Safety Design on Injury Patterns." Surg. Gynec. Obstet. 105:257-263, September, 1957.

Brav, E.A. "Voluntary Dislocation of Neck: Unilateral Rotary Subluxation of Atlas." Am. J. Surg. 32:144, 1936.

Bricker, D.L. "Major Abdominal and Thoracic Trauma Associated with Spinal Cord Injury: Problem in Management." J. Trauma 11:63-73, 1971.

Brussatis, F., et al. "[Vertebral Luxation in the Region of the Upper Thoracic Spine]" Z. Orthop. 102:367-71, March 1967. (Ger)

Cailliet, R. "The Diagnosis of Neck and Arm Pain by Examination." Illinois Med. J. 133:277-88, March, 1968.

Cameron, B.M. "Whiplash Injuries." Amer. J. Nurs. November, 1962.

Cerciello, C. "[Anterior Approach to the Cervical Column]" Minerva Chir. 23:1257-64, December, 1968. (Italian)

Cheshire, D.J. "A Classification of the Functional End-Results of Injury to the Cervical Spinal Cord." Paraplegia 8:70-73, August, 1970.

Cibeira, J.B. "Some Conclusions on a Study of 365 Patients with Spinal Cord Lesions." Paraplegia 7:249-54, February, 1970.

Clark, C.C. and Faubert, D. A Chronological Bibliography of the Biological Effects of Impact. Martin Company, Baltimore, Maryland, Report ER-11953, 27 September, 1961.

Cloward, R.B. "Treatment of Acute Fractures and Fracture Dislocations of the Cervical Spine by Vertebral Body Fusion." J. Neurosurg. 18: 201-209, 1961.

Comarr, A.E. and Kaufman, A.A. "A Survey of the Neurological Results of 858 Spinal Cord Injuries." J. Neurosurg. 13:95-106, 1956.

Comarr, A.E. "Interesting Observations on Females with Spinal Cord Injury." Med. Serv. J. Canada 22:651-61, July-August, 1966.

Constantin, P. et al. "Relations Between the Cervical Spine and the Vertebral Arteries." Acta. Radiol. (Stockholm) 11:91-96, 1971.

Curran, W.J. and Chayet, N.L. Trauma and the Automobile. Anderson, Cincinnati, 1966.

Daw, E.F., Svien, H.J., and Michenfelder, J.D., et al. "The Role of the Anesthesiologist in the Management of Acute Intracranial and Spinal Cord Emergencies." Surg. Clin. N. Amer. 45:919-926, 1965.

Dreyfus, P. "[Cervico-cephalic Complications of the Automobile Accidents]" Minerva Med. 62:2625-2628, 1971. (Ital)

Dreyfus, P. et al. "[Cervicocephalic Complications of Automobile Accidents]" Cah. Med. 12:565-568, 1971. (French)

Dunbar, H.S. and Ray, B.S. "Chronic Atlanto-Axial Dislocations with Late Neurologic Manifestation." Surg. Gynec. Obstet. 113:757-762, 1961.

Dunlop, J. and Parker, C.H. "Correction of Compressed Fractures of Vertebrae." JAMA 94:89, 1930.

Dunlop, J. and Parker, C.H. "Treatment of Compressed and Impacted Fractures of Bodies of Vertebrae." Radiology 17:228, 1931.

Dunlop, J. and Parker, C.H. "Correction of Compressed and Impacted Fractures of Vertebrae." J. Bone and Joint Surg. 15:153, 1933.

Dzenitis, A.J. "Spontaneous Atlanto-Axial Dislocation in a Mongoloid Child with Spinal Cord Compression." J. Neurosurg. 25:458-460, 1966.

(Editorial) "Whiplash Injury in Infancy." Med. J. Aust. 2:456, 1971.

Ehlert, H. "[On the Treatment of Spinal Fractures]" Mschr. Unfallheilk. 69:109-12, March, 1968. (Ger)

Ellis, J. "Compression Fractures of Vertebral Bodies." J. Bone and Joint Surg. 42:139, 1944.

Erlacher, G., et al. "[Vertebral Fractures in Children]" Hefte Unfallheilkd. 108:124-127, 1971. (Ger)

Evarts, C.M. "Traumatic Occipito-Atlantal Dislocation." J. Bone Joint Surg. 52:1653-1660, December, 1970.

Fang, H.S. and Ong, G.B. "Direct Anterior Approach to the Upper Cervical Spine." J. Bone Joint Surg. 44A:1588-1604, 1962.

Fischer, H. "[Accidental Injuries of the Spinal Cord and Their Sequelae]" Z. Allgemeinmed. 46:1080-1084, 1970. (Ger)

Fitz Hugh, G.S., et al. "Injuries of the Larynxand Cervical Trauma." Ann. Otol. Rhin. Laryn. 71:419-442, 1962.

Flax, H.J., et al. "The Whiplash Injury." Bal. Assoc. Med. PR 63:161-165, June, 1971.

Franke, K. "[Intervertebral Disk Calcification Following Fracture of the Cervical Spine in Athletic Injury]" Hefte Unfallheilkd. 108:81-2, 1971. (Ger)

Freyschuss, U. and Knutsson, E. "Cardiovascular Control in Man with Transverse Cervical Cord Lesions." Life Sci. 8:421-424, 1969.

Fusek, I. "[Surgical Treatment of Inveterated Post-traumatic Deformations of the Cervical Spine by the Frontal Approach]" Rozhl. Chir. 48:340-6, August, 1969. (Cze)

Fusek, I. "[Surgical Management of Kyphotic Deformations of the Cervical Spine Following Laminectomy Using the Anterior Approach]" Cesk. Neurol. 33:188-91, July, 1970. (Cze)

Gage, E.D. "Surgical Repair of a Fractured Cervical Spine in the Dog." J. Amer. Vet. Med. Ass. 153:1407-11, 1 December, 1968.

Geisler, W.O., Wynne-Jones, M. and Jousse, A.T. "Early Management of the Patient with Trauma to the Spinal Cord." Med. Serv. J. Can. 22:512-523, 1966.

Gnesina, E.A., et al. "[Changes in the Electroencephalogram in Closed Cranicerebral Injuries Associated with Injuries of the Thorax and Spine, and Fractures of the Extremities]" Vestn. Khir. Grekov. 101:109-13, July, 1968. (Rus)

Gillingham, J. "The Problem of Head and Spinal Injuries: Prevention of the Second Accident." Med. Sci. Law 10:104-109, April, 1970.

Gogler, E. and Laqua, H. "[The Significance of Trauma Records for Clinical Surgery]" Langenbecks Arch. Klin. Chir. 275:477-518, 1953. (Ger)

Goni, P.B. "[Atlanto-Axial Dislocation]" Cir. Cir. 38:15-86, 1970. (Spanish)

Gray, A.R. et al. "Injuries of the Trachea." Arch. Surg. 76:138-142, 1958.

Grebeniuk, V.I. "[Classification of Spinal Cord Compression in Closed Injuries of the Spine]" Vestn. Khir. Grekov. 97:100-4, November, 1966. (Rus)

Groh, H. "[Whiplash Trauma of the Cervical Vertebral Column]" Munch. Med. Wochenschr. 112:Suppl. 49:1-2, 1970. (Ger)

Gurdjian, E.S., Lissner, H.R. and Patrick, L.M. "Protection of the Head and Neck in Sports." JAMA 182:509-512, 1962.

Gurdjian, E.S., et al. (ed.) Impact Injury and Crash Protection. C. C Thomas, Springfield, Illinois, 1970.

Guzman, H. "[Injuries of the Nervous System. IV. Injuries of the Spine and Medulla]" Gac. Med. Mex. 98:1523-6, December, 1968. (Spa)

Haisova, L. et al. "Facial Bone Fractures Associated with Cervical Spine Injuries." Oral Surg. 30:742-748, December, 1970.

Hall, H.B. "Whiplash Injuries of the Spine." Minn. Med., July, 1958.

Hambly, E.H.T. "Fracture of the Odontoid Process--A Method of Fixation." Lancet 2:851, 1944.

Hanafee, W., et al. "Trauma of the Spine and Its Contents." Radiol. Clin. N. Amer. 4:365-82, August, 1966.

Hancevic, J., et al. "[Extension of the Cervical Spine with a Rolling Support]" Hefte Unfallheilkd. 108:82-4, 1971. (Ger)

Harmon, H., et al. "Surgical Repair of a Vertebral Fracture in a Dog." J. Amer. Vet. Med. Ass. 149:46-7, July, 1966.

Harrington, O.B., et al. "Traumatic Injuries of the Cervical Trachea." Amer. J. Surg. 103:541-543, 1962.

Harris, L.S., et al. "'Spinal Injury' and Sudden Infant Death. A Second Look." Amer. J. Clin. Path. 52:289-95, September, 1969.

Harris, P. "The Diagnosis and Early Treatment of Patients with Spinal Cord Injury." Proc. 16th Annual Clinical Spinal Cord Injury Conf., 1967. Long Beach, California, Veterans Administration Hospital, p. 14-18, 1967.

Hatchette, S. "Isolated Fracture of the Atlas." Radiology. 36:233, 1941.

Hellstrom, B., et al. "Prevention of Spinal Cord Injury in Hyperextension of the Fetal Head." JAMA 204:1041-4, June, 1968.

Herrschaft, H. "[Involvement of the Vertebral Artery in Whiplash Injury]" Arch. Orthop. Unfallchir. 70:248-264, 1971. (Ger)

Hijikata, F., et al. "[Ocular Symptoms Following Head Injury and Whiplash Injury and Treatment for Them with Special Reference to the Effect of Medium Tranquilizer NC:123]" Folia Ophthal Jap. 20:1106-14, December, 1969. (Jap)

Hinchey, J.J. and Bickel, W.H. "Fracture of Atlas." Ann. Surg. 121:826, 1945.

Hinz, P., et al. "[Forensic Evidence of the So-called Vital Signs in Street Traffic Victims with Injuries of the Cervical Spine]" Z. Rechtsmed. 68:95-100, 1971.

Hoffman, W., et al. "[Therapeutic Results in Vertebral Compression Fractures]" Mschr. Unfallheilk. 69:574-8, December, 1966. (Ger)

Holdsworth, F.W. "Diagnosis and Treatment of Fractures of the Spine." Manitoba Med. Rev. 48:13-5, January, 1968.

Holdsworth, F. "Fractures, Dislocations, and Fracture-Dislocation of the Spine." J. Bone Jt. Surg. 52:1534-1551, December, 1970.

Huddleston, O.L. "Whiplash Injuries" Calif. Med. 89:319-321, November, 1958.

Ice, J., Snyder, R.G., Hyde, A.S. and Leverett, S. Jr. Biomedical Research Studies in Acceleration, Impact, Weightlessness, Vibration, and Emergency Escape and Restraint Systems: A Comprehensive Bibliography: Supplement 1. A joint report of the Federal Aviation Agency and USAF Aerospace Medical Division, 1966.

Irger, I.M. "[A New Method of Occipito-Cervical Arthrodesis in Instability of the Atlanto-epistropheal Joint and in Fracture-Dislocations of Cervical Vertebra II]" Vop. Neirokhir. 32:1-9, July-August, 1968. (Rus)

Iumashev, G.S., et al. "[Surgery of Uncomplicated Fractures of the Spine]" Khirurgiia (Sofiia) 22:48-54, April, 1969 (Rus)

Iumashev, G.S., et al. "[Remote Results of the Surgical Treatment of Uncomplicated Compression Fractures of the Vertebrae]" Ortop. Travm. Protez. 30:26-9, April 1969 (Rus)

Jackson, F.E., et al. "The Treatment of Chronic Complications of Cervical Spine Injuries." Med. Serv. J. Canada. 22:497-511, July-August, 1966.

Jacobs, C.M. "Atlas and Axis Luxation." Am. J. Orthop. Surg. 16:357, 1918.

Jakob, A., Schweiz, Z., "[Vertebral Fractures in Skiing]" *Sportmed*. 15: 1-19, 1967 (Ger)

a

Jamieson, K.G., et al. *Traffic Crashes in Bristane*. Australian Road Research Board, Special Report No. 2, 1971.

Jellinger, K., et al. "[Progressive Late Myelopathy After Dislocation Fracture of the Odontoid Process]" *Deutsch Z. Nervenheilk* 190: 107-35, 1967. (Ger)

Jonasch, E. "[Isolated Fractures of the Spinous Processes]" *Munchen Med. Wschr*. 109:2001-2, September 29, 1967. (Ger)

Jungmichel, D., et al. "[Spinal Examinations in Athletes]" *Beitr. Orthop. Traum*. 17:690-691, 1970. (German)

Kageyama, N., et al. "[Examination of the Neck in Head Injuries]" *Shujutsu* 25:117-124, 1971 (Jap)

Kahn, E.A. "The Role of the Dentate Ligaments in Spinal Cord Compression and the Syndrome of Lateral Sclerosis." *Journal of Neurosurgery* 4:191, 1947.

Keim, H.A. "Spinal Stabilization Following Trauma." *Clin. Orthop.* 81:53-55, December, 1971.

Kelly, D.L., Jr. "Initial Treatment of Acute Head and Spinal Injuries." *N. Carolina Med. J*. 29:463-8, November, 1968.

Key, A.G., et al. "Spinal Cord Injuries. An Analysis of 300 New Lesions." *Paraplegia* 7:243-9, Feb. 1970.

Kirschner, R. "[Natural and Stabilizing Surgical Factors of the Injured Cervical Spine]" *Rozhl. Chir*. 48:445-51, October, 1969. (Cze.)

Kline, D.G. "Atlanto-axial Dislocation Simulating a Head Injury; Hypoplasia of the Odontoid." *J. Neurosurg*. 24:1013-1016, 1966.

Knight, P.O. and Wheat, J.D. "The Whiplash Injury-Clinical and Medico-Legal Aspects." *Bull. Tulane Univ. Med. Fac*. 18(4): August, 1959.

Landoff, G.A. "Vertebral Fractures in Insured and Uninsured Patients." *Acta. Orthop. Scandinav.* Suppl. 13, 1953.

Lapidus, A.E. "[Treatment of Spinal Fracture with Associated Spinal Cord Injury]" *Vestn. Khir. Grekov*. 97:105-10, November, 1966. (Rus)

Lausberg, G. "[Differential Therapeutic Discussions on Spinal Cord and Cauda Injuries]" *Deutsch. Med. Wschr*. 91:1109-1114, 1966. (German)

Lewit, K., et al. "[Anteflexion Headache in Childhood]" *Cesk. Pediatr*. 26:233-237, 1971. (Czech.)

Lichtenstein, M.E. "Acute Injuries Involving Large Blood Vessels in the Neck." Surg. Gynec. Obstet. 85:165-175, 1947.

Long, N.G. "Whiplash." Industr. Med. Surg. 28(1):11-14, January, 1959.

Loth, F., et al. "[Distinctions to be Made in Compression Fractures of the Spine in Children]" Chir. Narzad. Ruchu. Ortop. Pol. 35:173-7, 1970 (Pol)

Love, G. and Camp, J. "Root Pain Resulting from Intraspinal Protrusion of Intervertebral Discs." J. Bone and Joint Surg. 19:776, 1937.

Macik, I. "[Surgical Treatment of Cervical Spine Injuries]" Rozhl. Chir. 50:430-437, 1971. (Czech)

MacNab, I. "The Whiplash Syndrome." Orthop. Clin. N. Amer. 12:389-403, 1971.

Malawski, S. "[Treatment of Old Dislocations of the Cervical Vertebral Column]" Beitr. Orthop. Trauma 13:168-72, March, 1966. (Ger)

Markwalder, H. "[Indications for Surgical Treatment of Spinal and Spinal Cord Injuries in Their Early Stage]" Praxis 55:708-9, June 23, 1966. (Ger)

Mastny, V., et al. "[Rehabilitation Care in Cervical Vertebrae Injuries]" Beitr. Orthop. Traumatol. 18:280-4, May, 1971. (Ger)

McCarroll, H.R., et al. "Neck, Shoulder and Arm Pain." Postgrad. Med. 36(4): Oct. 1964.

McOsker, T.C. "Neck Injury and Rear-end Collision." Rhode Island Med. J. 45:252-254, 1962.

McRae, D.L. "Asymptomatic Inadvertible Disc Protrusions." Acta Radiol. 46:9-27, 1956.

Mead, S. "Spinal Cord Injuries." Mod. Treatm. 5:949-70, September, 1968.

Melzer, B., et al. "[Early Functional Treatment of Vertebral Fractures]" Beitr. Orthop. Traumatol. 16:59-62, 1969. (German)

Michaux, P., et al. [Delayed Left Phrenic Paralysis Secondary to Cervical Torsion Due to an Automobile Accident]" Acta. Med. Leg. Soc. (Liegl) 20:315-321, 1967. (Fre)

Miyagi, S., et al. "[Whiplash Injury]" Surg. Ther. (Osaka) 24:433-437, April, 1971. (Jap)

Mohing, W. "[Athletic Injuries and Chronic Spinal Lesions Caused by Sports]" Hefte Unfallheilk 91:155-162, 1967. (Ger)

Moll, K. "[Latent Herniated Disk in Accidental Injuries]" Orv. Hetil. 107:2286-7, November, 1966. (Hun)

Morscher, E. "[The Spinal Column and Sports in Youth]" Schweiz. Z. Sportmed. 17:151-162, 1969. (German)

Moser, H. "[Spinal Injuries]" Wien. Med. Wschr. 120:952-955, 1970. (German).

Msakhuradzhe, R.A. "[Post-traumatic Changes in Vertebrae After Uncomplicated Fracture]" Ortop. Traum. Protez. 29(6):35-38, 1968. (Russian)

Murphey, F. and Simmons, J.C. "Ruptured Cervical Disc: Experience with 250 Cases." Amer. Surg. 32:83-88, 1966.

Nicoll, E.A. "[Fractures and Dislocations of the Spine" in Modern Trends in Orthopaedics-3, Fracture Treament." (ed. Clark, J.) Butterworths, London, 1962.

Nikitin, M.N. "[Bilateral Anterior Displacement of the Atlas Without Fracture of the Odontoid]" Ortop. Traum. Protez. 29(10):43-45, 1968. (Russian)

Nikitin, M.N. "[Treatment of Active Rotational Subluxation of the Atlas]" Ortop. Traum. Protez. 32(1):11-14, 1971. (Russian)

Norburn, C.S. and MacRae, J.D. "Fracture of Odontoid Process of Axis: Report of Case with Bony Union." Am. J. Surg. 21:454, 1933.

Olsen, G.A., et al. "The Lateral Stability of the Spine." Clin. Orthop. 65:143-56, July-August, 1969.

Olson, N.R. "Dashboard Injuries of the Larynx." Proceedings, 14th AAAM, pp. 29-46, 1970.

Owen-Smith, M.S. "Fractures of the Odontoid Process of the Axis." Proc. Roy. Soc. Med. 61:41-3, Jan 1968.

Pang, L.Q. "The Otological Aspects of Whiplash Injuries." Laryngoscope 81:1381-1387, 1971.

Patrick, L.M. "The Biomechanical Development of Injury-Attenuating Motor Vehicle Design." J. Trauma 10:220-231, 1970.

Perlmutter, I. "Common Spinal Injuries--Diagnosis and Treatment." Med. Times 96:649-60, June, 1968.

Petrie, J.G. and Howorth, M.B. Injuries of the Spine. Williams & Wilkins, Baltimore, 1964.

Phillips, H.B. "Unusual Fracture Dislocation of Cervical Spine." JAMA 110:1266, 1938.

Poupa, J. et al. "[Spinal Fractures in Old People]" Acta Chir. Orthop. Traum. Cech. 34:249-51, June, 1967 (Cz)

Pouyanne, L., et al. "[Fractures of the Atlas]" J. Chir. 98:7-18, 1969. (French)

Povacz, F. "[Results and Prognosis of Spinal Fractures in Children]" *Chirurg*. 40:30-33, 1969. (German)

Price, M., Tobin, J.A., Reiser, M., et al. "Renal Function in Patients with Spinal Cord Injuries." *Arch. Phys. Med. Rehab*. 47:406-411, 1966.

Przychodzki, M. "[Functional Non-plaster Treatment of Compression Stable Fractures of the Spine]" *Chir. Narzad. Ruchu. Ortop. Pol.* 31:647-52, 1966, (Pol)

Raaf, J.E. "Surgical Treatment of Patients with Cervical Disk Lesions." *J. Trauma* 9:327-337, 1969.

Raynor, R.B. "Severe Injuries of the Cervical Spine Treated by Early Anterior Interbody Fusion and Ambulation." *J. Neurosurg*. 28:311-316, 1968.

Rehn, J. "[Evaluation and Treatment of Spinal Injuries]" *Langenbecks Arch. Chir*. 322:322-327, 1968. (German)

Rippstein, J. "[Problems on the Evaluation of Spinal Injuries]" *Z. Orthop*. 109:740-2, September, 1971 (Ger)

Rizzi, M. "[Development of an Adjustable Backrest for Auto and Quiet Sitting]" *Ergonomics* 12:226-33, March, 1969. (German)

Roberts, S.M. "Congenital Absence of the Odontoid Process Resulting in Dislocation of the Atlas on the Axis." *J. Bone & Joint Surg*. 15:988, 1933.

Robinson, R.A. and Southwick, W.O. "Surgical Approaches to the Cervical Spine." *A.A.O.S. Instructional Course Lectures*. 17:299, 1960.

Rossier, A. "[The Initial Treatment of Traumatic Spinal Cord Injuries]" *Praxis* 55:703-7, June, 1966. (Ger)

Rostad, H., et al. "[Fractures of the Spine]" *Nord. Med*. 81:211-5, February 1969. (Nor)

Rostad, H., et al. "Fracture of the Spine." *Acta. Orthop. Scand*. 40:664-5, 1969.

Roy, L., et al. "Cervical Spine Fusions in Children." *Clin. Orthop*. 73:146-151, November, 1970.

Ruiz Garcia, F. "[Fusion and Anterior Decompression in Fracture-Luxation of the Cervical Spine]" *Rev. Esp. Oto. Neurochir*. 29:162-167, 1971. (Spanish)

Russell, L.W. "Whiplash Injuries of the Spine." *J. Florida Med. Assoc*. 43(11):1099-1104, May, 1957.

Ruter, A. "[Surgical Treatment of Cervical Spinal Injuries]" *Hefte Unfallheilkd*. 108:138-40, 1971. (Ger)

Ryan, G.A. "Injuries in Traffic Accidents." *New England J. Med.* 276:1066-1076, 1967.

Salmon, J.H. "Fractures of the 2nd Cervical Vertebrae; Neurosurgical Management." Med. Trial. Tech. Quart. 17:194-200, December, 1970.

San Giorgi, S.M. "Orthopaedic Aspects of the Treatment of Injuries to the Lower Cervical Spine." Acta Neurochir (Wien) 22:227-33, 1970.

Schatzker, J., et al. "Fractures of the Dens (Odontoid Process). An Analysis of 37 Cases." J. Bone & Joint Surg. 53:392-405, 1971.

Schlegel, K.F. "[Undiagnosed Fractures and Intervertebral Disk Ruptures in Whiplash Injuries]" Hefte Unfallheilkd. 108:32-34, 1971. (German)

Schmieden, V. "[Trauma and the Vertebrae]" Unfallheilkunde 8:4, 1931. (German)

Schmeisser, G., Jr. "Orthopedic Aspects of Spinal Cord Injuries." Maryland Med. J. 19:95-9, Feb. 1970.

Schneider, R.C. "Concomitant Craniocerebral and Spinal Trauma with Special Reference to the Cervicomedullary Region." Clin. Neurosurg. 17:266-309, 1969.

Scott, M. "Surgery of the Spinal Column and Spinal Cord." Progr. Neurol. Psychiat. 21:397-408, 1966.

Scoville, W.B. "Types of Cervical Disk Lesions and Their Surgical Approaches." JAMA 196:479-481, 1966.

Scoville, W.B. "Lateral Rupture of Cervical Intervertebral Disks." Postgrad. Med. 39:174-180, 1966.

Selivanov, V.P., et al. "[Horizontal Fractures of the Vertebrae]" Ortop. Traum. Protez. 32(1):5-8, 1971. (Russian)

Serci, M., et al. "[On Spinal Cord Injuries of Boxers in the Ring]" Bratisl. Lek. Listy. 51:341-4, March, 1969, (Cze)

Serre, H., et al. "[Dangers of Vertebral Manipulations]" Rev. Rhum. 35:445-9, September, 1968.

Severy, D.M., et al. "Safei Seat Designs." Proceedings, 13th Stapp Car Crash Conference, SAE 690812, 1969.

Seyss, R. "[On Biostatics After Vertebral Body Fractures]" Mschr. Unfallheilk. 71:23-8, 1968. (Ger)

Shapiro, S.K. and Torres, F. "Brain Injury Complicating Whiplash Injuries." Minn. Med. 43:473-476, July, 1960.

Sheldon, C.H. "Prevention, the Only Cure for Head Injuries Resulting from Auto Accidents." JAMA 159:981-986, 1955.

Shkol'nikov, L.G. "[Main Trends of the Modern Treatment of Closed, Uncomplicated Injuries of the Spine]" Ortop. Travm. Protez. 28:3-9, July, 1967. (Rus)

Siebens, A.A., Kirby, N.A. and Poulos, D.A. "Cough Following Transection of the Spinal Cord at C-6." Arch. Phys. Med. Rehab. 45:1-8, 1964.

Sinilo, M.I., et al. "[Occupational Medical Expertise in Closed, Uncomplicated Spinal Fractures in Miners]" Ortop. Travm. Protez. 28:14-8, July, 1967, (Rus)

Smith, R.W., Jr., et al. "Relationship of Vertebral Size to Fracture in Osteoporotic Spines." Henry Ford Hosp. Med. J. 15:101-6, Summer, 1967.

Snyder, R.G., Ice, J., Duncan, J.C., Hyde, A.S. and Leverett, S., Jr. Biomedical Research Studies in Acceleration, Impact, Weightlessness, Vibration, and Emergency Escape and Restraint Systems: A Comprehensive Bibliography. A joint report of the Federal Aviation Agency, and USAF Aerospace Medical Division, CARI Rept. 63-30, December, 1963.

Spence, K.F. and Pitlyk, P.J. "Atlantoaxial Locked Dislocation Causing Spinal Cord Compression: Operative Reduction and Fusion." J. Trauma 8:605-613, 1968.

Stadaas, J., et al. "Cranio-cerebro-Cervical Injuries." J. Oslo City Hosp. 20:149-160, November, 1970.

Stone, H.H. and Callahan, G.S. "Soft Tissue Injuries of the Neck." Surg. Gynec. Obstet. 117:745-752, 1963.

Stuck, R.M. "Whiplash Injuries, a New Approach to the Problem." Med. Times 90(5):493-505, May, 1962.

Swischuk, L.E., "Spine and Spinal Cord Trauma in the Battered Child Syndrome." Radiology 92:733-8, March, 1969.

Synkova, K.I. "[Diagnosis of Injuries of the Ligamentous Apparatus of the Spine of Closed Trauma]" Ortop. Travm. Protez. 30:37-9, December, 1969. (Rus)

Talbot, H.S. "Spinal Cord Injury." Arch. Surg. 102:539-540, June, 1971.

Taranu, A., et al. "[Acute Medullary Syndrome Caused by Hyperextension of the Cervical Spine]" Neurologia (Bucur) 13:419-24, Sep-Oct. 1968 (Rum)

Tinchurina, S.G., et al. "[Experience of the Institute in the Treatment of Fractures of the Spine]" Ortop. Travm. Protez. 31(6):12-15, 1970. (Russian)

Tkachenko, S.S. "[A Special Tightening Device and the Technic of Its Application in Compression Fractures of the Spine]" Vestn. Khir. Grekov. 104:72-8, Feb. 1970 (Rus)

Tsuchiya, K., et al. "[Study of Deep EEG Patterns from the Brain Stem of Rabbits with Experimental Whiplash Injury]" J. Jap. Orthop. Ass. 42:1057-65, November, 1968. (Jap)

Uchida, M., et al. "[Cardiovascular Complications During Anesthesia for Cervical Spinal Cord Injury]" Jap. J. Anesth. 15:745-9, August, 1966. (Jap)

Verkuyl, A. "Problems and Results of Rehabilitation of Patients with Cervical Cord Lesions." Acta. Neurochir. (Wein) 22:269-85, 1970.

Vignon, G., et al. "[The Spine in the Fifties]" Presse Therm. Glimat. 103:241-4, 1966. (Fr)

Vigouroux, R.P. "[On the Importance of Neuro-injuries in Traffic Accidents]" Rev. Franc. Odontostomat. 14:1003-10, June-July, 1967 (French)

Walicka, J. "[Results of Observation and Examination of Patients with Spinal Cord Injuries]" Chir. Narzad. Ruchu. Ortop. Pol. 31:447-51, 1966. (Pol)

Wallace, J.O. "Crush Fractures of the Spine." J. Bone & Joint Surgery 5:28, 1923.

White, R.J. "Prevention of Paralysis Following Spinal Cord Injury in Monkeys." JAMA 207:259, 1969.

Whitesides, T.E., et al. "Lateral Approach to the Upper Cervical Spine for Anterior Fusion." Southern Med. J. 59:879-83, August, 1966

Wiberg, G. "Back Pain in Relation to the Nerve Supply of the Intervertebral Disc." Acta. Orthop. Scandinav. 19:211, 1949.

Zotikova, V.L., et al. "[Degenerative Changes in the Intervertebral Discs Following Spinal Fracture]" Ortop. Travm. Protez. 27:31-4, February, 1966. (Rus)

Zotikova, V.L. "[Working Capacity of Persons Following Compressive Fractures of the Vertebral Bodies]" Klin Khir. (Kiev) 2:71-4, Feb. 1966, (Rus)