REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE AUG 93

3. REPORT TYPE AND DATES COVERED Interim 1 Oct 92-10 Aug 93

4. TITLE AND SUBTITLE
The Effect of Head and Body Position on +Gz Acceleration Tolerance

5. FUNDING NUMBERS
PR - 7930
TA - 14
WU - 39

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8. PERFORMING ORGANIZATION REPORT NUMBER
AL-JA-1992-0069

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

94-22193

11. SUPPLEMENTARY NOTES
Aviation, Space, and Environmental Medicine May 1994

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

It has been suggested there is a relationship between acceleration-induced loss of consciousness (G-LOC) and head/body position. A two-part investigation was conducted to determine whether head and body position affects acceleration tolerance. A retrospective analysis of high-G training data (N= 1,914) compared G-LOC accurace during straight-ahead exposure to a "check-6" exposure [10s at +9 Gz; 6G/s onset rate; G-suit inflated; anti-G straining maneuver (AGSM) performed]. A prospective study (N= 12) was conducted with acceleration exposures using light loss criteria with subjects in straight-ahead, above, over-the-right shoulder, or over-the-left shoulder positions. Profiles consisted of 0.1 G/s onset-rate runs (no G-suit inflation; relaxed) to a maximum of +9 Gz and 0.5 G/s onset-rate runs (G-suit inflated; AGSM performed) to +9 Gz for up to 26 s. In the retrospective study, no significant difference existed between G-LOC occurrence during straight-ahead (22/1914) and check-6 (32/1914) positions. During the prospective study with AGSM runs, there was no significant difference in the time at maximum G among any of the positions. During the relaxed runs, several comparisons yielded significant differences in peak G attained. These results indicate there may be an underlying physiologic effect of head and body position on acceleration tolerance; however, the AGMS and the G-suit overcame this effect.

14. SUBJECT TERMS
Acceleration, G-LOC, Head position, Body position, +Gz, tolerance, anti-G straining maneuver

15. NUMBER OF PAGES 5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

The Effect of Head and Body Position on $+G_z$ Acceleration Tolerance

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TONG A, HILL RC, TRIPP L, WEBB JT. *The effect of head and body position on $+G_z$ acceleration tolerance.* Aviat. Space Environ. Med. 1994; 65(5, Suppl):A90–4.

It has been suggested there is a relationship between acceleration-induced loss of consciousness (G-LOC) and head/body position. A two-part investigation was conducted to determine whether head and body position affects acceleration tolerance. A retrospective analysis of high-G training data (N = 1,914) compared G-LOC occurrence during straight-ahead exposure to a "check-6" exposure [10 s at $+9\ G_z$; 6 G/s onset rate; G-suit inflated; anti-G straining maneuver (AGSM) performed]. A prospective study (N = 12) was conducted with acceleration exposures using light loss criteria with subjects in straight-ahead, above, over-the-right shoulder, or over-the-left shoulder positions. Profiles consisted of 0.1 G/s onset-rate runs (no G-suit inflation; relaxed) to a maximum of $+9\ G_z$ and 0.5 G/s onset-rate runs (G-suit inflated; AGSM performed) to $+9\ G_z$ for up to 26 s. In the retrospective study, no significant difference existed between G-LOC occurrence during straight-ahead (22/1914) and check-6 (32/1914) positions. During the prospective study with AGSM runs, there was no significant difference in the time at maximum G among any of the positions. During the relaxed runs, several comparisons yielded significant differences in peak G attained. These results indicate there may be an underlying physiologic effect of head and body position on acceleration tolerance; however, the AGSM and the G-suit overcame this effect. Although task saturation and distraction may compromise performance of the AGSM and subsequently predispose acceleration-related hazards, a proper AGSM, combined with effective protective systems, remains essential components of a protection strategy.

ACCELERATION-INDUCED loss of consciousness (G-LOC) continues to be a hazard for fighter aircrew. During the period from 1982 to 1992, the U.S. Air Force (USAF) lost 16 crewmembers and 20 aircraft in accidents attributable to G-LOC. (Personal communication. Air Force Safety Agency, Norton AFB, CA; 1993.) The fighter aircrew is highly mobile in the cockpit during aerial combat because seeing the adversary is an essential part of a winning strategy. It is commonly assumed that most cases of G-LOC occur when the crewmember attempts to look back or "check-6" in a high-G defensive maneuver (3). Whether the possible relationship between body position and G-LOC occurrence is based upon physiologic/physical or situational factors is unknown. Since operational experience has associated head/body position with G-LOC, the leadership of the Air Combat Command (ACC) tasked the Armstrong Laboratory to investigate this relationship. The hypothesis of this study was that head/body position affects G-LOC occurrence and acceleration tolerance.

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MATERIALS AND METHODS

There were two major thrusts in this investigation: 1) a retrospective analysis of the G-LOC incidence data collected during high-G training of fighter aircrew on the Armstrong Laboratory Centrifuge at Brooks Air Force Base, TX; and 2) a prospective study on the Dynamic Environment Simulator (DES) at Wright-Patterson Air Force Base, OH, to determine the effect of head/body position on acceleration tolerance.

Retrospective Analysis of Training Exposures

From 1985 to 1989, high-G training was given to 2,095 male Tactical Air Command fighter crewmembers, according to methods previously described (4). All training was conducted in a 6-m radius human-use centrifuge; trainees sat in an F-16 configured seat (30° seat back angle with raised rudder pedals). A standard light bar was mounted in front of the trainee. The first exposure was a gradual-onset run (GOR) with a G-onset rate of 0.1 G/s to a visual end point (100% peripheral light loss, PLL, or 50% central light loss, CLL) with no anti-G straining maneuver (AGSM) and no G-suit inflation. At PLL or CLL, the trainee began the AGSM until PLL or CLL recurred or $+9\ G_z$ was achieved. The next series of exposures were rapid-onset runs (ROR) with a G-onset rate of 6 G/s to $+6\ G_z$ for 30 s, $+8\ G_z$ for 15 s, and $+9\ G_z$ for 15 s. In all of these runs, the subjects were seated with the head and body facing straight-ahead performing the AGSM, and the G-suit (CSU-13B/P) was inflated. The trainee initiated acceleration by pulling on an F-16 side-mounted control stick. The final ROR was conducted under identical conditions except the trainee first turned his head to the left to view a numeric display (check-6 position) and was exposed to $+9\ G_z$ for up to 10 s. The trainees were coached during the exposures to improve straining techniques. Data recorded during each run included the time of termination, the reason for termination, and the trainee's estimate of PLL and CLL.

The retrospective analysis compared the G-LOC occurrence from the last two runs of the training series. G-LOC occurrence during the first 10 s of the 15-s straight-ahead position ROR was compared to the G-LOC occurrence during the 10-s check-6 run.

Prospective Study

G-LOC is a highly variable event; therefore, we employed light loss to indicate acceleration tolerance in the prospective centrifuge experiments. At relatively low rates of G-onset, light loss usually occurs progressively. A series of centrifuge exposures was conducted to measure visual light loss in subjects with respect to various head/body positions.

Subjects: For this study, 12 healthy and experienced centrifuge subjects (9 males and 3 females, mean age of 30.4 years, mean height of 177.8 cm, mean mass of 78.6 kg) representative of USAF aircrew population were employed.

Gondola configuration: The DES, a 6-m radius centrifuge at Wright-Patterson Air Force Base, OH, was used for all exposures. Relocation of the standard light bar proved impractical for light loss evaluation. The gondola was modified with orange strips at four positions: straight-ahead (eye-level straight), above (90° vertical elevation), left 172°, and right 172°. At each of the four positions, the strips were placed to allow determination of PLL at 60° field of view (FOV) and CLL at 10° FOV (Fig. 1). A seat representing the F-16 (30° seat back angle, raised rudder pedals, and simulated stick and throttle) was mounted in the centrifuge. Three video cameras (above, in front of, and behind the subject) ensured a view of the subject's face in all positions.

G-exposure conditions: Each subject was scheduled for two exposures in each of four test positions. The four positions were: straight-ahead (straight), above, over-the-left-shoulder (OTLS), and over-the-right-shoulder (OTRS). Subjects were instructed to maintain their hands on the simulated controls on either side of the seat, while focusing their gaze on the orange strip representing the center of the visual field. Only one position was studied per test day. Each test day was separated by a minimum of 2 d and a maximum of 7 d. The order of the positions was randomized.

The first exposure was a 0.1 G/s GOR to a maximum of $+9\ G_z$, without an AGSM or G-suit inflation. The subject wore an uninflated G-suit (CSU-13B/P) and was

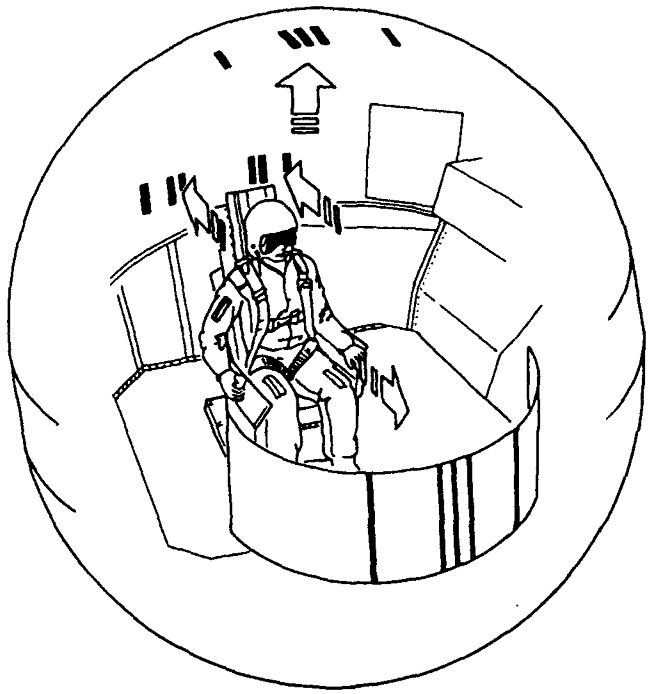

Fig. 1. Dynamic Environment Simulator gondola configuration.

instructed not to strain. The run was terminated when a subject reported PLL or when $+9\ G_z$ was attained. Subjects were not informed of individual performances. Data recorded included peak $+G_z$ reached. Prior to starting the second exposure of each day, we waited until the subject's heart rate returned to baseline, the subject reported being rested, and at least 2 min elapsed.

The second exposure of each day was 0.5 G/s onset-rate run to $+9\ G_z$. The subject assumed the same position as used in the GOR. The subject wore the anti-G suit, which followed the normal inflation schedule (1.5 psi/G above 2 G, 10.5 psi maximum). The subject was instructed to perform an AGSM at will, but was not coached in any way. The run was terminated when the subject reported a visual field of less than 10°. A 30-s plateau was planned, but problems with the timing system consistently truncated this plateau to 26 s. Data recorded included time spent at $+9\ G_z$.

Data Analysis

For the retrospective study, a sign test was used to detect differences between the number of trainees experiencing G-LOC during the straight-ahead and check-6 positions. For the prospective study, a two-way analysis of variance (ANOVA) followed by a Bonferoni multiple comparison technique was conducted on both data sets (peak $+G_z$ for GOR runs and time at $+9\ G_z$ for 0.5 G/s runs). The level of significance was set at $p = 0.05$.

RESULTS

Retrospective Analysis of Training Exposures

Of the 2,095 crewmembers receiving training, 215 (10.26%) experienced G-LOC. A total of 1,914 trainees were exposed to both the +9 G_z forward position run and the +9 G_z check-6 run. This subset of the 2,095 trainees reflects the elimination of some trainees prior to the check-6 run because of difficulties they experienced or problems with the centrifuge during earlier runs, or changes in the training syllabus. Of the 1914 trainees, 22 (1.15%) experienced G-LOC in the first 10 s of the forward position runs; 32 (1.67%) experienced G-LOC on the check-6 runs; 5 (0.26%) experienced G-LOC on both the straight-ahead position and check-6 runs. These latter five occurrences added no statistical power to the analysis because they did not discriminate between the treatment effects. There was no significant difference in G-LOC occurrence between the forward position and check-6 runs (Table I).

Prospective Study

GOR, relaxed, no G-suit inflation: We eliminated the data points from two subjects because they could not refrain from straining during their exposures. One subject was unable to run the last scheduled position exposure (OTLS). The mean peak +G_z attained by the remaining subjects were 5.1 for the straight-ahead position, 5.4 for the above position, 6.3 for the OTLS position, and 6.8 for the OTRS position (Table II, Fig. 2). There were significant differences in mean peak +G_z between the straight-ahead position and both over-the-shoulder positions; between the two over-the-shoulder positions; and between the above and both over-the-shoulder positions.

0.5 G/s onset rate, straining, G-suit inflated: One subject was unable to run the last scheduled position exposure (OTLS). One subject experienced an unintended G-LOC shortly after reaching +9 G_z on the last scheduled exposure. The mean durations (in seconds) at sustained +9 G_z were 16.1 for the straight-ahead position, 18.3 for the above position, 14.1 for the OTLS position, and 14.1 for the OTRS position. There were no significant differences among these means (Table III, Fig. 3).

DISCUSSION

Any head/body position effect on acceleration tolerance and G-LOC occurrence could be related to at least two factors, physiologic/physical and situational. Brain blood flow is dependent on the vertical height of the column of blood between the heart and the brain (1,2,5). Although a level rotation of the head is unlikely to change the vertical length of the column, any increase in elevation (above position), with or without a rotation of the head, may alter this length. Further, any contortion of the carotid arteries, whether in elevation or rotation, is likely to stretch these vessels and decrease the lumen diameter. Whether changes in the lumen are sufficient to cause an increase in resistance is unknown. A parallel study (4) found cerebral blood flow was diminished significantly with marked head/neck extension under normogravic conditions, while rotation had no significant effect on normogravic cerebral blood flow. Finally, distortion of the carotid baroreceptors may bias the system's blood pressure response. Although these factors may affect relaxed and normogravic responses, they appear minor compared to the cardiovascular and pulmonary changes as a result of high acceleration and the AGSM.

Performance of an effective AGSM is an essential part of improving acceleration tolerance. The emphasis of centrifuge-based high-G training is on forward posi-

TABLE II. PEAK +G_z ATTAINED AT STATED POSITIONS WITH 0.1 G/s ONSET RATE, RELAXED, NO AG-SUIT INFLATION.

Subjects	Straight (N = 10)	Above (N = 10)	OTLS (N = 9)	OTRS (N = 10)
A	7.0	6.2	6.7	7.2
B	4.4	4.6	—	6.2
C	7.2	6.4	6.9	7.6
D*†	6.6	9.0	9.0	9.0
E†	7.8	5.6	9.0	9.0
F*	5.4	4.9	6.7	6.7
G*	4.6	6.9	6.0	6.8
H	4.3	5.7	6.4	6.6
I	4.4	5.2	5.8	7.2
J	3.6	4.4	5.6	5.5
K	5.1	5.0	6.9	7.0
L	4.6	4.7	6.6	6.8
Mean	5.1	5.4	6.3‡	6.8

* = Female subjects.
† = Subjects who could not refrain from straining.
‡ = Mean includes estimated missing data; estimated data were not used in analysis.

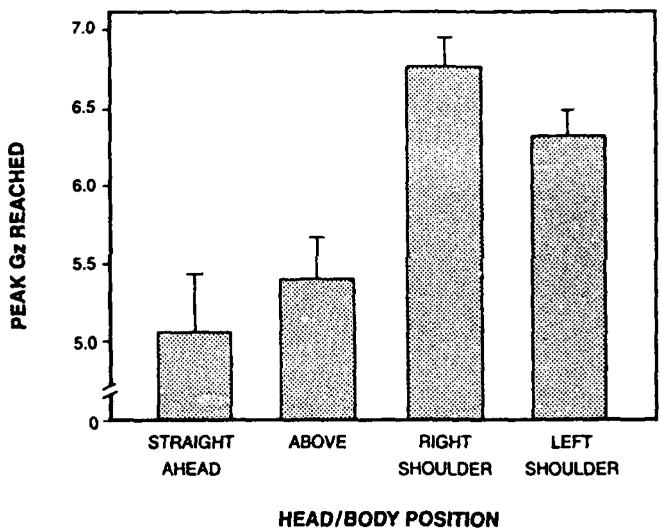

Fig. 2. Mean peak +G_z attained with 0.1 G/s onset rate, relaxed, no G-suit inflation. $F(3,26) = 18.39$; $p < 0.0001$.

TABLE I. OCCURRENCE OF G-LOC DURING +9 G_z RAPID ONSET RUNS COMPARING FORWARD POSITION VS. CHECK-6 POSITION; ONLY FOR TRAINEES ATTEMPTING BOTH RUNS.

G-LOC During Straight-Ahead Position	G-LOC Check-6 Position	Number of Trainees
No	No	1865
Yes	Yes	5
Yes	No	17
No	Yes	27
Total		1914

Sign test indicated no significant difference.

TABLE III. TIME (s) SPENT AT +9 G_z AT STATED POSITIONS WITH 0.5 G/s ONSET RATE, STRAINING, G-SUIT INFLATED.

Subjects	Straight (N = 12)	Above (N = 12)	OTLS (N = 11)	OTRS (N = 12)
A	26.0	26.0	13.4	6.0
B	3.0	24.0	—	13.4
C	26.0	15.6	3.0	5.9
D*	26.0	17.6	26.0	26.0
E	26.0	19.8	26.0	26.0
F*	7.0	6.0	3.8	14.8
G*	10.6	10.0	18.5	0.1
H	22.0	26.0	10.4	12.6
I	14.7	9.4	4.4	12.0
J	17.0	12.6	0.1†	9.2
K	7.6	26.0	26.0	17.0
L	6.8	26.0	26.0	26.0
Mean	16.1	18.3	14.1‡	14.1

* = Female subjects.
† = Subject suffered G-LOC.
‡ = Mean includes estimated missing data; estimated data were not used in analysis.

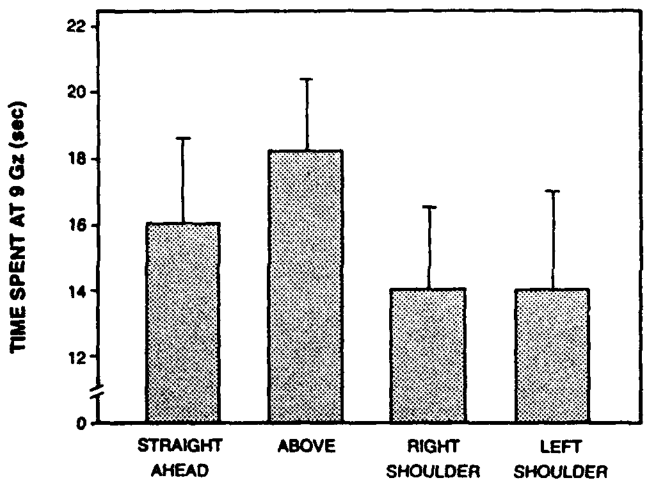

Fig. 3. Mean duration at +9 G_z with 0.5 G/s onset rate, straining, G-suit inflation. $F(3,32) = 0.78$; $p = 0.5151$.

tion performance of the AGSM. In operational flight, much of the high-G exposure is coincident with head/body position changes so pilots are naturally more attuned to these physical events. However, the strong skeletal muscle contractions associated with vigorous body motion during combat may alter a crewmember's ability to perform an effective AGSM.

Effective aerial combat demands dynamic body motions for the aircrew to see the adversary. With either offensive or defensive tactics, these motions are most likely to occur when the aircraft is maneuvering and the accelerative loads are the greatest. Since G-LOC is more probable during the highest G loads, changes in body position may simply be incidental to the G-LOC occurring during this time. Additional factors which may compromise the crewmember's AGSM performance include task saturation and distraction.

An advantage of the retrospective analysis was that data from actual fighter aircrew were used, contributing to the operational relevance without an arduous training period. These fighter aircrew were exposed to ROR of 6 G/s, covering the range of acceleration capabilities of current aircraft. Furthermore, this effort used G-LOC as an end point, which allowed data collection on more severe responses than a possibly related indicator such as PLL and CLL.

Several offsetting factors may have affected the retrospective study. First, because the check-6 run was conducted as the last run of the day, the trainees may have been fatigued, but they were also more experienced in high-G techniques. Second, on the earlier straight-ahead runs, trainees may have conserved energy so they could expend all of their energy reserves on the check-6 runs. Third, we only counted the G-LOC occurrences in the first 10 s of the 15-s straight-ahead ROR, and this may have introduced bias. Finally, even though the sample size was large, the actual occurrence of G-LOC during the forward position and check-6 positions was relatively low (22 and 32 occurrences, respectively); thus, the sensitivity to treatment effects may not be as strong as desired.

The retrospective and prospective portions of this investigation were complementary. The prospective centrifuge experiments addressed most of the problems with lack of variable control inherent in using retrospective data. First, randomization of exposure minimized any order effect. Second, the testing interval was controlled to minimize cumulative fatigue and G-layoff effects. Third, the subjects were not informed of their performance and received no coaching. Finally, the subjects' relaxed G tolerances were very similar to those of the fighter aircrew (3), and they were similar in age, height and weight (5).

Subject comments after each exposure and videotape review led us to conclude that the subjects cannot be relaxed in the over-the-shoulder positions. In addition, there may be a decrease in heart-to-eye distance in the above position. All of these factors may have contributed to the increase in GOR tolerance in subjects not faced straight-ahead.

We used a 0.5 G/s onset rate for our data collection on straining acceleration tolerance due to facility limitations. The ANOVA with Bonferoni multiple comparison technique showed no significant differences. Of the 47 data points, 15 ended in the maximum-allowed +9 G_z plateau duration, which raises the question of whether the statistical assumptions of the standard two-way ANOVA may have limited our ability to detect a difference. Therefore, an additional statistical step was utilized. Paired *t*-tests were performed excluding all intrasubject data that resulted in a tie. Again, there were no significant differences (Table IV).

Under the conditions of this investigation, aircrew head/body position had no effect on straining acceleration tolerance at 0.5 G/s and G-LOC at 6 G/s. This finding suggests that head/body positional effects are not related to physiologic factors. This does not rule out situational factors; i.e., the problems are related to the environment and not body position. Visual decrement and G-LOC will continue to be hazards as the crew-

TABLE IV. PAIRWISE COMPARISON OF HEAD/BODY POSITIONS, EXCLUDING SUBJECTS WITH IDENTICAL DATA FOR THE POSITIONS BEING COMPARED; WITH 0.5 G/s ONSET RATE, STRAINING G-SUIT INFLATED. DEPENDENT VARIABLE = TIME SPENT AT $+9\ G_z$ (s).

Position-1	Position-2	Mean for Pos-1	Mean for Pos-2	N	p-Value
Above	OTLS	17.73	14.32	9	0.2396
Above	OTRS	18.25	14.08	11	0.1510
Above	Straight	18.25	16.06	11	0.5131
OTLS	OTRS	14.32	14.14	8	0.9476
OTLS	Straight	14.32	17.25	9	0.5039
OTRS	Straight	14.08	16.06	10	0.5910

member dramatically alters body position during aircraft maneuvering. Training, supervision, and systems development are the probable solutions to the problem.

ACKNOWLEDGMENTS

We sincerely appreciate the efforts of Charles D. Goodyear, Logicon Technical Services, Inc., and Joseph R. Fischer, Jr., Sustained Operations Branch, for statistical support. We are especially grateful to John W. Frazier for the research ideas and suggestions to better convey the results. We also appreciate the support from Dr. William Albery and the personnel of the Combined Stress Branch, the Flight Motion Effects Branch, and Systems Research Laboratories.

This research was sponsored by the Armstrong Laboratory, Brooks AFB, TX, and under USAF Contracts F-33615-89-C-0574, F-33615-89-C-0603 and F-33615-92-C-0018. The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 169-3. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the U.S. Air Force.

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