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THE EFFECT OF EXHAUST SMOKE ON AIRCRAFT DETECTABILITY

Robert D. Baldwin, et al

Human Resources Research Organization

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Combat experience in Vietnam suggested that a correlation might exist between aircraft losses to gunfire and the amount (density) of smoke emitted by the aircraft. In connection with Joint Task Force Two (JTF-2) testing of aircraft vulnerability to air defense weapons, preliminary tests on the smoke factor were conducted using manual data collection. Comparisons were made on the detection times--using different courses, altitudes, and test sites--for two types of aircraft that differ significantly in the amount of smoke emitted.

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THE EFFECT OF EXHAUST SMOKE ON AIRCRAFT DETECTABILITY

December 1966

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Prepared for
The Joint Chiefs of Staff
Joint Task Force Two
Sandia Base, New Mexico

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THE EFFECT OF EXHAUST SMOKE ON
AIRCRAFT DETECTABILITY (U)

I. (C) GENERAL

(U) Test 3.1/3.5 is being conducted by Joint Task Force Two (JTF-2) to evaluate: (a) aircraft vulnerability at low altitude to engagement by various visually-sighted air defense weapons and (b) the effectiveness of these weapons. One of the objectives of these tests is to determine the relationship between visual detectability and aircraft distance for several relevant parameters, for example, aircraft altitude, speed, and maneuver.

(C) Combat experience in Viet Nam suggests that a correlation may exist between aircraft losses to gunfire and the amount (density) of smoke emitted by the aircraft. Since an evaluation of this possible relationship was not included in the original set of parameters for Test 3.1/3.5, the Weapon Systems Evaluation Group (WSEG) has requested JTF-2 to extend the scope of Test 3.1/3.5 to evaluate the exhaust smoke factor.

(C) The data obtained via the current instrumentation system used for Test 3.1/3.5 eventually will permit an evaluation of the effect of smoke on engagement sequence data. However, WSEG desires that more limited information be made available immediately after the relevant trials of the field test are completed. For this reason, HumRRO Division No. 5, Fort Bliss, Texas, at the request of JTF-2, conducted limited tests using manual data collection. HumRRO was responsible for the collection, reduction and analysis of this manually-gathered data.

II. (C) TEST CONCEPT

A. (C) This portion of Test 3.1/3.5 obtained data on visual detection ranges for two types of A-4 aircraft which differ significantly in the amount of smoke emitted. The A-4B/C (J-65 engine) is the standard for minimum smoke generation. The A-4E/F (J-52 engine) produces a significantly greater amount of smoke. Approximately 180 trials were flown to satisfy the basic test objective and to determine the effect of two levels of smoke emission on detection time.

B. (U) Table 1 lists the combinations of variables scheduled for the A-4 aircraft trials.

C. (U) In order that the influence of the secondary variables of the test be held to a minimum, each trial of an A-4B/C (or E/F) aircraft was followed immediately by an A-4E/F (or B/C) aircraft; i.e., A-4B/C and A-4E/F trials were paired, with the two aircraft in each pair being separated in time over target by three to six minutes. In this way, the

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Table 1 (C)

Combination of Variables for A-4 Aircraft Trials (U)

Type	Raid Size	Speed	Altitude	Maneuver	Unmask Distance				
					d_1	d_2	d_3	d_4	
A-4E/F	Single Aircraft	S_3	A_1	M_1	10	10	10	10	40
				M_2				10	10
			A_2	M_2	10	10	10	10	40
A-4B/C	Single Aircraft	S_3	A_1	M_1	10	10	10	10	40
				M_2				10	10
	Single		A_2	M_2	10	10	10	10	40
					Total Trials				1[illegible]

A_1 = 50-250 feet
A_2 = 250-500 feet

S_3 = 450 KTAS

M_1 = Straight and Level
M_2 = Angle Off Pop Up

d_1 = 0-2.5 NM
d_2 = 2.5-4.0 NM
d_3 = 4-5.5 NM
d_4 = > 5.5 NM

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effects of such environmental conditions as time of day, sun elevation, azimuth and atmospheric visibility were maintained almost constant. The aircraft courses and maneuvers of succeeding trials were identical in order to present similar aircraft background conditions to the observers. Early warning conditions were constant for pairs of trials, except the altitude and bearing to the second aircraft could be predicted by observers from their observation of the first aircraft in each pair.

III. (U) DATA

A. The amount of elapsed time between initial detection and aircraft crossover was obtained for each trial. These observations were made by a special group of enlisted men provided by USCONARC. This group of "Timers" had not participated in the earlier phase of the HLMR tests.

B. A second group of observers, "Smoke Judges", provided opinion data concerning the relative amount of smoke emitted for selected random pairs of A-4C and A-4E trials. After certain specified pairs of trials, these Smoke Judges, who were selected from crewmen not serving as gun crew participants at the time, were asked three questions by the Timers:

1. Which of the two previous aircraft was easier to detect?
2. Did the two aircraft show the same amount of smoke?
3. If not, which aircraft showed more smoke?

IV. (U) DETAILED OBSERVER PLAN

A. Observers. As stated above, two different groups of observers (Timers and Smoke Judges) were used to obtain the two types of performance data.

1. Group 1, "Timers": Ten EM, equipped with stop watches and recording forms, measured and recorded the elapsed time from detection to crossover for each trial. These observers were selected and trained in the test procedures by HumRRO. Six observers were provided by the U.S. Army Air Defense Human Research Unit, and four were obtained from the U.S. Army Training Center Human Research Unit.

2. Group 2, "Smoke Judges": On each test day, ten CDEC EM, currently assigned as crewmen for the air defense weapons provided judgments of the relative smoke density of the aircraft for selected pairs of trials. The smoke judges were selected from CDEC enlisted men who were serving as gun crew participants at the time.

B. Observer Location. Within each weapon complex, the Timers were stationed close to AD weapons so they received the early warning information normally provided for each trial. The proximity of these timers to the weapon crews also facilitated administration of the smoke questionnaire to the Smoke Judges. The location of the specific weapon sites used by the Timers is shown in Figure 1, along with plan projections of the aircraft flight paths.

C. Test Monitors. The Timers at each Weapon Complex were under the supervision of a SMOKEHOUSE Monitor, who had the following responsibilities:

1. At beginning of each AM and PM test sessions, the Monitor accomplished a "head count" to determine that the correct group of timing observers were present at the complex.

2. He issued timing and recording equipment.

3. He determined that each Timer had a properly-functioning stop watch, the appropriate recording forms, and pencils and clip-board.

4. He determined that the Timers had the appropriate trial schedule, questionnaire forms, and information concerning the identity of the CDEC "Smoke Judges" for the session.

5. He monitored the Timers during the test session to insure that all required activities were being accomplished.

D. Rotation of Observers. On each test day the 10 Timers were randomly assigned to a specific weapon site to be used for the day. Following completion of the AM trials (and noon mess) it was planned to rotate the Timers each day so that all Timers would make an equal number of observations at each of the 10 selected weapon sites.

E. Daily Procedure.

1. Measuring Elapsed Time. The Timers remained at the weapon site and received the early warning (EW) information given the crewmen by the CDEC controller. Upon receipt of EW, the Timers began visual search of the designated sky space.

When an aircraft was detected, the Timer started the stop watch. When the aircraft reached the crossover point, the Timer stopped the watch and printed the elapsed time (to the nearest second) for the trial on the record form.

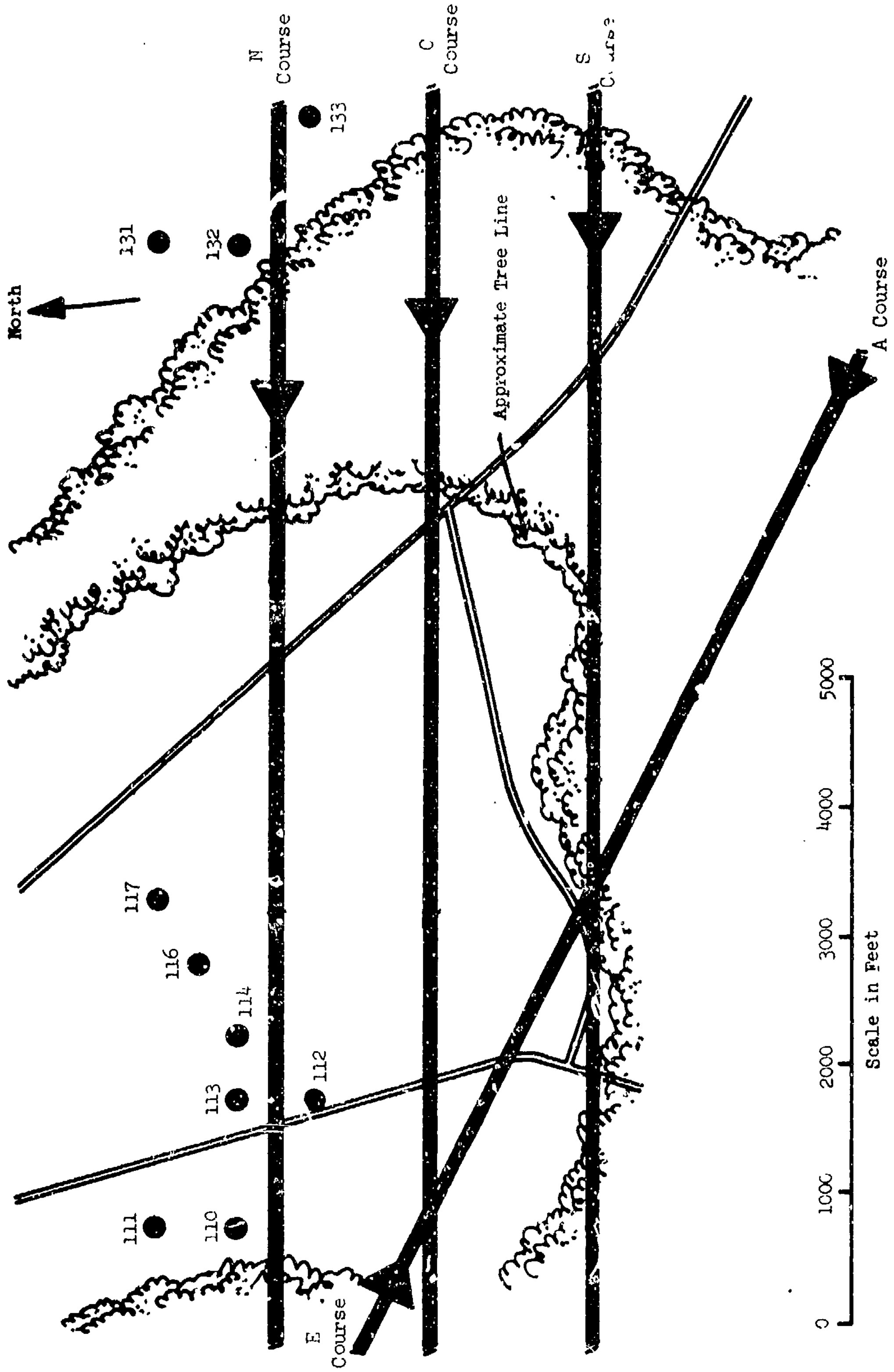

Figure 1. Observer Locations at Weapon Sites (U)

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3. Smoke Judgments. Following the completion of the specially selected pairs of trials, the Timers administered the Smoke Questionnaire to the crewmen in each complex who had been designated as "Smoke Judges" for the AM (or PM) test session. The questionnaires provided the following information:

a. The "Smoke Judge's" name and serial number.
b. The numbers of the trials being compared.
c. The weapon complex and weapon location number.
d. The time of day (to the nearest minute).
e. The "Judge's" answers to the three questions.

V. (C) RESULTS

A. (C) Elapsed Time Data.

1. (C) Average Time for All Trials. A total of 960 paired observations were made of the E and B aircraft. The average (mean) elapsed time difference between the two types was 4.97 seconds, with the A-4E being detected before the A-4B. This difference was statistically reliable at $p < .01$ (Student's $t = 6.68$, with 959 degrees of freedom).

2. (C) Average Time for Valid Trials. Inspection of the time in view measures indicated that on many trials the aircraft were detected after Early Warning had been announced but before the aircraft actually was on the assigned course and at the scheduled altitude for the trial. In many instances the aircraft apparently were detected while on the 180-degree leg of the approach to the course. Since these trials would not provide valid comparisons for the two types of aircraft for each combination of altitude and course, the data were screened to eliminate the erroneously long time measures:

a. For flights on the Valley A Course, all time in view measures exceeding 60 seconds were dropped.

b. For the Crossing flights (N, C, and S), all time measures exceeding 45 seconds were eliminated.

c. No observations were eliminated for the Maneuver 2 flights on the E Course.

If one score of a pair had to be dropped, both scores were dropped.

After eliminating the invalid pairs of observations, a total of 739 paired observations remained. For these remaining valid observations, the mean detection time for the A-4E was 2.30 seconds earlier than the A-4B. This difference, while small, was statistically reliable (Student's $\underline{t}$ = 5.00, with 738 degrees of freedom).

3. (C) Average Time Differences for Courses and Altitudes. Table 2 presents the time differences with reference to the test matrix of courses and altitudes. These comparisons are of the 739 "valid" trials only. A negative time difference indicates that the B aircraft was seen before the E aircraft.

The statistical analysis indicated that the E type was reliably seen before the B type for course-altitude combinations A-1, A-2, and C-2. In contrast, the B-engined aircraft were seen before the E-engined type for S-1 and C-1. The negative difference for N-1 was not statistically reliable at p = .10. As stated earlier, when averaged over all courses and altitudes, the A-4E was seen earlier than the A-4B.

4. (C) Comparison of Test Sites. The mean differences (E minus B) for all observations made at each of the 10 weapon sites is shown in Table 3. Analysis of the data for each weapon site indicated that for three of the sites (111, 113, and 117) the E-engine aircraft were detected reliably before the B-engined. At one test site (116) the opposite result occurred, and at those sites having very near terrain mask (131, 132, and 133) there were no reliable differences between the two engine types.

5. (C) Comparison for Each Altitude at Maneuver 1. The paired observations were also averaged over the A, S, C, and N courses to compare the elapsed time difference for each altitude for the flights using Maneuver 1. On the average, the E aircraft were seen before the B types 2.12 seconds at Altitude 1 and 2.57 seconds at Altitude 2. Both of these mean differences were statistically reliable at p = .10 or less (Student's $\underline{t}$'s were 3.53 and 4.50, respectively).

6. (U) Average Time in View. The mean and standard deviation of the actual time in view for each aircraft flight is shown in Appendix A for each combination of test parameters. This form of the data should be of interest to those agencies having knowledge of the terrain unmask distances and the actual aircraft speeds.

7. (C) Smoke Judgments. Prior to the actual test, twenty pairs of trials were selected for collecting the opinions of observers concerning the ease of detection and amount of smoke emitted by each aircraft in a pair. After completion of each of these selected trial-pairs, the Timers asked three questions of the CDEC "Smoke Judges". The Timers also answered the questions before questioning the CDEC Judges.

Table 2 (C)

Elapsed Time Differences Between Engine Types
for Each Course and Altitude (U)

Course	Altitude 2/	No. of Pairs	Mean Diff. (Secs.)	Standard Deviation	Student's t	Stat. Reliable 1/
A	1	87	11.62	16.97	6.35	Yes
	2	30	7.91	14.66	4.79	Yes
S	1	109	- 0.84	4.68	- 1.91	Yes
	2	43	- 1.28	5.09	- 1.62	No
C	1	72	- 1.92	5.28	- 3.10	Yes
	2	71	1.72	6.48	2.23	Yes
N	1	71	- 0.86	4.61	- 1.56	No
	2	102	0.59	5.44	1.09	No
E	2	104	2.20	23.10	0.97	No
All	All	739	2.30	13.00	5.00	Yes

1/ Statistically reliable at $p = .10$ or less.

2/ Altitude 1 = 50-250 feet; Altitude 2 = 250-500 feet.

Table 3 (C)

Elapsed Time Differences for Each Weapon Site (U)

Weapon Site	No. of Pairs	Mean Diff.	Stat. Reliable[1]
110	91	1.10	No
111	79	7.49	Yes
112	64	2.86	No
113	84	6.19	Yes
114	74	0.86	No
116	103	- 1.33	Yes
117	74	3.57	Yes
131	51	- 0.49	No
132	57	2.67	No
133	62	0.15	No

[1] Statistically reliable at $p = .10$ or less.

(C) The 20 pairs of trials were selected to counterbalance the sequence in which the E and B aircraft appeared, and to include several altitudes and courses. Two pairs of trials involving successive flights of the same engine type were included to provide a means of determining if the judges exhibited any biases: For example, did judges tend to rate the second aircraft of a pair as emitting more smoke than the first aircraft. The questionnaire results are shown in Table 4. Of 327 answers, 78% of the judgments indicated that the A-4E was easier to detect. Ninety-seven percent of the judgments indicated that the observers were aware of differences in the smoke output, and 90% of the time the more dense exhaust smoke was associated with the A-4E.

VI. (C) DISCUSSION

A. (C) Elapsed Time Differences. The rather perverse nature of the E versus B time comparisons obtained for the various courses and altitudes warrants some speculation. The results suggest that as the terrain unmask distance increased, the B-engined aircraft were more difficult to detect. This difference was probably most dramatically reflected in the mean E vs. B difference obtained before the off-course detections were eliminated. The comments of the Timers and Test Monitors indicated that these invalid observations tended to occur when the aircraft was at a high altitude and in its glide path to the programmed test altitude. That is, the aircraft were well above terrain and became apparent against a sky background. Unfortunately, information concerning the aircrafts' actual altitudes at the time these "invalid" detections occurred cannot be correlated with the detection times, because the latter did not share a common time base with the 3.1/3.5 instrumentation system.

(C) However, when the invalid observations were deleted from the statistical analysis, the approximately five seconds greater detectability of the E-engined aircraft decreased to 2.3 seconds. That is, as the amount of masking increased, the detection difference decreased.

(C) The most curious result concerned the greater detectability of the B-engined aircraft while flying the crossing courses at Altitude 1. All averages for the Altitude 1 flights on the N, C, and S courses indicated that the B-engined aircraft were seen earlier. It would be expected that the E-engined aircraft would produce very dense smoke at this altitude. Since most of the crossing flights at Altitude 1 had a sky background at the time of unmask, the greater smoke output of the E-engined aircraft would have further increased its detectability. It can only be guessed that, for some reason, when on the crossing courses the B-engined aircraft tended to fly at a slightly higher altitude than the A-4E. One can speculate that performance characteristics of the A-4B when at low altitude may have caused the pilots to seek a little extra altitude when flying

Table 4 (C)

Results of Smoke Judge Questionnaire[1/] (U)

Condition	Course	Altitude	No. of Opinions	Percentage of Answers							
				A/C Easier to See?			Smoke the Same?		Which Smoked?		
				A-4E	A-4B	Neither	Yes	No	A-4E	A-4B	N/A
1	N	1	78	87	9	4	0	100	97	3	0
2	C	2	76	85	9	5	7	93	87	5	8
3	A	1	67	69	22	9	1	99	82	16	1
4	S	2	66	70	27	3	3	97	97	0	3
5	N	2	16	69	19	12	12	88	88	0	12
6	A	2	24	79	4	17	0	100	96	4	0

1/ When originally answered, the judges indicated whether it was the first or second aircraft in each pair. The actual identity of the aircraft was collated with the data after the test.

over the rolling terrain and approaching the prominant hill which intersected the crossing courses. Additional light can be cast on this problem when the aircraft altimeter data is obtained by JTF-2.

B. (C) Smoke Judgments. The results of the questionnaires given after selected pairs of trials are not too informative. The results indicate that the observers were very much aware of the differences in the quantity of smoke produced and tended to believe that the smoky aircraft were easier to detect. Unfortunately, the observers were often incorrect in their evaluation of specific situations.

C. (C) Timers and Monitors Comments. In comparing the two engine types at sites 131, 132, and 133, test observers reported that the E-engined aircraft was not as easily detected on the Valley A course because the aircraft usually had a terrain background when it unmasked at Altitude 1. It appeared that the smoke, which aided detection of the A-4E by other weapon sites, was not discriminable when the aircraft had a terrain background.

(C) In discussing the observation of the flights using Maneuver 2, test observers reported that the aircraft usually was detected while it was accomplishing the climbing portion of the maneuver. At this time, the aircraft presented a lateral (side view) rather than a head-on aspect to the observers. Since, at any distance, the lateral aspect subtends a larger solid visual angle than a head-on aspect, early detection of both types of aircraft tended to occur. Also, in reference to Maneuver 2, the observers reported that they did not become aware of the exhaust smoke of the E-engine aircraft until it had completed its climb and begun to roll over. As the aircraft aspect changed to head-on, the exhaust smoke seemed to "blossom", probably because the observers were viewing the end of a "tube of smoke" rather than looking at the much less dense side of the "smoke tube". However, most frequently detection of the Maneuver 2 flights had already occurred before the exhaust blossomed.

APPENDIX A (C)

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Table A-1(C)

Number of Observations, Mean Time in View and Standard Deviation for Each Weapon Site, Engine Type, Course and Altitude (U)

Site & Statistic		Course, Altitude & Engine																			
		A-1		A-2		S-1		S-2		C-1		C-2		N-1		N-2		E-2		Total	
		E	B	E	B	E	B	E	B	E	B	E	B	E	B	E	B	E	B	E	B
110	N	15	15	10	10	11	11	5	5	8	8	6	6	11	11	11	11	14	14	91	91
	M	20.2	15.5	24.3	19.5	22.6	24.4	28.0	29.0	21.1	23.5	28.7	25.8	19.0	20.6	24.0	21.7	20.6	20.3	22.4	21.3
	S.D.	13.2	5.7	3.0	8.0	4.3	3.2	3.5	5.2	5.3	2.6	8.8	4.8	[illegible]	2.0	5.2	3.5	24.3	24.1	12.0	11.0
111	N	9	9	7	7	11	11	4	4	8	8	8	8	8	8	12	12	12	12	79	79
	M	48.1	14.8	49.9	22.4	25.8	24.4	25.5	24.5	20.6	22.8	27.6	[illegible]	19.4	21.2	23.7	22.9	48.7	37.5	32.6	25.1
	S.D.	12.0	6.2	11.0	6.0	3.0	2.9	6.2	3.8	6.6	2.3	6.2	11.8	1.4	1.5	3.5	7.0	39.3	23.1	20.6	12.5
112	N	8	8	8	8	7	7	2	2	7	7	8	8	5	5	8	8	11	11	64	64
	M	21.0	19.0	27.6	23.1	22.9	25.7	25.0	24.5	22.4	23.6	30.9	24.9	24.8	20.8	26.2	21.9	51.5	46.0	29.7	26.8
	S.D.	10.0	6.6	10.4	3.6	6.1	3.5	4.0	1.5	3.0	3.4	7.2	3.8	10.8	3.4	7.0	4.1	33.7	29.5	18.8	15.6
113	N	13	13	10	10	10	10	3	3	6	6	6	6	9	9	12	12	15	15	84	84
	M	45.9	21.8	45.2	20.0	22.1	22.1	20.7	21.3	19.2	21.3	27.2	23.0	9.4	14.0	16.8	16.7	32.0	33.1	28.3	22.1
	S.D.	15.0	9.3	15.8	3.8	5.1	3.5	4.2	6.1	4.3	3.8	8.4	2.7	4.0	2.8	7.6	2.8	24.3	26.5	18.6	13.4
114	N	10	10	8	8	11	11	3	3	9	9	7	7	6	6	9	9	11	11	74	74
	M	25.9	15.3	23.6	19.5	18.7	19.3	26.0	24.3	20.4	21.3	25.1	25.3	9.7	9.7	10.2	11.4	38.5	42.9	22.5	22.6
	S.D.	12.9	11.2	9.5	7.7	6.4	6.6	[illegible]	3.9	4.1	3.5	4.6	3.8	2.4	1.9	2.6	2.5	24.6	26.5	14.5	15.4
116	N	13	13	11	11	17	17	8	8	9	9	10	10	10	10	13	13	12	12	103	103
	M	19.8	17.9	18.4	17.4	16.9	18.5	18.6	26.1	14.7	18.4	20.0	18.9	12.3	11.7	14.4	16.4	45.3	49.0	20.2	21.5
	S.D.	5.0	7.7	4.1	4.9	5.4	5.2	5.0	4.7	3.6	2.4	4.8	4.0	3.6	3.4	5.1	3.7	28.9	23.8	14.4	14.0
117	N	8	8	5	5	10	10	7	7	11	11	8	8	6	6	11	11	8	8	74	74
	M	40.6	20.8	44.2	24.2	17.9	18.7	21.7	21.9	15.9	18.2	21.2	17.2	15.8	15.3	18.4	17.1	41.5	42.9	25.0	21.5
	S.D.	19.4	15.9	0.8	9.1	4.3	3.8	2.5	5.9	3.5	5.9	6.7	4.9	0.8	1.7	4.2	1.6	21.9	21.7	15.0	12.6
131	N	4	4	5	5	10	10	3	3	3	3	6	6	5	5	8	8	7	7	51	51
	M	6.0	9.2	10.8	13.8	12.6	12.8	13.3	13.7	7.3	10.3	11.3	10.3	7.2	7.8	9.0	8.8	37.7	36.3	13.8	14.5
	S.D.	1.4	4.0	7.8	[illegible]	2.0	1.9	2.5	1.7	3.3	0.5	1.6	1.2	0.8	1.2	1.9	2.4	24.6	19.0	13.7	11.8
132	N	1	1	8	8	11	11	4	4	6	6	6	6	5	5	9	9	7	7	57	57
	M	48.0	14.0	3.5	6.6	7.8	8.8	9.0	8.5	9.8	10.5	11.5	11.5	8.2	9.2	10.6	9.6	44.4	22.8	13.6	10.9
	S.D.	0	0	1.7	5.0	1.5	2.1	0.7	0.5	3.6	1.7	3.9	1.1	0.4	0.8	4.52	1.8	42.5	10.0	19.9	6.3
133	N	6	6	8	8	11	11	4	4	5	5	6	6	6	6	9	9	7	7	62	62
	M	4.2	4.0	5.1	5.1	11.2	12.7	13.2	12.0	10.6	10.6	13.5	11.2	8.0	[illegible]	[illegible]	9.6	36.0	37.6	12.3	12.5
	S.D.	2.2	0.8	0.8	0.9	2.5	1.6	0.8	1.2	1.6	1.7	2.9	1.2	0.6	[illegible]	[illegible]	2.3	34.6	30.0	14.8	13.8
ALL	N	87	87	80	80	109	109	43	43	72	72	71	71	71	71	102	102	134	134	739	739
	M	28.0	16.4	25.0	17.1	17.6	18.5	20.0	21.3	17.1	19.0	22.1	20.4	[illegible]	[illegible]	16.6	16.0	38.9	20.7	22.6	20.3
	S.D.	18.5	9.7	17.5	8.6	7.0	6.5	6.9	7.7	6.2	5.7	9.0	8.5	[illegible]	5.5	7.7	6.2	31.5	26.2	17.5	13.8

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