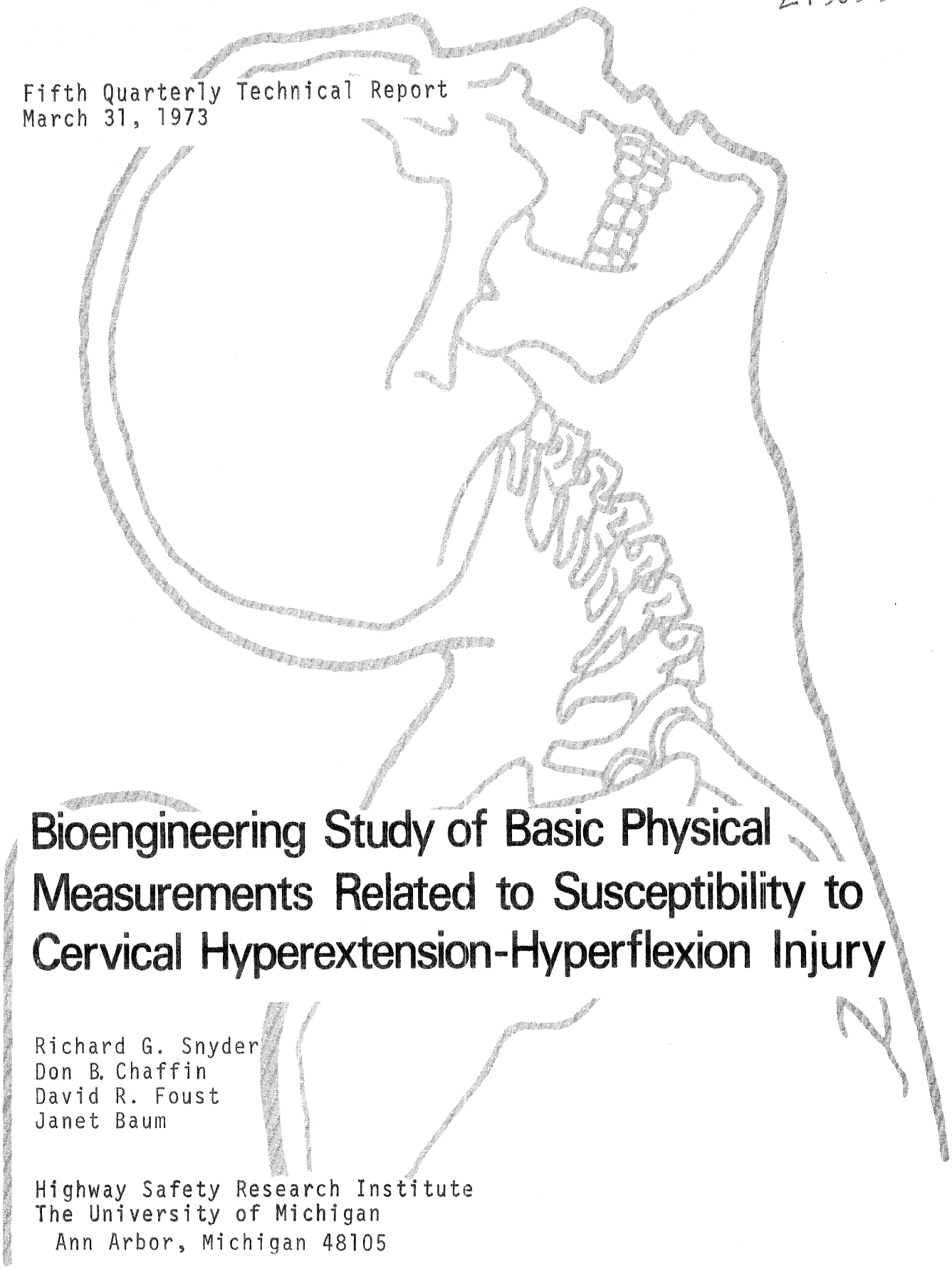
Fifth Quarterly Technical Report
March 31, 1973



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

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SUMMARY

During this fifth reporting period, January 1 through March 31, emphasis has been placed on data acquisition, initial data analysis, and preliminary preparations for publication of the results. Major task accomplishments during this period include the following:

1. The literature survey has been essentially completed with the addition of 200 additional references. A total of 2312 references are currently in the bibliography. Emphasis during the period was centered on re-examination of previously-used sources and a review of the most recent publications.

2. The subject pool has been expanded to fill the young and middle age groups and to provide initial subjects in the elderly age group. As expected, the percentage of potential subjects who are rejected on the basis of health history has increased somewhat with age. The rejection rate ranges from 14% for young subjects to just over 19% for elderly ones.

3. Fifty-three subjects were tested for cervical mobility using X-ray and photogrammetry procedures. To date, there are useful range of motion data available from 119 subjects. However, the number of subjects whose X-rays were rejected increased substantially, with five elderly and three other subjects being not acceptable for various reasons. Range of motion analysis to date indicates a decrease in mobility with age and an increase corresponding to increased stature.

4. Anthropometry from 99 subjects was keypunched and all 48 measures were summarized by computer. Many of the measures seem to

be correlated to age, sex, or physical stature. In the categories where sample sizes are sufficiently large, the study population correlates very well with the U.S. population in the key measures of weight, stature, and erect sitting height.

5. Neck muscle reflex tests have been completed with 100 subjects. Several different characteristic responses to the controlled-jerk stimulus have been observed. These are probably related to varying degrees of inherent "stiffness" of the neck structures. Test results are presented from analyses of reflex times, maximum head stopping forces, and time to maximum stopping forces for neck extensors and flexors. There is some indication that males have slower reflexes than females and that reflex times become slower with increasing age. In general, the neck flexors seem to react more slowly than the neck extensors.

6. Neck strength test data from 100 subjects show that males are considerably stronger than females, and that age adversely affects muscle strength. The neck extensors are consistently stronger than the neck flexors.

7. Data analyses during the quarter were largely limited to initial data reduction and preparation of data summaries by subject category. Five different statistical analysis techniques have been identified for more sophisticated treatment of the data.

8. Six potential papers or publications have been identified that can be used to disseminate the results of the study. Abstracts for two papers were submitted and have been accepted.

I. INTRODUCTION

Neck injuries to motor vehicle occupants are a common consequence of rear-end collisions. 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 conducted to result in several major classes of information relating to the basic characteristics of the neck in a representative U.S. population. Neck measurements being determined include both x-ray and body landmark anthropometry, the voluntary range of cervical motion in flexion and extension, neck muscle reflex time, and neck muscle strength. Statistical analysis of the data will identify inter-relationships, and mathematical modeling is being used to predict dynamic sensitivity to changes in the parameters measured.

Principle activities during the fifth 90-day period of this investigation are reviewed in the following report. Emphasis during this period has been upon data acquisition, initial data analysis, and planning for final analysis and reporting of the results.

II. TASK PROGRESS

1. Literature Survey

Efforts continued during this quarter to locate additional references related to the neck and its characteristics. The general body of literature is considerable, although relatively few studies directly pertinent have been located to date.

The bibliography format used in previous reports has been continued. Additional references located during this period are organized into five general categories: motion/mobility; mechanisms of injury; anatomy/radiography; experimental strength/stress; and injuries/fractures. We continue to find the majority of references are clinical reports of cervical injuries. These are included to indicate the wide range of cervical injuries encountered in medical practice and the widespread interest of the medical profession in this problem.

The bibliography has been enlarged by some 200 references in the past three months. The total bibliography now numbers 2312 references. Only the newly-acquired references are included in the bibliography of this report. The bibliographies from the five Quarterly Reports will be combined and organized into a comprehensive bibliography to be published as one of the final reports of this investigation.

During the quarter, a re-examination of previously-used sources was conducted to be certain that all pertinent references had been located. In addition, the most recent publications were reviewed to obtain the most up to date references. Several useful articles were located in late 1972 and early 1973 publications.

An additional 15 references were located related to the study of cervical motion and mobility. However, no data were presented in these

articles which has a direct bearing on our study. The possible exceptions are several articles by Jirout (noted in this and the previous quarterly report). However, these have not yet been translated from the original Czech, and a determination of their value will be made subsequently.

Recent acquisitions have expanded the various categories of the bibliography as follows: motion/mobility, 15 new references, for a total to date of 222 (of which only 23 provided useful data on normal cervical motion); mechanisms of injury, fifteen acquisitions, to bring the total to 117; anatomy/ radiology, an increase of 28 to a total of 364; experimental strength and stress studies, 14 additional references for a total of 232; and clinical reports of injuries and fractures, 129 acquisitions, for a total of 1377.

At this time, the bibliography may be considered virtually complete. However, any new references retrieved prior to the end of the study will also be included.

voluntarily withdrew, etc.). The disposition of questionnaires received thus far is indicated in Table I below.

TABLE I

DISPOSITION OF MEDICAL QUESTIONNAIRES

Age Group	Rec'd	Accepted		Health		Rejected - other reasons		Rejected Total	
		No.	%	No.	%	No.	%	No.	%
18-24	142	78	54.9	20	14.1	44	31.0	64	45.1
35-44	78	60	77.0	14	17.9	4	5.1	18	23.0
62-74	26	19	73.1	5	19.2	2	7.7	7	26.9

At the end of the quarter, we required only one short male and one medium female to complete the entire young age group. One medium and three short females will complete the 35-44 year female categories. Approved questionnaires on hand will nearly complete the medium age male categories, and it is anticipated that follow-up of unreturned questionnaires will result in a sufficient number to complete these cells. The questionnaires received from elderly subjects have so far been representative of each group required. Remaining efforts in locating subjects will concentrate on retirement centers. The two retirement centers contacted to date will allow us to place a flyer advertising the project in each resident's mailbox. That distribution alone will contact about 175 basically healthy people age 62 or older. In sum, we are optimistic about locating the required numbers of subjects to complete the study in accordance with the statistical design.

3. Radiography

X-ray techniques and procedures described in earlier reports were continued throughout the quarter, and no procedural changes were instituted. We had anticipated having to reduce the number of x-rays to four (by eliminating the dropped-shoulders view) in order to accommodate elderly subjects. However, the number of x-rays has so far not been a problem. The prospective subject either declines to participate because he wants no x-rays at all taken, or he allows the entire sequence.

During this quarter, a sharp increase was noted in the number of subjects whose x-rays were rejected during the clinical review. This was expected as testing began with elderly subjects, since people whose basic health history is good may still exhibit unacceptable degrees of degenerative arthritis. Dr. Baum, our radiologist consultant, has developed a detailed set of ranking criteria to allow her to objectively analyze x-rays of older subjects. She is permitting further testing on subjects who show normal aging effects, but rejecting those who might conceivably be jeopardized by the reflex time or strength testing. To date, three elderly subjects have been rejected because of arthritic conditions.

In the study to date, thirteen subjects have been rejected on the basis of clinical review of the x-rays; five were reported previously. The eight subjects not approved during this quarter are noted below, together with the reasons for rejection.

Subject	Reason for rejection
Short male, age 20	Mild scoloisis
Short male, age 39	Scoliosis & blocked vertebra @ C5-C6
Medium size male, age 41	Possible old injury @C2-C3
Short male, age 64	Mild lordokyphoscoliosis
Medium size male, age 70	Severe degenerative arthritis
Tall male, age 69	Moderately severe degenerative arthritis
Medium size female, age 71	Possible old compression fracture, C6
Medium size female, age 66	Moderately severe degenerative arthritis

The status of subjects who have completed the x-ray portion of the study is shown in Table II. The table is organized to show for each of the 18 subject categories how many subjects have been x-rayed (in total and during this quarter),and how many subjects have been approved for further testing. In the younger age category, not all of the approved subjects completed the entire test sequence. However, all x-rays which provide useful data are being analyzed. The format of Table II will be the common format used for data presentation throughout this report.

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TABLE II

STATUS OF X-RAY PORTION OF

STUDY -- BY SUBJECT CATEGORY

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	X-rays taken to date: 11 During qtr: 5 X-rays app'd, to date: 11	13 3 13	15 0 13
	35-44	7 3 7	10 5 9	11 3 11
	62-74	2 2 2	2 2 0	2 2 2
MALE	18-24	10 5 9	14 0 13	14 0 13
	35-44	6 6 5	4 3 3	9 5 9
	62-74	1 1 0	4 4 3	4 4 3
TOTALS		139 53 126		

Notes 1) of the 126 approved sets of x-rays, 7 provided no useful data. They were taken early in the study before procedures were standardized.

2) Of the 53 sets of x-rays taken during this quarter, 8 were rejected for medical reasons and 45 were approved.

Analysis of x-ray (and photographic) range-of-motion data is now being accomplished using a program from the University of Michigan Statistical Research Laboratory. Data from 118 sets of x-rays has been analyzed for this report. The statistical summary for total range of motion in each subject category is presented, together with corresponding photographic data, in Table III. (Note that subject categories are indicated by check marks in the proper sex, age and height columns.)

Sufficient data has now been gathered to permit some observations. First, there appears to be little sexual difference in range-of-motion as measured from x-rays. With the exception of the shorter young subjects, in which males are more "mobile" than females, the ranges of motion of men and women of similar ages and statures are not significantly different. Second, although the sample size of elderly subjects is still small, there is a definite age effect seen in range-of-motion. Comparison of similar sex and stature groups reveals an entirely consistent pattern of decreasing range-of-motion with increasing age. Third, an increase in physical stature tends to result in an increased range-of-motion. The notable exception is females age 35-44, in which the trend is reversed.

Work will begin early in May to obtain specific anthropometric measures from the x-rays. These will be used to increase the sophistication of the computer models, provide information for anthropometric dummy neck design, and provide data for radiological analysis by Dr. Baum.

TABLE III

RANGE-OF-MOTION ANALYSIS

One x-ray sequence and 3 photographic sequences - by subject category

Female	Male	18-24	35-44	62-74	1-20%	40-60%	80-99%	TOTAL RANGE OF MOTION, degrees								
					X-RAYS			PHOTO I			PHOTO II			PHOTO III		
					N	MEAN	S.D.	N	MEAN	S.D.	N	MEAN	S.D	N	MEAN	S.D.
X		X			X			11	128.9	18.8	10	126.0	13.9	10	129.2	11 9	10	131.5	14.6
X		X				X		12	137.5	23.1	12	131.8	17.5	10	137.0	19.9	9	132.8	17.1
X		X					X	11	148.9	16.8	11	143.3	14.3	10	147.7	14.0	10	146.7	14.5
X			X		X			7	124.9	6.1	7	123.0	17.1	7	125.4	14.3	7	120.9	15.8
X			X			X		8	122.2	11.7	8	122.1	18.9	8	122.9	18.1	8	126.1	20.3
X			X				X	11	118.6	16.1	11	123.9	16.6	11	129.2	16.8	11	129.0	15.0
X				X	X			2	81.3	12.4	2	90.5	4.2	2	94.0	2.1	2	100.3	1.8
X				X		X													
X				X			X	2	97.5	24.0	2	96.3	17.3	2	94.0	28.3	2	92.0	42.4
	X	X			X			9	134.3	16.7	9	132.7	17.9	9	134.1	14.6	9	136.1	12.6
	X	X				X		11	143.6	17.0	11	131.2	9.9	10	134.8	9.4	10	138.9	9.3
	X	X					X	13	146.3	15.3	13	139.9	13.1	10	138.2	8.3	12	139.9	13.1
	X		X		X			4	92.4	6.4	4	102.0	19.8	4	102.9	12.4	4	105.3	12.6
	X		X			X		2	121.8	10.3	2	120.3	28.6	2	120.5	38.9	2	123.3	30.1
	X		X				X	8	124.1	13.8	9	116.9	23.3	9	119.7	25.7	9	119.2	26.0
	X			X	X														
	X			X		X		2	79.5	28.3	3	85.0	19.6	3	87.5	9.4	3	89.8	10.1
	X			X			X	3	105.2	14.0	3	110.3	14.3	3	109.5	12.1	3	109.5	12.9

4. Photogrammetry

The photogrammetry portion of the study continued through the quarter without the need for procedural changes. The only potential problem noted was that some elderly subjects tend to move their upper torso as they assume the extension position. Close observation and requesting the subject to repeat the position when necessary are minimizing this problem.

Range of motion data have been measured from the photogrammetry of 118 subjects. Computerized statistical summaries of total range of motion were obtained and are presented in Table III. The format used directly compares the results of analysis of the x-ray and the three photographic repetitions. The data are organized by subject category.

Observations noted for the x-ray range-of-motion data tend to be similar for the photographic data. There is little sexual difference; a distinct reduction in range of motion occurs as age increases; and range-of-motion shows some tendency to increase as stature increases (though the tendency is less pronounced than that noted in the x-rays). The effect of repetitions on total range-of-motion may also be observed in Table III. Subjects tend to assume the same position when they are requested to move their head forward or back "as far as you can." Particularly in the categories with larger sample sizes, the range of angular differences in total range-of-motion is generally less than ten degrees.

5. Anthropometry

Anthropometry has been completed on 100 subjects to date, using the 48 measurements described in the Third Quarterly Report. Included are six elderly subjects, three females and three males. The data from 99 subjects have been keypunched and statistically summarized by computer. End-of-quarter summaries by subject category of all 48 measures are available, and fifteen of the 48 have been selected for presentation in this report. These are incorporated as Tables A-1 through A-15 in the Appendix, and include the following measurements:

Table No.	Measurement
A-1	Weight
A-2	Stature
A-3	Standing Cervicale Height
A-4	Erect Sitting Height
A-5	Sitting Cervicale Height
A-6	Erect Seated Eye Height
A-7	Lateral Neck Breadth
A-8	Anterior-Posterior Neck Breadth
A-9	Anterior Neck Length
A-10	Posterior Neck Length
A-11	Superior Neck Circumference
A-12	Inferior Neck Circumference
A-13	Head Circumference
A-14	Head Breadth
A-15	Head Length

In each of the tables, the data are presented by subject category, in a format similar to that used in Table I.

Review of the information presented in Tables A-1 through A-15 reveals some general observations, all of which will be statistically tested as the cells are filled. Certain measures correlate closely to stature, such as weight, erect sitting height, cervicale height, etc. (Tables A-1 through A-6). These all show significant differences

between sexes (with males larger), and step increases with increasing stature. The most pronounced differences appear to occur in the time span between the middle age group and the elderly group, and these are not significant differences. A better assessment of age differences will be made as sample sizes of elderly subjects increase. The second group of measurements (Tables A-7 through A-12) are all used to describe the neck. Except for posterior neck length, which tends to be random in distribution, these measures show that males are slightly larger on the average, there is very little age difference, and only a small increasing trend related to stature. The final three measures (Tables A-13 through A-15) are the primary head measures -- circumference, breadth, and length. These are similar to the neck measures, in that they show a slight sex difference (males being larger), very small age differences, and small differences directly related to stature. An interesting observation is that an individual's neck length does not necessarily increase with his stature as might be expected.

It is of continuing interest to determine how closely the population we are using in this study approximates the overall U.S. population upon which our stature criteria were based. The key population measures of weight, stature, and erect sitting height are compared in Table IV for the study population to date and the U.S. population as reported by the U.S. Public Health Service. The 50th percentile measurements given in Table IV are not weighted, in order to reduce the effects of uneven sample sizes in the various stature categories of a given sex and age group. In the young and middle age female, and young male

TABLE IV

COMPARISON OF POPULATION MEASURES

Subjects	50th Percentile Measurements					
	Weight, lb.		Stature, cm		Erect Sitting Height, cm	
	Study Pop.	U.S. Pop*	Study Pop.	U.S. Pop.	Study Pop.	U.S. Pop.
Females, 18-24 N = 29**	129	124	162.6	162.3	85.6	85.6
Females, 35-44 N = 24	130	135	161.2	161.0	85.4	85.6
Females, 62-74 N = 3	128	143	159.7	156.5	83.9	81.8
Males, 18-24 N = 28	156	155	175.1	174.2	91.1	91.2
Males, 35-44 N = 12	189	169	175.2	174.2	90.3	91.4
Males 62-74 N = 3	163	159	175.7	169.7	90.2	88.4

* U.S. population figures are 50th percentile figures for the indicated sex and age, as reported in National Health Survey, Weight, Height and Selected Body Dimensions of Adults: United States, 1960-62, Public Health Service. This report was the source for our subject stature criteria.

** N is total number of subjects tested in this age category to date.

groups, sufficient numbers of subjects have been tested to be representative of the final study population. In these cases, only a few pounds or a few millimeters difference exists. This is a positive indication that the study population is being randomly selected from the same sort of population as that surveyed by the U.S. Public Health Service. The large differences in the middle age male and elderly male and female groups stem from highly unbalanced cell sample sizes, as reference to Tables A-1, A-2 and A-4 will reveal.

As the cells fill enough to allow meaningful comparisons, additional measurements (hip breadth, knee height, head and neck measures, etc.) will be correlated with summaries reported by other investigators. Measurement data thus verified may be used in our computer simulations as a accurate representation of the U.S. adult population.

6. Reflex Time Measurements

Testing with a subject has been completed when the data from neck muscle reflex time and strength tests have been obtained. During the quarter, testing was completed with 54 subjects (32 females and 22 males), bringing the total number of subjects tested to date to 100. The distribution of these 100 subjects by sex, age, and stature categories is contained in Table V. The cells for middle age males and elderly males and females will be filling rapidly during the next quarter as subjects responding to the latest advertisements are tested.

No new technical problems arose during the reporting period. We continued to exercise great care, both in placing the electrodes and in conducting the tests, to be certain that a clearly recognizable muscle reflex was being elicited. In addition, a strip-chart record of each test is produced. This is used immediately to verify the muscle response and force levels and later to analyze the test for reflex times and force levels.

Three measurements are obtained from the strip-chart record of each reflex time test. These measurements, consisting of muscle reflex time, peak stopping force and time to peak stopping force, are illustrated in Figure 1. Reflex time is the time difference between the start of head acceleration and the start of a noticeable increase in muscle activity. The acceleration forces are biphasic--an initial head acceleration phase, caused by the one-

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TABLE V

SUBJECT STATUS - ALL TESTING COMPLETED

--BY SUBJECT CATEGORY

		1-20%ile	40-60%ile	80-99%ile	AGE TOTALS
FEMALE	18-24	TO DATE: 10	8	11	29/31
		THIS QTR: 9	4	1	14
	35-44	7	8	10	25/31
		4	6	5	15
	62-74	1	0	2	3/30
		1	0	2	3
MALE	18-24	8	10	10	28/30
		4	3	3	10
	35-44	2	1	9	12/30
		2	0	7	9
	62-74	0	1	2	3/30
		0	1	2	3
TOTALS		100/182			
		54			

Note: These figures represent subjects from whom useful reflex time and strength data have been obtained.

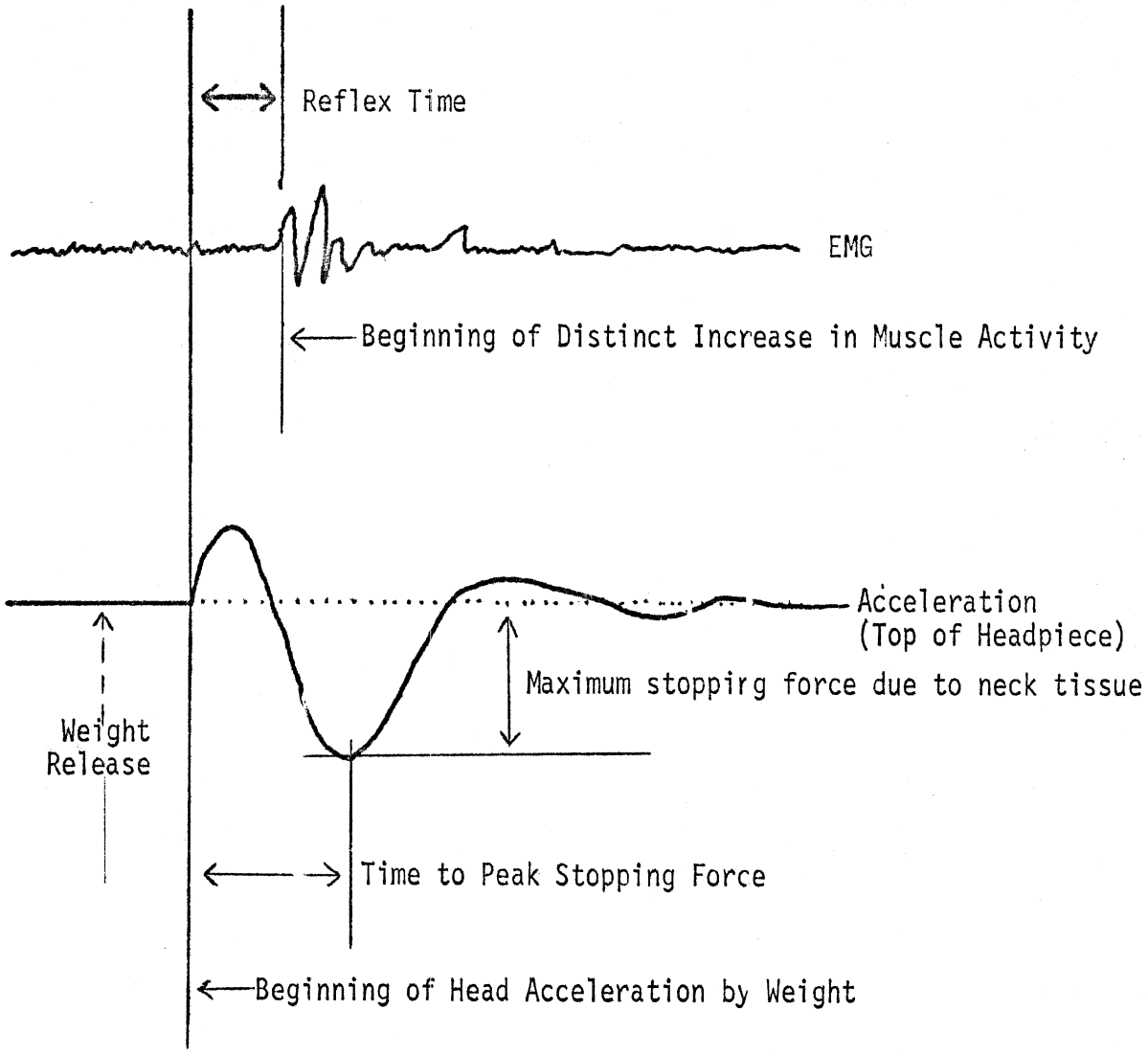

FIGURE 1

STRIP-CHART ANALYSIS OF NECK MUSCLE REFLEX TEST

pound weight when it reaches the end of its travel, followed by a stopping phase, caused by the neck tissues as the head is decelerated and brought to rest. The force levels summarized in this report are those measured by the accelerometer mounted at the top of the headpiece. These forces are twice to three times as strong as those measured at the forehead (and therefore at the center of gravity of the head). This provides a safety margin in the testing procedures, since forces at the top of the headpiece are not permitted to exceed 1.5 G's. Time to peak stopping force is the time difference between the start of head acceleration and the point of maximum stopping force.

Analysis of the test results to date has revealed several characteristic responses to the controlled-jerk tests. The most typical results are illustrated in Figure 2. Basically, responses produce either a low level of head acceleration of fairly long duration, or a higher level of acceleration of short duration, or a more complex "bimodal" two-phase response in which the EMG and acceleration records reflect a two-stage effort to stop the head. The investigators feel that these characteristic responses are related to the physiology of the neck structures and have a relationship to the inherent "stiffness" of the vertebrae, ligamental structures and musculature. A "stiffer" neck with well-developed vertebral column structure should mitigate a given force input (the one-pound weight) over a longer period and at a lower force level, with correspondingly less need for strong muscle action, than a lightweight neck with less supporting tissue. This in fact seems to be the case, since most problems in measuring reflex time occur with large male subjects.

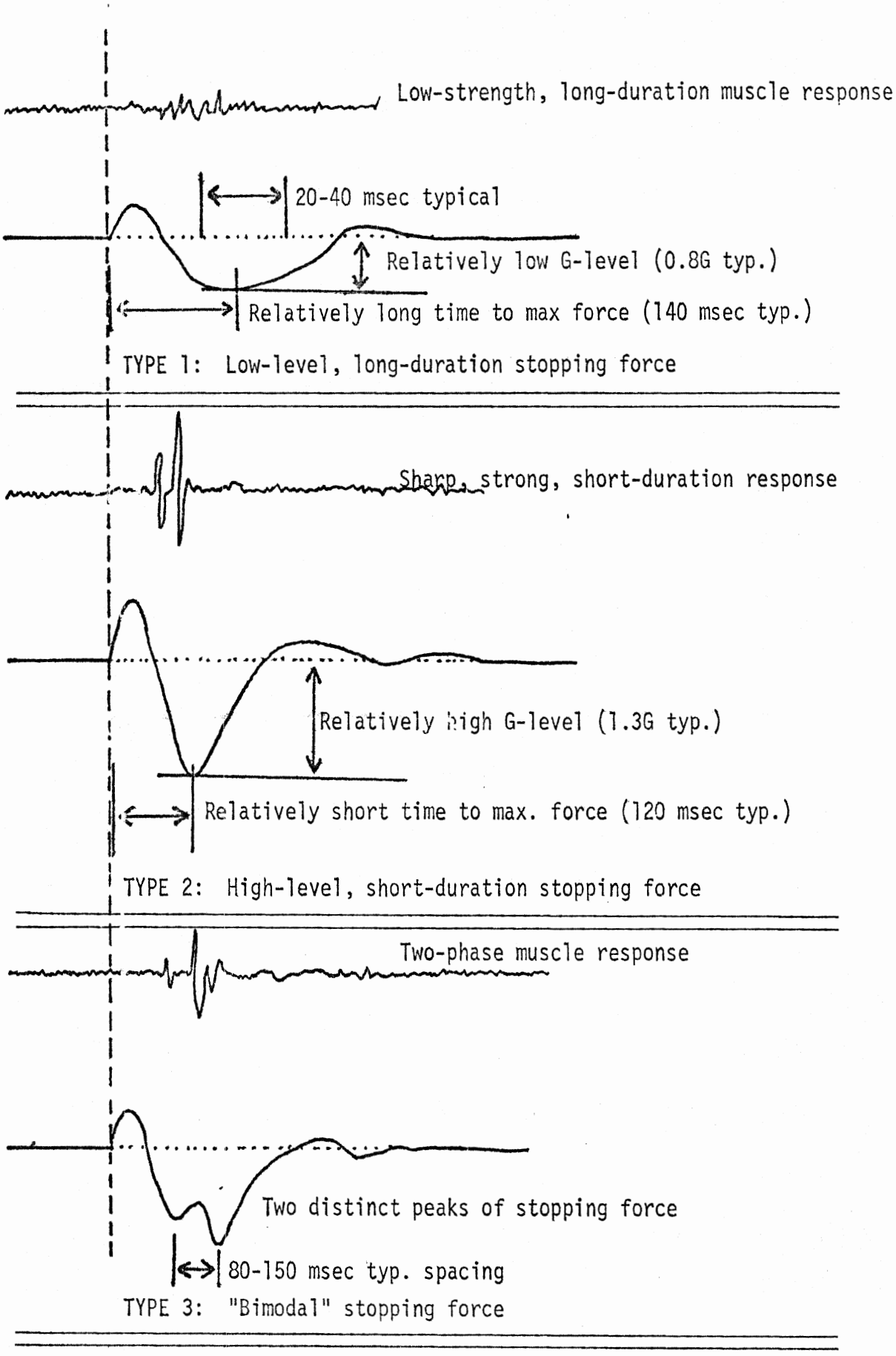

FIGURE 2

TYPICAL RESULTS OF REFLEX TESTS

An attempt will be made to test this observation by comparing x-ray anthropometry measurements of the vertebral column and external measures of the neck to reflex test results on an individual subject basis. A high degree of correlation will substantiate the observation. The relationship between the observed reflex time and the type of response will also be explored.

Data from the muscle reflex tests have been summarized and are presented by subject category in six tables. The average reflex times of the neck flexors (sternomastoid) and neck extensors (semi-spinalis capitis) are in Tables VI and VII, respectively. Corresponding head stopping forces and times to maximum stopping force are contained in Tables A-16 through A-19 in the Appendix.

Allowing for small sample sizes, especially in the older age groups, several observations can be made relative to the reflex time data (Tables VI and VII). There appears to be a sexual variation exhibited in both flexors and extensors, with males having slower reflexes than females, for a given age and stature group. There are also preliminary indications that muscle reflexes become slower as age increases. This effect was noted to some extent in both muscle groups. There is no clear indication that physical stature influences the reflex time of the neck extensors. However, the neck flexors do tend to react more slowly in taller persons. Contrasting the two muscle groups reveals that, on the average, the neck flexors tend to react more slowly than the neck extensors.

Rather large standard deviations have been noted in several reflex time data cells. These large variations in reflex time may be in part due to the different types of characteristic responses

TABLE VI

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AVERAGE REFLEX TIME OF NECK FLEXORS

TESTS IN EXTENSION (WEIGHT DROPPED BEHIND HEAD)

Units in MSEC

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 9 $\bar{x}$= 59.63 S= 8.37	8 61.03 9.11	10 69.53 14.93
	35-44	7 57.76 9.29	8 63.09 15.38	10 62.08 9.89
	62-74	1 100.7	0	2 85.65 3.32
MALE	18-24	7 61.83 11.23	10 64.87 9.37	8 74.08 12.16
	35-44	2 99.35 9.40	0	9 75.16 14.44
	62-74	0	1 82.7	2 91.70 26.87
TOTALS				

TABLE VII

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AVERAGE REFLEX TIME OF NECK EXTENSORS

FLEXION TESTS (WEIGHT DROPPED IN FRONT OF HEAD)

Units in MSEC

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 9 $\bar{x}$= 52.74 S= 6.01	8 59.18 5.82	10 57.88 8.02
	35-44	7 58.57 4.31	8 65.63 15.90	10 59.80 7.01
	62-74	1 76.7	0	2 88.70 2.83
MALE	18-24	6 61.62 16.39	9 64.93 14.09	8 58.75 5.22
	35-44	1 60	0	9 63.56 9.57
	62-74	0	1 87.3	2 76.35 10.82
TOTALS				

described earlier. If so, it may be necessary to define reflex times in terms of the total neck response to the stimulus. The necessity of incorporating this constraint will be evaluated as more refined data analysis is carried out.

The direct relationship between peak stopping force and time to peak stopping force is illustrated for the neck flexors in Tables A-16 and A-17 and for the neck extensors in Tables A-18 and A-19. In general, the lower the average stopping force, the longer the time required to reach it. While the effects of the sex, age, and stature variables are not especially pronounced, several observations may be pertinent. Males tend to stop the head more slowly and at lower force levels than females. There is a tendency for persons of taller stature to be "stiffer" (as evidenced by lower force levels), although this is not always reflected in increased stopping times. There is no age effect apparent at this time. The neck flexors show some tendency toward higher stopping forces, but this might be expected since the flexors are longer, more slender muscles than the extensors.

It is important to note that the observations reported to date have been made upon a limited number of subjects. As additional data are subsequently collected, they may be subject to change. In final analysis, all observations with respect to the key study variables will be statistically tested for validity.

7. Neck Muscle Strength Measurements

The procedures used to measure neck muscle strength were not changed during the quarter. Strength data from 99 of the 100 persons tested to date have been summarized by subject category and are presented in Tables VIII and IX. Table VIII contains the results of neck flexor strength tests and Table IX contains similar test results for neck extensors.

On the average, males are considerably stronger than females. For given age and stature groups and for either flexor or extensor muscles, the males tend to average 10 to 15 pounds stronger than the females. The limited data obtained thus far shows a definite age effect in the elderly group. Both men and women are significantly weaker than their younger counterparts, and the effect is seen in both muscle groups. There is also a slight tendency for taller people to have stronger neck muscles. Finally, in every subject category (and in fact for most individual subjects), the extensors are stronger than the flexors, with women tending to show a somewhat greater strength differential than men. In cells with larger sample sizes, the neck extensors of women averaged 7 to 11 pounds stronger than the flexors; for men, the difference averaged 4 to 10 pounds, with extensors being stronger.

TABLE VIII

as of 3-31-73

NECK FLEXOR MUSCLE STRENGTH

Units in LBS

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{x}$=	17.51	19.45	20.56
		S=	2.87	4.89	6.65
	35-44		7	7	10
			15.17	18.80	16.45
			4.38	5.20	3.53
	62-74		1	0	2
			7.9		12.95
					11.52
MALE	18-24		8	10	10
			27.16	33.35	36.32
			8.58	7.46	11.65
	35-44		2	1	9
			39.25	33.2	35.72
			21.00		9.11
	62-74		0	1	2
				16.3	26.70
					3.82
TOTALS					

TABLE IX

as of 3-31-73

NECK EXTENSOR MUSCLE STRENGTH

Units in LBS

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 10 $\bar{x}$= 24.08 S= 7.53	8 29.29 6.87	11 28.71 8.15
	35-44	7 23.11 7.31	7 27.47 6.57	10 27.65 6.38
	62-74	1 18.1	0	2 19.90 16.54
MALE	18-24	8 34.24 3.83	10 37.23 11.77	10 42.95 8.46
	35-44	2 48.25 3.32	1 53.0	9 45.74 10.57
	62-74	0	1 17.2	1 31.05 2.19
TOTALS				

8. Analysis of Test Data

Analysis of test subject data will be on two levels--initial data summaries and detailed statistical analyses. Initial data summaries for range of motion, anthropometry, reflex time and strength were presented in this report. This type of summary is being used to provide initial indications of possible trends and tendencies and to provide a basis for more detailed analysis.

In order to isolate or highlight the significant aspects of the variables being measured, several forms of statistical analysis will be employed. First, observations made from initial data summaries will be tested. Second, an analysis of variance will be performed to determine the significance of the sex, age, and stature variables on all of the measures being taken. Third, a factor analysis will be conducted to determine the set of anthropometric measures that best correlates with major functional measures. This will provide the most sensitive group of size measurements to be used as factors in the computerized crash simulation model. Fourth, a large number of correlation tests will be conducted, to include at least the following:

a. Range of motion vs selected anthropometric measures
b. Range of motion vs reflex times
c. Range of motion vs neck muscle strength
d. Subject pool anthropometry vs U.S. population anthropometry
e. Anthropometry vs reflex times
f. Anthropometry vs strength
g. Reflex times vs peak stopping forces

h. Reflex times vs time to peak stopping force

i. Reflex time vs head displacement

j. Reflex time vs strength

k. Peak stopping forces vs time to peak stopping force.

Fifth, in certain cases, analysis of covariance will be conducted to isolate the effects of multiple variables. Finally, other types of analysis will be employed as needed if they are found to be useful in isolating factors that might influence neck injury susceptibility.

9. Methods of Reporting Results

In lieu of a formal final report to the Insurance Institute for Highway Safety, the results of the test program and subsequent analyses will be submitted for publication in the open scientific literature. Several articles or publications are anticipated or are being planned.

A sizable bibliography of neck references has been compiled during the past fifteen months. It is likely that this will be published as a separate Highway Safety Research Institute document. If so, an effort will be made to evaluate or include abstracts of some of the more important references. This would greatly increase the usefulness of the bibliography as a reference work. Peter Van Eck would be a principal contributor to this publication.

Several diverse testing techniques were combined and several unique testing methods were developed to gather data for this project. Dr. Chaffin, Dr. Snyder and David Foust have discussed the possibility of submitting a brief "methodology" paper for publication. The preferred journal for such a paper would be the Journal of Applied Physiology.

Results of the X-ray and external anthropometric studies, including the influence of various size factors on neck injury susceptibility, will be the subject of a paper for which Dr. Snyder will be the principal author. The American Journal of Physical Anthropology would be a good vehicle for this information, but there is a substantial lag time for publication in this journal, and an alternative would be the Journal of Aerospace Medicine.

This journal is international in scope and is widely read, and it would disseminate the information to a large group of researchers who are interested in occupant protection. Also, publication can often be achieved in fewer than six months.

Range of motion, reflex time and strength test results will be published as a technical paper to be presented at the 17th Stapp Car Crash Conference. An abstract for a paper entitled "Cervical Range of Motion and the Dynamic Response and Strength of the Cervical Muscles," of which D. R. Foust will be principal author, was submitted to the Stapp Conference Advisory Committee on March 1, 1973. On April 6, 1973, we received notification that the paper has been accepted. The draft is to be submitted by June 29, 1973, and the final manuscript by August 10, 1973. The paper will be presented at the Stapp Conference in Oklahoma City on November 12 or 13, 1973.

The application of our test results to the HSRI Two-Dimensional Crash Victim Simulator is the basis for a proposed paper with D. H. Robbins as the principal author. An abstract for a paper entitled "A Mathematical Study of the Effect of Neck Physical Parameters on Susceptibility to Injury" was submitted to both the Stapp Conference and the S.A.E. General Convention. This paper was also accepted by the Stapp Conference, but Dr. Robbins indicates it will be withdrawn since the data will not be available in time to complete a draft by the end of June. It is now likely that the paper will be published either as a Society of Automotive Engineers' technical publication or in the Journal of Biomechanics.

Finally, Dr. Baum is anticipating a publication in the field of radiology as a result of her work on the study. The precise title has not yet been determined, but this paper will be submitted to a medical journal.

In summary, at this time it is anticipated that six technical publications will result from this study. We will keep the sponsor informed of changes and progress in these publication plans, and would expect to forward drafts of such technical submissions for your information.

III. WORK TO BE ACCOMPLISHED DURING REMAINDER OF PROJECT

All efforts funded under this project are now expected to be completed by the end of August 1973. The target date for completion of the data acquisition phase is the end of June, with data reduction and analysis proceeding concurrently when possible. The months of July and August will be devoted to detailed statistical analysis of the data and to conducting computer runs utilizing the Crash Victim Simulator Program. The Stapp Conference paper will rely chiefly on data summaries by subject category, so it should not be difficult to meet the deadline for submission.

Efforts during the remaining portion of the study will be closely interwoven between data acquisition and analysis. Also, the writing efforts at the end of June will be devoted to submission of papers for publication. Therefore, we do not intend to submit a quarterly technical report at the end of June. However, up-to-date data summaries can be prepared quickly and so will be available to the Insurance Institute for Highway Safety if so desired.

IV. APPENDIX

TABLE A-1

as of 3-31-73

WEIGHT*, POUNDS

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 10 $\bar{X}$= 116.4 S= 12.3	8 133.6 15.0	11 137.7 15.8
	35-44	7 120.7 11.8	7 128.2 17.3	10 140.1 31.5
	62-74	1 120.0	0	2 135.5 4.9
MALE	18-24	8 126.5 12.6	10 153.1 19.9	10 187.5 26.1
	35-44	2 213.5 12.0	1 153.0	9 201.7 31.0
	62-74	0	1 181.5	2 143.8 11.7
TOTALS				

*Precise definitions of each anthropometric measurement can be found in the Third Quarterly Report.

as of 3-31-73

TABLE A-2

STATURE, cm

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 10 $\bar{x}$= 153.5 S= 4.0	8 161.2 1.9	11 173.1 4.4
	35-44	7 153.8 3.5	7 161.8 1.7	10 168.0 2.5
	62-74	1 150.3 0	0 0 0	2 169.1 6.6
MALE	18-24	8 165.6 1.5	10 174.2 1.75	10 185.4 3.76
	35-44	2 169.6 0.4	1 173.3 0	9 182.8 5.1
	62-74	0 0 0	1 173.2 0	2 178.1 0.6
TOTALS				

TABLE A-3 as of 3-31-73

STANDING CERVICALE HEIGHT, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{X}$=	130.5	137.7	148.1
		S=	3.7	1.0	4.8
	35-44		7	7	10
			129.9	137.5	143.1
			3.2	1.5	2.6
	62-74		1	0	2
			128.1	0	145.8
			0	0	3.6
MALE	18-24		8	10	10
			140.6	147.8	158.8
			1.9	2.1	4.0
	35-44		2	1	9
			146.4	146.5	157.2
			1.0	0	5.1
	62-74		0	1	2
			0	150.3	153.5
			0	0	0.2
TOTALS					

as of 3-31-73

TABLE A-4

ERECT SITTING HEIGHT, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{x}$=	82.1	85.0	89.7
		S=	3.0	1.6	1.5
	35-44		7	7	10
			82.9	85.3	88.0
			1.9	1.8	1.9
	62-74		1	0	2
			80.4	0	87.4
			0	0	7.4
MALE	18-24		8	10	10
			87.0	91.4	94.8
			1.6	1.7	2.6
	35-44		2	1	9
			86.8	89.3	94.9
			0.9	0	1.3
	62-74		0	1	2
			0	91.2	89.1
			0	0	2.7
TOTALS					

TABLE A-5

as of 3-31-73

SITTING CERVICALE HEIGHT, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{X}$=	58.9	61.3	64.7
		S=	2.7	0.7	1.4
	35-44		7	7	10
			59.6	61.7	63.8
			1.2	1.4	2.0
	62-74		1	0	2
			58.4	0	64.2
			0	0	4.4
MALE	18-24		8	10	10
			62.0	65.4	68.8
			1.3	1.6	2.8
	35-44		2	1	9
			64.1	63.6	69.7
			2.7	0	1.7
	62-74		0	1	2
			0	69.1	65.5
			0	0	3.3
TOTALS					

TABLE A-6

as of 3-31-73

ERECT SITTING EYE HEIGHT, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{X}$=	70.0	73.0	77.3
		S=	3.3	2.1	1.5
	35-44		7	7	10
			71.3	73.6	75.4
			1.3	1.4	1.3
	62-74		1	0	2
			69.5	0	75.8
			0	0	7.1
MALE	18-24		8	10	10
			75.0	78.8	81.5
			2.1	1.8	2.8
	35-44		2	1	9
			73.9	77.8	81.8
			0.7	0	1.6
	62-74		0	1	2
			0	78.0	77.3
			0	0	2.6
TOTALS					

TABLE A-7

as of 3-31-73

LATERAL NECK BREADTH, cm

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 10 $\bar{x}$= 9.5 S= 0.8	8 9.9 0.5	11 9.9 0.3
	35-44	7 9.7 0.4	7 9.7 0.5	10 10.1 0.4
	62-74	1 10.3 0	0 0 0	2 9.7 0.2
MALE	18-24	8 10.8 0.6	10 11.5 0.6	10 11.9 0.9 ?
	35-44	2 11.9 1.2	1 11.8 0	9 11.7 0.8
	62-74	0 0 0	1 11.6 0	2 10.4 0.1
TOTALS				

TABLE A-8 as of 3-31-73

ANTERIOR - POSTERIOR NECK BREADTH, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{x}$=	9.2	9.3	9.5
		S=	0.7	0.4	0.4
	35-44		7	7	10
			9.4	9.8	9.6
			0.4	0.5	0.5
	62-74		1	0	2
			11.3	0	10.0
			0	0	0
MALE	18-24		8	10	10
			10.1	11.0	11.4
			0.4	0.7	0.8
	35-44		2	1	9
			12.7	11.9	12.5
			1.3	0	0.8
	62-74		0	1	2
			0	13.4	12.3
			0	0	0.2
TOTALS					

as of 3-31-73

TABLE A-9

ANTERIOR NECK LENGTH, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{x}$=	7.7	8.1	9.6
		S=	1.3	1.0	1.2
	35-44		7	7	10
			8.0	8.3	9.2
			1.0	1.4	1.9
	62-74		1	0	2
			7.3	0	9.3
			0	0	0.7
MALE	18-24		8	10	10
			9.5	9.3	10.3
			1.4	0.7	1.2
	35-44		2	1	9
			5.4	9.8	8.2
			0.3	0	1.5
	62-74		0	1	2
			0	6.7	8.2
			0	0	1.8
TOTALS					

TABLE A-10 as of 3-31-73

POSTERIOR NECK LENGTH, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{x}$=	10.2	9.8	10.7
		S=	0.9	1.9	1.8
	35-44		7	7	10
			10.0	10.2	9.8
			0.6	1.1	0.9
	62-74		1	0	2
			8.6	0	9.2
			0	0	1.6
MALE	18-24		8	10	10
			10.9	11.7	11.7
			1.6	1.5	1.6
	35-44		2	1	9
			8.1	8.2	10.6
			0.1	0	0.5
	62-74		0	1	2
			0	9.8	9.0
			0	0	0.4
TOTALS					

TABLE A-11 as of 3-31-73

SUPERIOR NECK CIRCUMFERENCE, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{x}$=	31.7	32.5	32.2
		S=	1.9	1.1	1.1
	35-44		7	7	10
			31.9	32.4	32.8
			1.3	1.9	1.2
	62-74		1	0	2
			36.1	0	33.8
			0	0	0.7
MALE	18-24		8	10	10
			34.1	37.2	38.8
			1.2	1.6	2.3
	35-44		2	1	9
			43.5	38 5	41.0
			6.3	0	3.2
	62-74		0	1	2
			0	43.2	39.2
			0	0	0.4
TOTALS					

TABLE A-12 as of 3-31-73

INFERIOR NECK CIRCUMFERENCE, cm

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	10	8	11
		$\bar{x}$=	35.7	36.6	35.3
		S=	2.2	2.0	1.3
	35-44		7	7	10
			35.1	36.0	36.1
			1.6	2.8	1.4
	62-74		1	0	2
			41.1	0	36.3
			0	0	0.9
MALE	18-24		8	10	10
			38.5	40.8	42.6
			1.5	2.3	2.0
	35-44		2	1	9
			45.4	41.6	44.0
			2.2	0	4.0
	62-74		0	1	2
			0	43.4	42.1
			0	0	0.1
TOTALS					

TABLE A-13 as of 3-31-73

HEAD CIRCUMFERENCE, cm

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 10 $\bar{x}$= 55.2 S= 1.4	8 55.5 2.0	11 55.9 1.9
	35-44	7 55.7 0.8	7 55.8 1.5	10 56.2 1.5
	62-74	1 56.0 0	0 0 0	2 56.4 0.8
MALE	18-24	8 56.4 1.3	10 57.6 0.8	10 58.8 2.1
	35-44	2 58.6 0.1	1 58.8 0	9 59.1 2.7
	62-74	0 0 0	1 57.5 0	2 58.4 3.3
TOTALS				

TABLE A-14 as of 3-31-73

HEAD BREADTH, cm

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 10 $\bar{x}$= 14.4 S= 0.5	8 14.6 0.2	11 14.9 0.4
	35-44	7 14.9 0.2	7 14.6 0.5	10 15.0 0.5
	62-74	1 15.0 0	0 0 0	2 14.7 0.4
MALE	18-24	8 14.7 0.4	10 15.2 0.5	10 15.4 0.5
	35-44	2 15.8 0	1 16.0 0	9 15.6 0.5
	62-74	0 0 0	1 15.4 0	2 15.8 1.4
TOTALS				

as of 3-31-73

TABLE A-15

HEAD LENGTH, cm

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 10 $\bar{x}$= 17.9 S= 0.6	8 17.7 0.7	11 17.7 0.6
	35-44	7 17.8 1.0	7 17.9 0.8	10 17.9 0.8
	62-74	1 17.9 0	0 0 0	2 18.1 0.7
MALE	18-24	8 19.0 1.5	10 18.9 0.7	10 19.2 0.8
	35-44	2 19.0 0.4	1 18.6 0	9 19.6 1.3
	62-74	0 0 0	1 19.5 0	2 19.1 0.3
TOTALS				

TABLE A-16

as of 3-31-73

AVERAGE PEAK STOPPING FORCE

TESTS IN EXTENSION

Units in G's as measured at top of headpiece

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 9 $\bar{X}$= 1.12 S= 0.26	8 0.99 0.28	10 0.79 0.21
	35-44	7 0.89 0.15	8 0.94 0.11	10 1.00 0.24
	62-74	1 1.13	0	2 1.18 0.27
MALE	18-24	7 0.92 0.16	10 0.97 0.23	8 0.78 0.32
	35-44	2 1.06 0.28	0	9 0.86 0.09
	62-74	0	1 0.86	2 1.00 0.21
TOTALS				

TABLE A-17

as of 3-31-73

AVERAGE TIME TO PEAK STOPPING FORCE

TESTS IN EXTENSION

Units in MSEC

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 9 $\bar{x}$= 113.9 S= 8.4	8 124.6 6.9	10 131.4 27.4
	35-44	7 123.6 12.7	8 124.9 11.1	10 125.2 19.2
	62-74	1 117.0	0	2 137.5 13.4
MALE	18-24	7 120.3 31.9	10 127.4 10.3	8 137.4 20.0
	35-44	2 153.5 13.4	0	9 137.3 17.3
	62-74	0	1 129	2 137.5 6.4
TOTALS				

as of 3-31-73

TABLE A-18

AVERAGE PEAK STOPPING FORCE

TESTS IN FLEXION

Units in G's as measured at top of headpiece

			1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N=	9	8	10
		$\bar{x}$=	1.06	0.90	0.79
		S=	0.26	0.30	0.14
	35-44		7	8	10
			1.09	1.04	1.04
			0.19	0.13	0.15
	62-74		1	0	2
			1.07		1.03
					0.11
MALE	18-24		6	9	8
			0.88	0.83	0.74
			0.32	0.15	0.19
	35-44		1	0	9
			1.04		0.84
					0.07
	62-74		0	1	2
				0.78	0.87
					0.24
TOTALS					

TABLE A-19 as of 3-31-73

AVERAGE TIME TO PEAK STOPPING FORCE

TESTS IN FLEXION

Units in MSEC

		1-20%ile	40-60%ile	80-99%ile
FEMALE	18-24	N= 9 $\bar{x}$= 124.9 S= 2.7	8 143.6 25.5	10 144.7 29.6
	35-44	7 124.7 6.7	8 135.1 7.2	10 124.2 9.8
	62-74	1 127	0	2 142.0 1.4
MALE	18-24	6 155.5 57.9	9 127.8 17.3	8 133.0 16.9
	35-44	1 121	0	9 127.7 10.2
	62-74	0	1 127	2 135.5 6.4
TOTALS				

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