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With the opening of the fighter cockpit to women, it is imperative to expand the current data base of responses of females to high impact acceleration environments. It is hypothesized that since women tend to have less upper-body strength than men, they may not be able to brace their heads as effectively against the loads which occur during impact and escape. This may be exacerbated by the changing center of gravity of helmets due to technological advances (e.g., night vision, head-up displays, etc).

The objective of the current experimental effort is to examine the ability of subjects of both sexes to brace against an impact acceleration in the X or Y axes, and to attempt to identify a correlation between such ability, static strength measurements, anthropometric measurements, or any combination thereof.

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1.0 Introduction:

With the opening of the fighter cockpit to women, it is imperative to expand the current database of responses of females to high impact acceleration environments. It is hypothesized that since women tend to have less upper-body strength than men, they may not be able to brace their heads as effectively against the loads which occur during impact and escape. This may be exacerbated by the changing center of gravity of helmets due to technological advances (e.g. night vision, head-up displays, etc).

The objective of the current experimental effort is to examine the ability of subjects of both sexes to brace against an impact acceleration in the X or Y axes, and to attempt to identify a correlation between such ability, static strength measurements, anthropometric measurements, or any combination thereof.

The potential for injury to the pilot is increased if adequate data is not available for design of restraint and impact protection systems. It is currently unknown if women are more likely to suffer injuries to the head and neck as a result of impact accelerations.

1.1 Critical Issues

The critical issues that will be addressed by this test program and subsequent analytical efforts using the collected data are summarized as follows:

a. How well does neck strength correlate to head motion under impact?

b. Do anthropometric parameters correlate to head motion under impact?

c. Does gender correlate with head motion under impact?

1.2 Specific Objectives

The objectives of this experimental effort will be accomplished by analysis of the data that will be collected. This objective is to correlate collected data with each subject's recorded head movement under impact.

The specific parameters to be measured are:

a. Neck diameter and neck length from occiput to C_7.
b. Passive range of motion (ROM) of the neck (e.g., rotation, side-to-side)
c. Maximum strength of the neck in lateral and front-to-back direction and duration of maximum voluntary contraction (MVC).
d. Deflection of the head during an impact acceleration in the -Gx and -Gy directions.

2.0 Experimental Description:

Approximately 25 subjects, both male and female, will be measured for anthropomorphic characteristics. They have been requested to exert force against pads fixed to load cells in order to quantitate their neck strengths.

In the second phase of the project, the same subjects undergo horizontal impact exposures in which the motion of the subject's head is recorded via infrared sensors and accelerometers. The collected data will then be analyzed to determine if there is a correlation between gender and ability to resist an impact, or between anthropomorphic measurements and resistance.

2.1 Static test phase:

Range of motion measurements were taken of the neck (side to side and rotation). The subjects were seated in a hard chair which is bolted to a rigid framework. A framework bearing adjustable pads was lowered over the subject's head and adjusted to fit by telescoping extensions. The other end of the extensions were connected to load cells so that the force exerted with the head could be measured. A maximal effort using only the muscles of the neck was recorded in the X and Y directions, sustained for approximately 10 seconds or until a 30% decrease from maximum occurred. A maximal short-duration (i.e. 2 second) effort, allowing use of the upper torso and extremities, was then recorded. This data was digitized and collected onto disk using a PC-compatible and appropriate software.

2.2 Dynamic test phase:

In the dynamic measurement phase, which is currently in progress, the same volunteers are being exposed to impact accelerations in the X and Y axes. The acceleration and displacement of the head and chest are measured. The impact accelerations are provided by the AL Horizontal Impact Accelerator at a magnitude of 10 G or less (i.e. within the approved limits of the Generic Impact Acceleration Protocol #84-01). Head and chest accelerations and displacements are measured with a transducer pack composed of linear accelerometers and an infrared motion target. The accelerations and displacements at C7 are also measured with a transducer pack of linear accelerometers and an infrared motion target. This pack is secured to the skin around C7 with a special adhesive tape.

3.0 Results:

As of 1 Aug 95, 28 subjects (15 males and 13 females) had completed a total of 103 impacts. Several of the smaller female subjects withdrew from the study after experiencing the 6.5 Gy impact; one left after witnessing a 6.5 Gy run, and one declined further impacts after an uneventful 4 Gx training run. There were no clinically significant injuries. There were also unexpected complaints of neck soreness from two of the large male subjects (resulting in the withdrawal of one). In order to forestall further withdrawals, Y impact testing was restarted at 4 G. This was well tolerated by the remaining subjects, while still providing sufficient head motion.

4.0 Conclusions:

No analysis of the data has been performed, as testing is still in progress. Some subjects have not completed the Gx impacts due to other commitments; this is expected to take place by the third week of August 1995.

Since data collection is still in progress, formal conclusions would be premature at this time. However, empiric observation does <u>not</u> suggest a strong correlation between subject strength and head deflection. Factors which are difficult to quantitate, such as motivation and experience, may be swamping the measured parameters. In addition, the height and weight of the subjects may not be strongly correlated with their neck strengths.

5.0 References:

Hearon, B.F., "Generic Impact Acceleration Protocol, 1988-89", AAMRL Protocol No. 84-01-03.

Shaffer, John T., "The Impulse Accelerator: An Impact Sled Facility for Human Research and Safety Systems Testing", Technical Report AMRL-TR-76-8 (Wright-Patterson AFB, OH: Aug. 1976).

APPENDIX

Detailed Description of Experimental Design and Test Plan

1.0 Static data acquisition

1.1 Anthropometry

Subjects were measured for neck circumference, neck length (occiput to C_7), head rotation, and side-to-side movement. They were then measured for their neck maximal voluntary contraction (MVC) in the +/- x and +/- y direction.

1.2 Isometric strength measurement

Subjects were placed in a seat with a suspended frame which contains four load cells with pads against which they may push in the x and y axes. There were two separate measurements in each of four directions (+/- x and +/- y): first, the maximum sustained effort for 10 seconds using only the muscles of the neck; second, the peak short-duration (i.e. 1 second) effort while bracing the feet on the floor and hands on grips provided at the level of the seat pan.

2.0 Dynamic data acquisition

2.1 Test Matrix

A VIP manikin (see Section 3.5.1), and a minimum of twenty-five volunteer human subjects will be tested at each of the cells given in Table I using the Armstrong Laboratory Impulse Accelerator. The acceleration waveform approximates a half-sine pulse.

Subjects are currently required to perform a minimum of one impact acceleration test per month to remain qualified. They will undergo an orientation test (cell X) if required to meet the monthly requirement. The subjects are tested in a seated posture and restrained to an uncushioned, rigid seat.

TABLE I. TEST MATRIX

PHASE	CELL	PULSE DURATION (mSEC)	PULSE AMPLITUDE (G)	AXIS
I	TH	200	4.0	-Gx
II	A1	200	6.5	-Gx
	A2	200	6.5	-Gx
	Y1	200	4.0	-Gy
	Y2	200	4.0	-Gy

3.0 Experimental methods

3.1 Static data: Isometric Facility

3.1.1 The facility consists of a stand supporting an adjustable frame with four load cells located at right angles to each other. The position of each load cell is manually adjustable since the location and size of the head will vary between subjects.

3.1.2 Static Test Procedures

The procedures for tests with volunteers are summarized as follows: The subject will be seated in the seat and adjusted so that his head is in the appropriate position within the helmet. The lap belt will then be attached. The subject then performs his best sustained and maximal effort in the designated direction at the command of the PI.

3.2 Dynamic data: Impact Facility

All tests will be conducted using the Impulse Acceleration (IA) facility. This facility consists of a Bendix 24-inch "Hyge" pneumatic accelerator driving a 2000 lb. sled down a 240 ft. track. The unit is capable of over 100 G acceleration, and a maximum stroke of 8.4 feet. Pulse widths range up to approximately 265 milliseconds, and the IA metering pins, which determine the shape of the acceleration pulse, are specified in the test matrix (Table I). A complete description of the facility is available (Shaffer, 1976).

3.3 Seat

The experimental test fixture is the 40-G seat mounted on the IA sled and oriented to provide a -Gx acceleration vector. The seat incorporates the geometry of MIL-STD-1472B modified for a zero degree seat back angle and with the seat back plane perpendicular to the seat pan plane.

3.4 Restraint System

The subjects used in this test program are restrained using a PCU-15/P harness, two shoulder straps, and an ACES II lap belt. The lap belt is pretensioned to 20 +/- 5 lb at each anchor point. Each of the shoulder straps is preloaded to 20 +/- 5 lb.

3.5 Subjects

Manikin and human subjects will be used in the tests.

3.5.1 Manikins. An anthropomorphic manikin will be used during this test program. Large (95th percentile) Grumman-Alderson Research Dummy (GARD) prototypes, known as the VIP-95, are being tested. Manikins are dressed in a HGU-55/P helmet and cutoff long underwear.

3.5.2 Volunteers. The human subjects are volunteers from the AL Impact Acceleration Test Panel. The subjects wear cutoff long underwear, an HGU-55/P helmet, and socks. No particular garb was required for the anthropometric and isometric phases of the experiment.

3.6 Data Acquisition Requirements

3.6.1 Accelerometer Mounting Techniques for Human Subjects. A triaxial accelerometer array is mounted to a bite-block, which has been individually fabricated for each subject by the medical technician. The second triaxial accelerometer array is be mounted to the subject's chest with a Velcro chest strap; a third is fixed to the skin over C7 with double-sided tape.

3.6.2 Motion Analysis Data. Motion analysis data is being collected prior to the acceleration of the sled as well as during the impact event. The motion analysis data is recorded using the Selspot system mounted on the test fixture at oblique and right angles to the subject. Data is collected at a 500 samples/second rate. The motion analysis data will consist of displacement-time histories of targets mounted on the test seat, impact sled, and test subjects. The positions of the targets mounted on the test subjects are as follows: top of helmet; temple (approximately 2 cm dorsal to the supraorbital ridge); mouth (mounted to bite bar); C7 vertebra; shoulder; chest pack.

4.0 Data analysis procedures

4.1 Data Computation Requirements

4.1.1 Static Data Computation Requirements

The data analysis shall include computation of resultants described below.

a. neck circumference and length (cm)
b. head rotation left and right in degrees
c. head motion, side-to-side (cm)
d. MVC of neck in +/- x (lb)
e. MVC of neck in +/- y (lb)
f. MVC for endurance in x and y

The data collected will be correlated with the various parameters of head motion obtained under the impact acceleration phase of the experiment. Specifically, the relationships of anthropometry, strength, and gender of subjects will be correlated with the magnitude of head motion under G_x, G_y, and G_{xy} accelerations.

4.1.2 Dynamic Data Computation Requirements

The data analysis shall include computation of resultants described below. The displayed data should be arranged to show grouped data such as right force, left force, center force, and summation in a quadripartite format (four plots per page). The plots to be arranged in this fashion include:

a. Head X, Y, Z, and Resultant Accelerations
b. Chest X, Y, Z, and Resultant Accelerations
c. Left Lap Belt X, Y, Z, and Resultant Forces
d. Right Lap Belt X, Y, Z, and Resultant Forces
e. Left Shoulder Strap X, Y, Z, and Resultant Forces
f. Right Shoulder Strap X, Y, Z, and Resultant Forces
g. Headrest X, Y, Z, and Resultant Forces
h. X, Y, and Z sled acceleration
i. Seat X and Y axis acceleration
j. Left, right, center and summation of seat pan Z axis forces

k. Left, right, center and summation of seat back X axis forces
l. Left X axis, right X axis, Y axis, and resultant seat pan forces
m. Top Y axis, bottom Y axis, Z axis, and resultant seat back forces
n. Head, Chest, and Waist Ry Accel, Velocity

5.0 Data processing

5.1 Electronic Data Handling

5.1.1 Static measurements

An IBM PC-compatible computer was used for data entry and collection during the anthropometric and isometric data collection phases. The subject data from anthropometric measurements was entered into the PC manually by the PI or designated assistant. Isometric strength data was then digitized in real-time (via a program written by the PI in C++ under LabWindows/CVI) and stored by the PC on floppy disks.

5.1.2 Dynamic measurements

The transducer signals are handled by the on-board Automatic Data Acquisition and Control System (ADACS). Signal conditioning, filtering, amplification, and digitizing (at a rate of 1000 samples/sec) takes place on-board the test fixture. The digitized data is transmitted to the computer room for storage on digital magnetic tape or disc and is post-processed by the DEC 3000-500 computer system.