PASSENGER COMFORT RESPONSE TIMES AS A FUNCTION OF AIRCRAFT MOTION

Technical Report
National Aeronautics and Space Administration
Grant No. NGR 47-005-202

Technical Report 403906
Short-Haul Air Transportation Program

Submitted by:

Edward J. Rinalducci

SCHOOL OF ENGINEERING AND APPLIED SCIENCE

RESEARCH LABORATORIES FOR THE ENGINEERING SCIENCES

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VIRGINIA 22901

Report No. ESS-4039-104-75

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Introduction

The main purpose of the research reported here was to examine the relationship between a passenger's response time of changes in level of comfort experienced as a function of aircraft motion. The aircraft used in this investigation was the Lockheed Jetstar modified to carry the GPAS (General Purpose Airborne Simulator) system and is described in more detail by Jacobson (1974). This aircraft is capable of providing a wide range of vertical and transverse accelerations by means of direct-lift flap control surfaces and side-force generator surfaces in addition to the normal control surfaces. See Fig. 1. Response times to changes in comfort were recorded along with the passenger's rating of comfort on a five-point scale where 1 is "very comfortable," 2 is "comfortable," 3 is "neutral," 4 is "uncomfortable," and 5 is "very uncomfortable." In addition, a number of aircraft motion variables including vertical and transverse accelerations were also recorded. See Appendix A.

Method

Subjects: Twenty subjects (or passengers) were used in this study. All were volunteers and ranged in age from 20 to 55 years. About 30% of the subjects were women and 70% men. Their previous flying experience and occupational backgrounds are shown in Tables 1 and 2.

Procedure: The subjects were instructed to meet at a given time with the Test Director. The Test Director reminded them of their volunteer status and let them read the instructions they were to follow during the flight, including instructions on the use of the five-point comfort rating scale. The subjects were also reminded that they were to rate their overall feeling of comfort and not to act as accelerometers (i.e., not to respond to their perception of the motion amplitude).

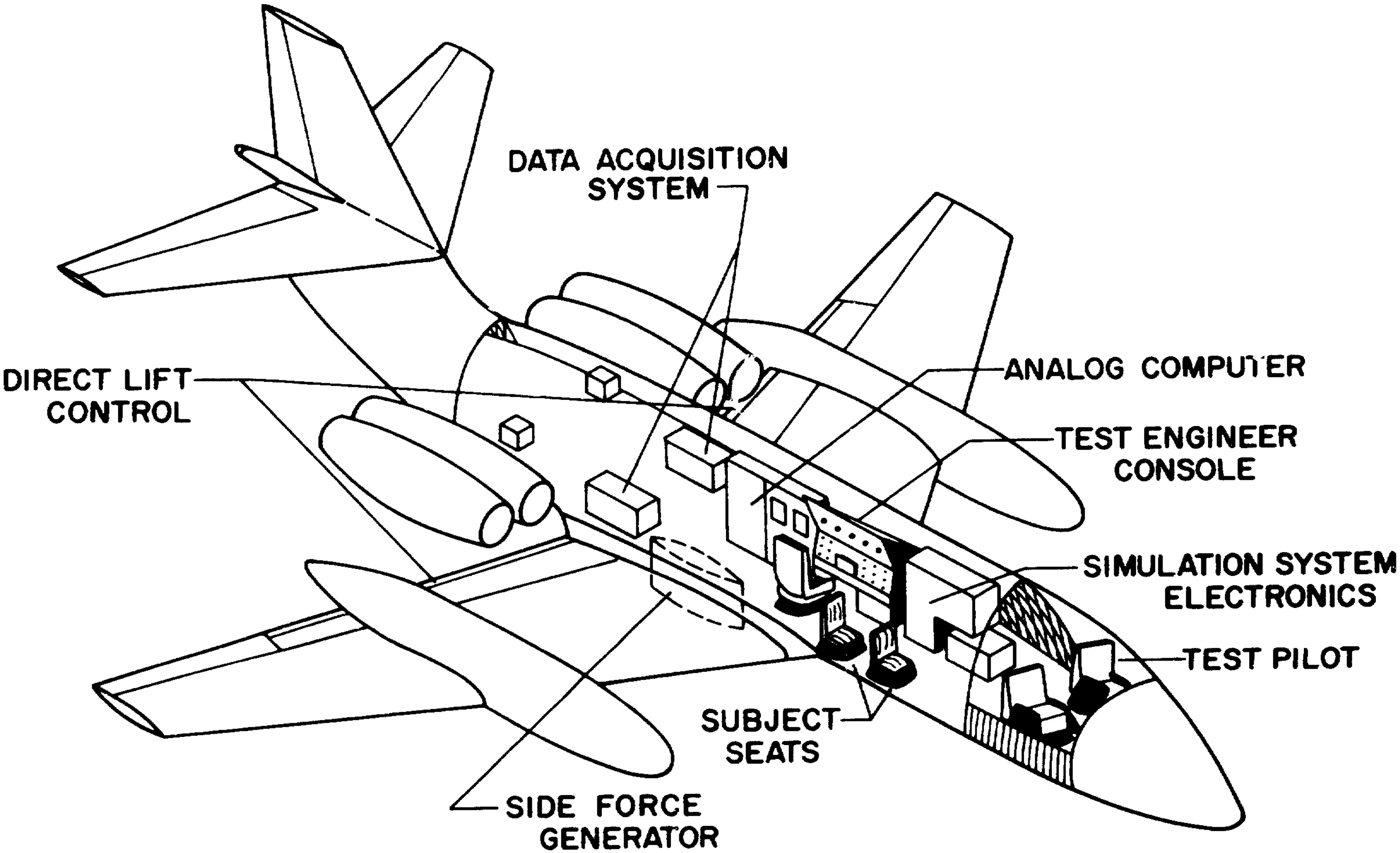

Fig. 1. NASA General Purpose Airborne Simulator (GPAS).
(From Jacobson, 1974)

Two subjects were chosen for each flight and were assigned the front or the back seat in the aircraft. The seating arrangement is shown in Fig. 1. Each seat was a coach-type aircraft seat placed beside a window. The forward area of the compartment and pilot's cabin adjacent to the subjects' seats were blocked from the view of the subjects.

On the right-hand arm of each seat was placed a box with buttons corresponding to the five-point rating scale and a reset button. Subjects were instructed to press the reset button each time they made a comfort rating. The subjects were told that periodically they would be reminded to press the reset button and rate their comfort. In actuality the flight engineer reminded them to do this about 15 seconds before the end of each one-minute flight segment. Each subject was also provided with a notebook and pencil in order to indicate any comments he might have concerning the flight. The notebook also contained a comfort bag and chewing gum. The subject was given a card with instructions on how to respond and rate his comfort which he could refer to from time to time.

The aircraft was readied and the subjects boarded just prior to take off as in a normal commercial flight. The aircraft then made a long taxi on the runway (about 15 min), took off, and climbed to an altitude at which the tests were to take place (usually about 20,000 ft). Climb-out took about 20 min. The aircraft then went into level flight and the GPAS system was engaged. A run of ten one-minute segments was made. The run was continuous and each segment had a different level of acceleration. The aircraft then executed a standard 180° turn, re-aligned itself and went through another run of ten one-minute segments. Two steep 180° turns were then executed and the aircraft landed. A typical flight pattern is shown in Fig. 2.

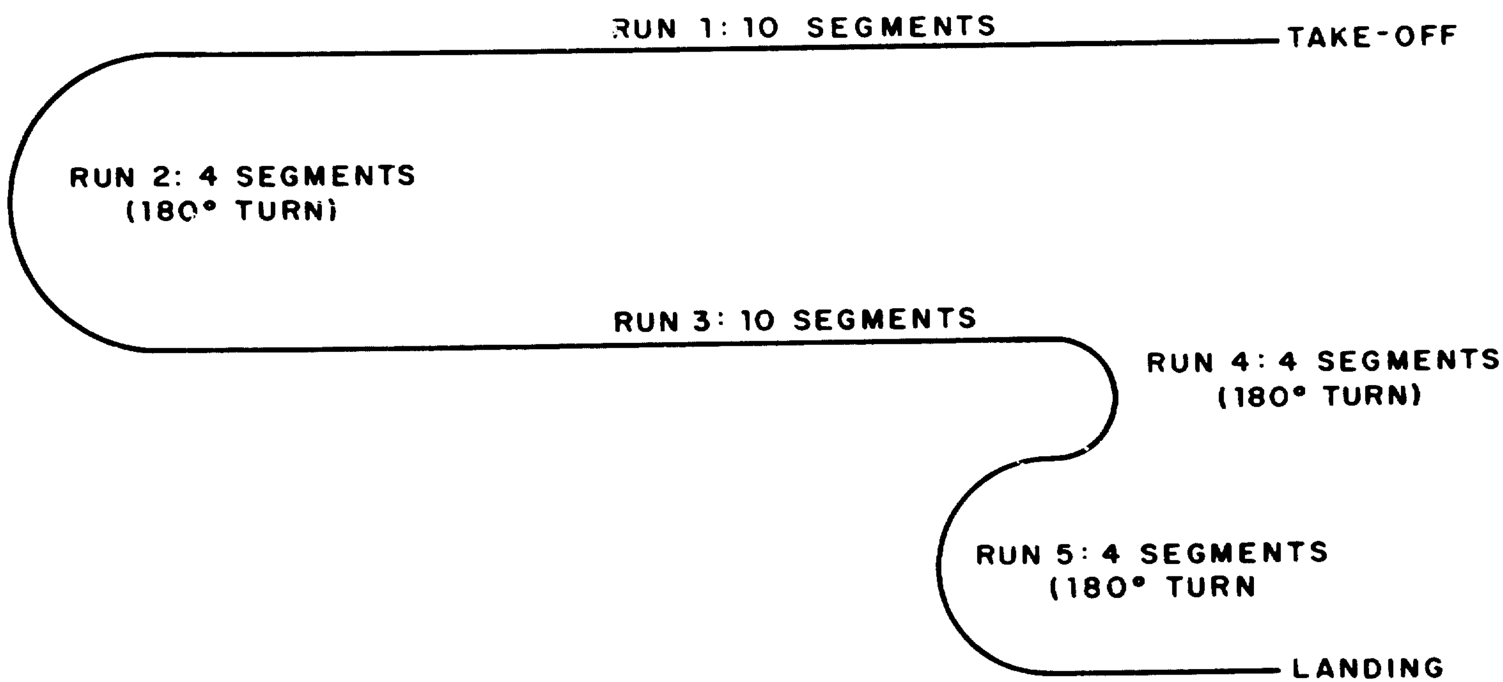

Fig. 2. Typical Flight Pattern. (From Jacobson, 1974)

Results and Discussion

Analysis of the data obtained in this study will be considered in two parts. Part I concerns the relationship of response times as a function of the absolute comfort ratings. The analysis presented here will be primarily of a graphical and tabular nature. However, distinct trends are evident in the results. In addition, a statistical analysis of the data has been made using multiple comparison procedures.

Part I: Relationship of Response Times to Absolute Comfort Ratings.

Figures 3 and 4 show that, in general, as the subject becomes more uncomfortable (indicated by an increase in the rating of comfort) his latency to respond shows a tendency to become shorter. This holds true for the subject's "first response change" (after the beginning of a flight segment) as well as his "final response change" (after which there are no further changes in his rating of comfort). The trend is linear and monotonic for both the first response time and the final response time. The final response time, as one might suspect, varies from 5.5 to 8.1 sec longer than the first response time. There were no five-level comfort ratings made by the subjects in this study. This could be in keeping with the reluctance of many subjects to use the extremes of a rating scale and may also be indicative of a lack of truly extreme acceleration conditions. Tables 3 and 4 show the mean response times (Table 3 shows the first response times and Table 4 shows the final response times), S.D.s, kurtosis, and skewness of the distribution of response times, and the number of observations making up each distribution. The S.D.s for the first response times range from 16.251 to 17.628 with a mean of 16.902. All the distributions appear to be somewhat flattened or platykurtic and appear to have a positive skew.

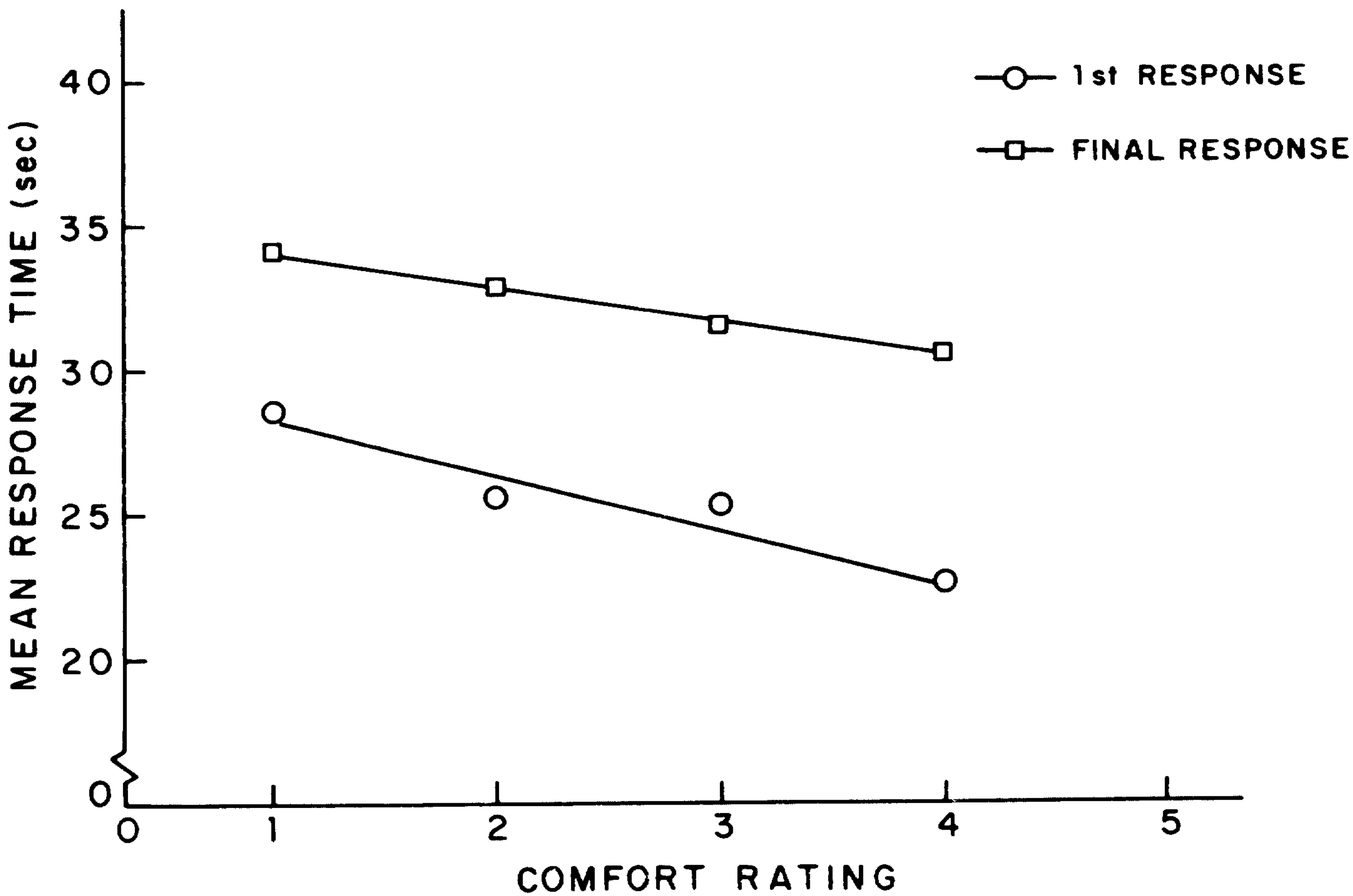

Fig. 3. First and final mean response times in seconds as a function of comfort rating.

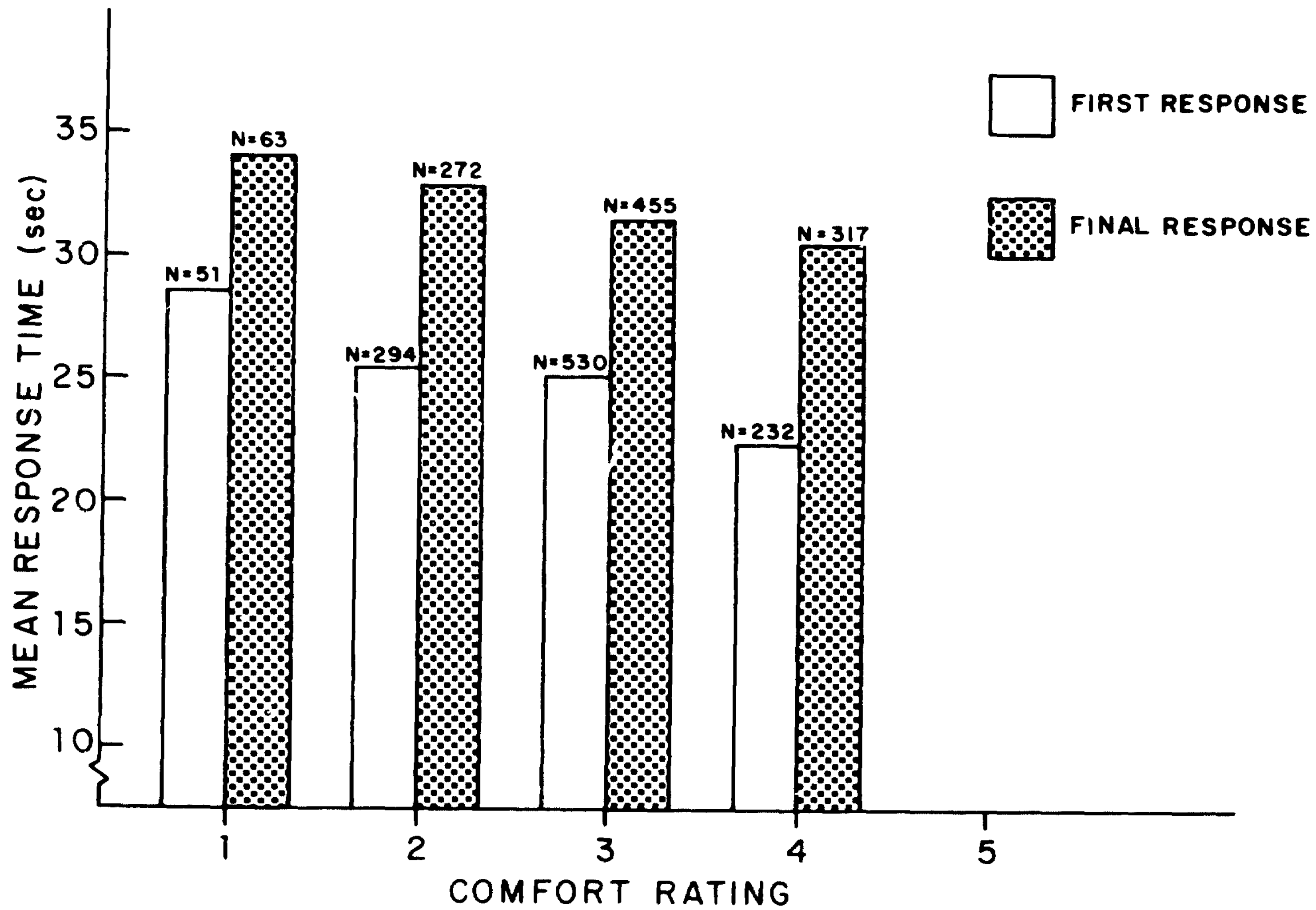

Fig. 4. Bar graph showing first and final mean response times in seconds as a function of comfort rating.

Table 3

First Response Time as a Function of Comfort Rating

Rating	Response Time and Statistics*	Acceleration**	
		$a_{\bar{v}}$(g's)	$a_{\bar{t}}$(g's)
1	$\bar{x}$ = 28.607 sec.	.054	.007
	SD = 17.628		
	K = -1.357		
	S = 0.020		
	N = 51		
2	$\bar{x}$ = 25.508		
	SD = 17.038	.060	.016
	K = -1.276		
	S = .341		
	N = 294		
3	$\bar{x}$ = 25.197	.077	.023
	SD = 16.693		
	K = -1.332		
	S = .324		
	N = 530		
4	$\bar{x}$ = 22.445	.089	.030
	SD = 16.251		
	K = -1.043		
	S = .594		
	N = 232		

*where $\bar{x}$ is the arithmetic mean, SD is the standard deviation of the response times, K is kurtosis, S is skewness, and N refers to the number of observations. All statistics defined in terms of SPSS.

**Average of the cumulative changes in S.D.s of the accelerations.

Table 4

Final Response Times as a Function of Comfort Rating

Rating	Response Times and Statistics	Acceleration $a_{\bar{v}}$ (g's)	$a_{\bar{t}}$ (g's)
1	$\bar{x}$ = 34.153 sec	.054	.007
	SD = 15.957		
	K = -1.010		
	S = - .507		
	N = 63		
2	$\bar{x}$ = 32.891	.060	.016
	SD = 16.652		
	K = -1.254		
	S = - .231		
	N = 272		
3	$\bar{x}$ = 31.508	.078	.023
	SD = 16.9[illegible]5		
	K = -1.361		
	S = - .166		
	N = 455		
4	$\bar{x}$ = 30.577	.088	.030
	SD = 17.573		
	K = -1.479		
	S = - .069		
	N = 317		

The S.D.s for the final response times range from 15.957 for the comfort level of 1 to 17.573 for the comfort level of 4, with an overall mean of 16.774. Again all the distributions appear to be platykurtic and also appear to be somewhat negatively skewed. Thus the first response times tend to be positively skewed and the final response times tend to be negatively skewed. In other words, the response times tend to pile up towards the shorter times for the first response and towards the longer times for the final responses. The mean of the S.D.s for both first and final response times is 16.838. Therefore the variability in the data would appear to be large.

Figures 5 - 8 and Tables 3 and 4 show the data relating response times to acceleration levels (average of the cumulative changes in the S.D.s of the accelerations). In all cases ther is a decreasing monotonic relationship between response times and acceleration. This holds for both first and final response times and for both vertical and transverse accelerations. In a related manner it can be seen by inspection of Figs. 9 and 10 that there is an increasing monotonic relationship between comfort rating and acceleration. Thus the greater the level of acceleration and therefore of the comfort scale rating or feeling of being uncomfortable, the shorter the response time whether it be the first response change from the start of the flight segment or the final change after which there are no further changes in rating.

Although the data analysis presented here is mainly of a graphical and tabular nature (employing descriptive statistics), a statistical analysis of the data was also made. Table 5 shows the results of an anlysis of variance or ANOVA (Winer, 1971) for the first response times as a function of the comfort rating. The F-ratio is significant at the 0.05 level. However, the Scheffe multiple range test (Winer, 1971) indicates that there is no significant difference between the

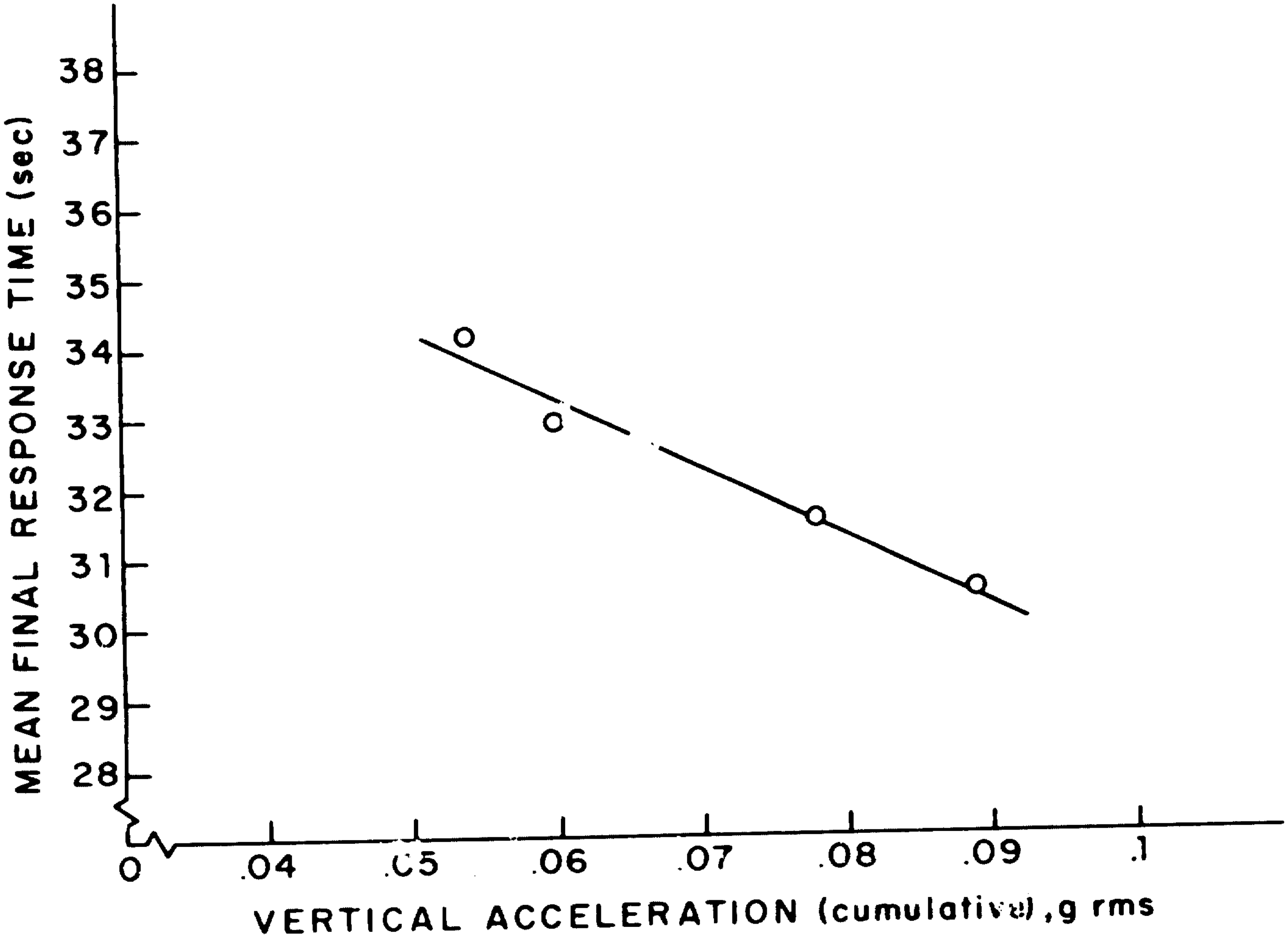

Fig. 5. Mean first response time in seconds as a function of vertical acceleration.

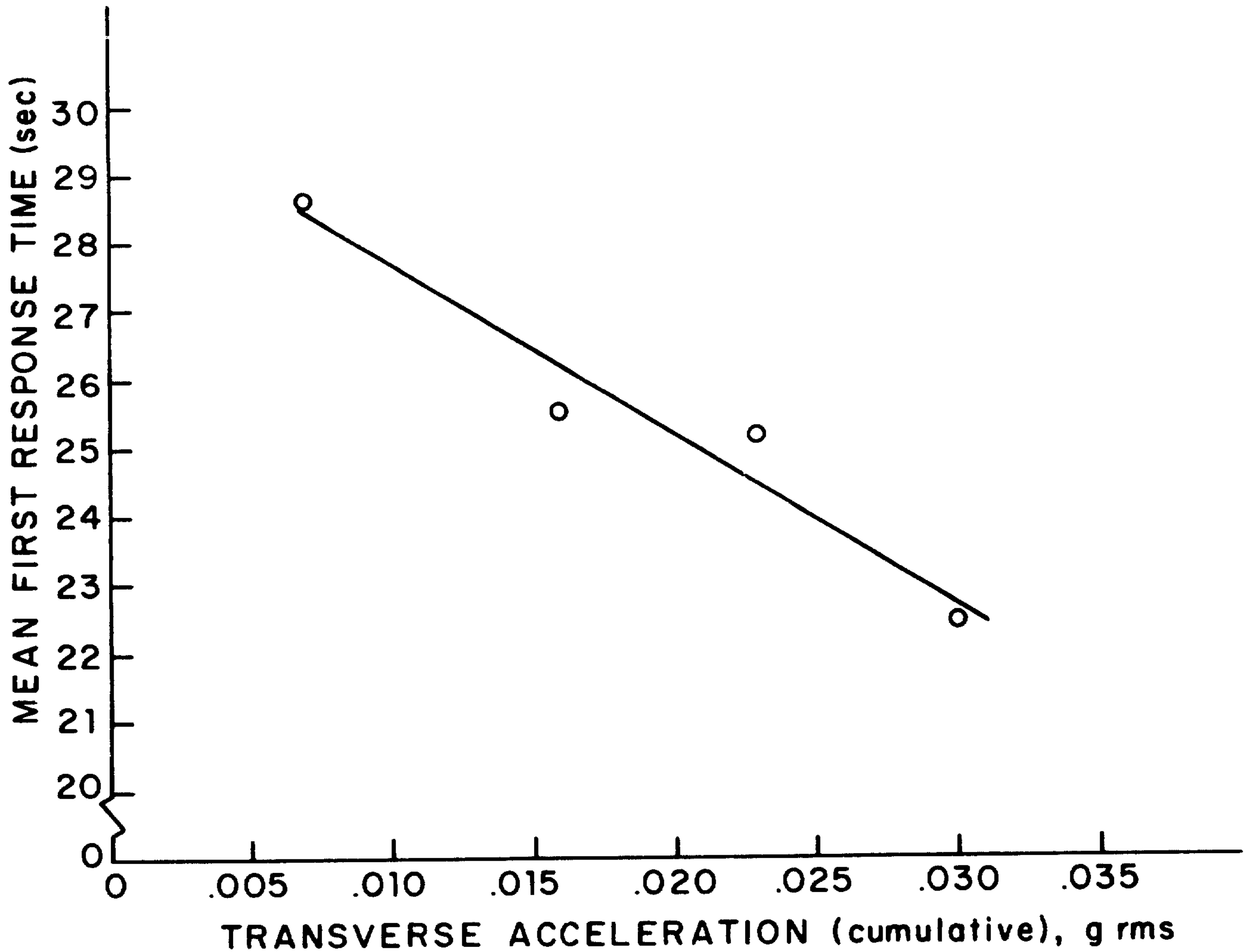

Fig. 6. Mean first response time in seconds as a function of transverse acceleration.

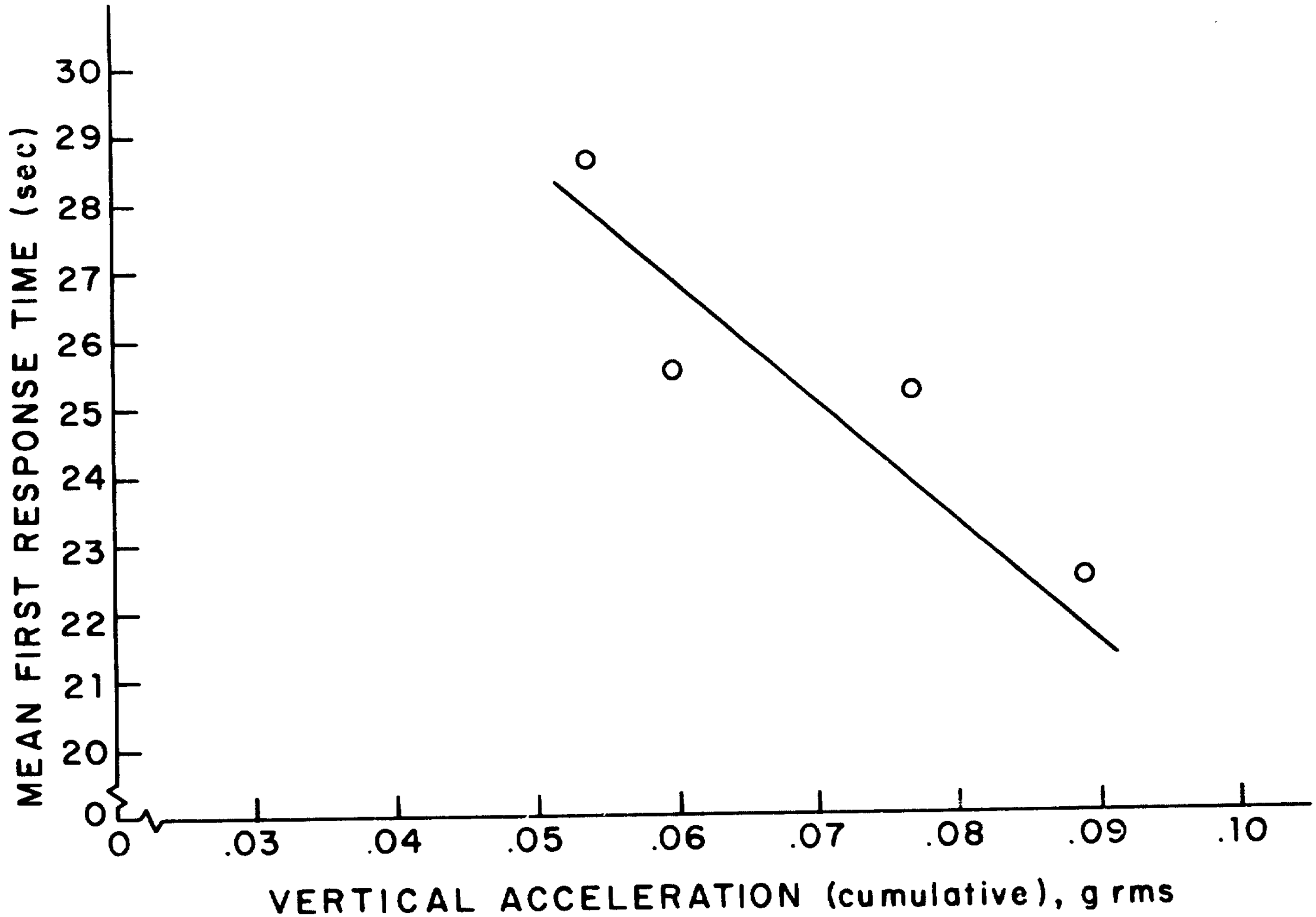

Fig. 7. Mean final response time in seconds as a function of vertical acceleration.

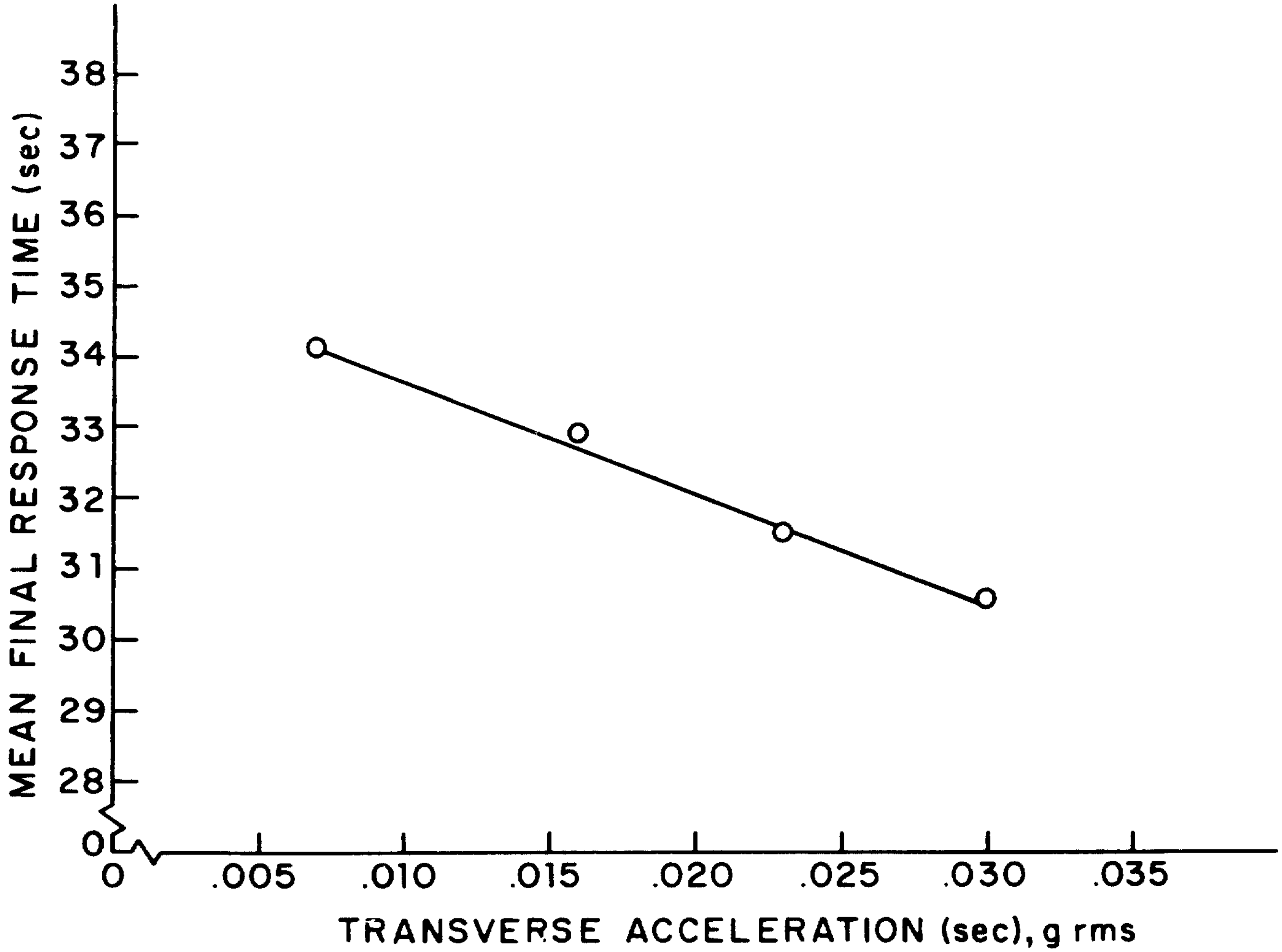

Fig. 8. Mean final response time in seconds as a function of transverse acceleration.

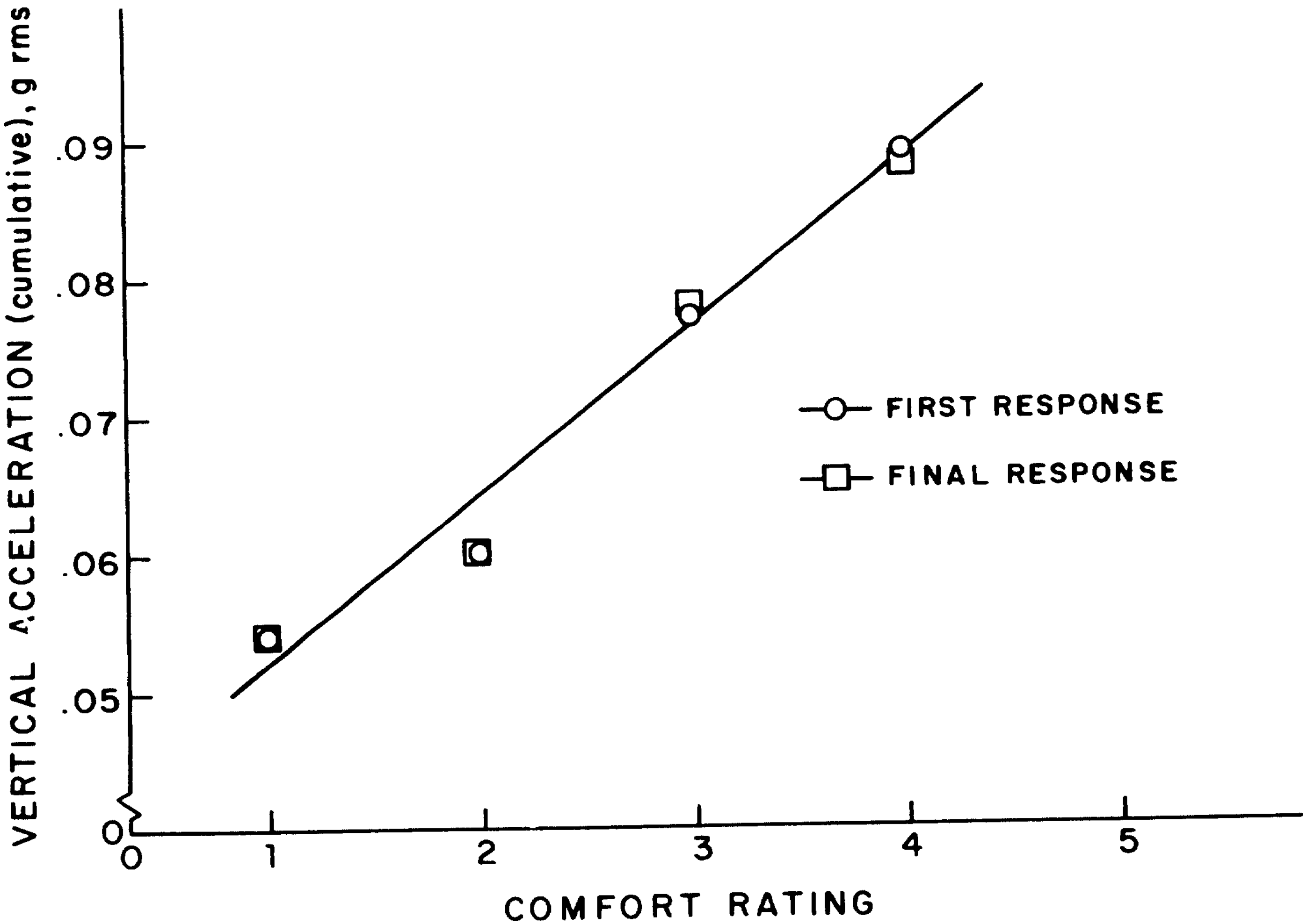

Fig. 9. Vertical acceleration as a function of comfort rating for the first and final response times.

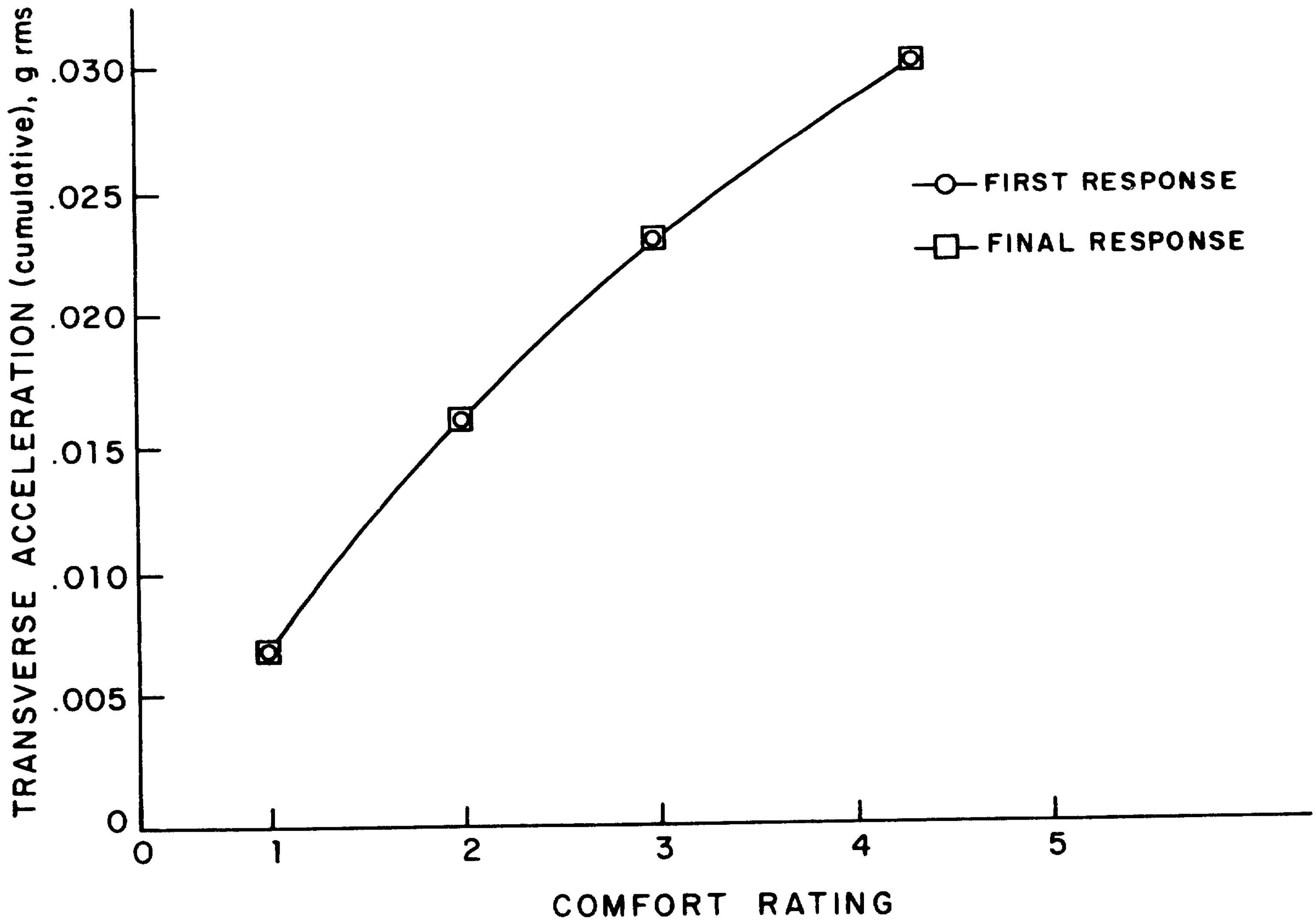

Fig. 10. Transverse acceleration as a function of comfort rating for the first and final response times.

Table 5

Analysis of Variance of First Response Times
as a Function of Comfort Rating

Source	DF	Sum of Squares	Mean Squares	F-Ratio	F-Prob
Between Groups	3	2252.56	750.85	2.68	.046
Within Groups	1103	309017.78	280.16		
Total	1106	311270.34			

mean response times for the different comfort ratings. Table 6 shows the results of an ANOVA for the final responses times as a function of comfort rating. Here the F-ratio is not significant at the 0.05 level. Thus the application of a post-hoc multiple comparison procedure is not appropriate. Again this would indicate that there are no significant differences between the mean response times for different comfort ratings. Although the statistical analysis of the data indicates that there are no significant differences between the mean response times as a function of comfort rating, the graphical and tabular analysis would seem to indicate important trends.

Part II: Relationship of Response Times to Direction and Amount of Change in Comfort Ratings.

Table 7 and Fig. 11 show the data for direction and rating of comfort as a function of the subject's first response time. It can be seen that upward changes have a shorter response time than downward changes. For the first change in comfort rating, by the subject, the larger the change the shorter the response time. This is particularly true for upward changes. Because upward changes are associated with shorter response times than downward changes, this suggests that it may take longer to become more comfortable than uncomfortable.

Table 8 and Fig. 12 show the data for direction and rating of comfort as a function of the subject's final response. Again upward changes have a shorter response time than downward changes except when the change in the comfort rating is as much as three. Generally speaking, however, the larger the change in rating the longer the response time of the subject, suggesting a decision process that may be involved in choosing a comfort rating or level. This situation is the reverse of that for the first response time. It

Table 6

Analysis of Variance of Final Response Times as a Function of Comfort Rating

Source	DF	Sum of Squares	Mean Squares	F-Ratio	F-Prob
Between Groups	3	1180.92	393.64	1.364	.252
Within Groups	1103	318416.88	288.68		
Total	1106	319597.80			

Table 7

Direction and Amount of Change: First Response (in seconds)

Starting Response	First Response	N	$\bar{x}$	Mdn	$a_{\bar{v}}$(g's)	$a_{\bar{t}}$(g's)
1	2	123	20.843	14.851	.0597	.0136
1	3	26	24.028	20.201	.0725	.021
1	4	5	11.794	10.676	.0846	.0088
2	1	45	27.247	24.326	.0534	.0064
2	3	233	23.476	17.651	.0758	.0194
2	4	19	20.613	10.200	.0879	.0207
3	1	6	38.806	45.528	.0597	.0014
3	2	149	30.134	26.602	.0593	.0145
3	4	208	22.868	17.464	.0887	.0197
4	2	20	21.607	13.858	.0589	.0088
4	3	269	26.778	23.051	.0788	.0171
5	1	2	6.737	6.737	.0968	.0012
5	2	2	28.274	28.274	.0721	.0006

Summary (weighted values)

Amount of Change in Comfort Rating	N	$\bar{x}$	$a_{\bar{v}}$(g's)	$a_{\bar{t}}$(g's)
+1	564	22.678	.0770	.0183
+2	45	22.587	.0790	.0208
+3	5	11.794	.0631	.0293
-1	463	27.904	.0701	.0152
-2	26	25.122	.0591	.0071
-3	2	28.274	.0721	.0006
-4	2	6.737	.0968	.0012
<u>Absolute Change</u>				
1	1027	25.034	.0738	.0168
2	71	23.493	.0716	.0158
3	7	16.447	.0656	.0211
4	2	6.737	.0968	.0012

Upward Change: 22.584

Downward Change: 27.674

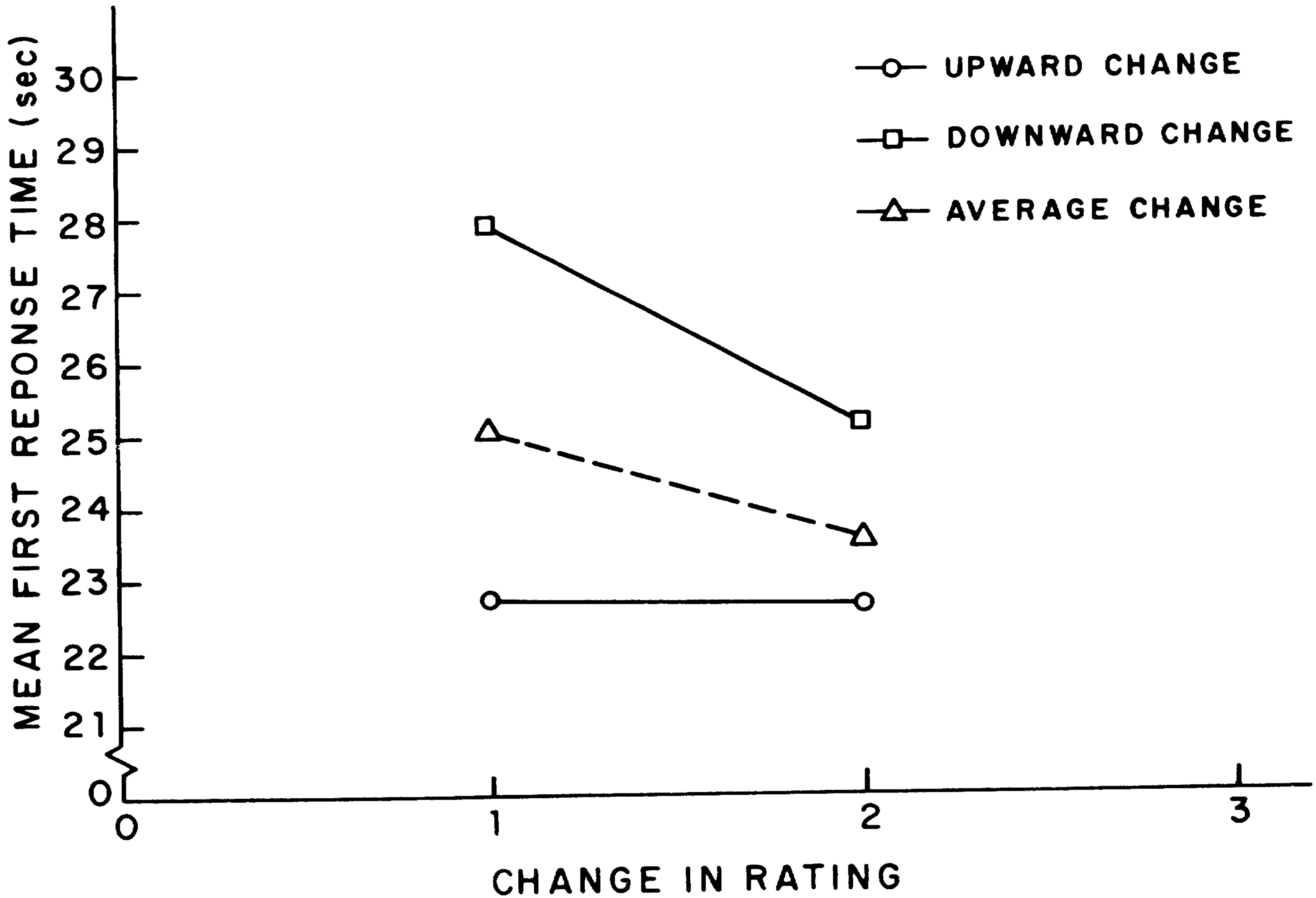

Fig. 11. Mean first response time in seconds as a function of change in comfort rating.

Table 8

Direction and Amount of Change: Final Response (in seconds)

Starting Response	First Response	N	$\bar{x}$	Mdn	$a_{\bar{v}}$ (g's)	$a_{\bar{t}}$ (g's)
1	2	69	28.204	29.426	.0527	.0142
1	3	60	36.51	41.29	.0829	.0236
1	4	22	34.646	39.74	.0883	.0281
2	1	38	30.29	32.291	.0532	.0066
2	3	174	28.435	28.014	.0737	.0215
2	4	70	33.072	25.01	.0875	.0245
3	1	12	43.138	47.803	.0494	.0078
3	2	130	33.426	33.934	.0598	.017
3	4	176	25.459	19.926	.0879	.0322
4	1	10	35.136	37.44	.0574	.0094
4	2	56	36.711	41.166	.0652	.0159
4	3	174	30.632	29.052	.078	.0234
5	1	2	6.737	6.737	.0968	.0214
5	2	2	28.274	28.274	.0722	.0241

Summary (weighted values)

Amount of Change in Comfort Rating	N	$\bar{x}$	$a_{\bar{v}}$ (g's)	$a_{\bar{t}}$ (g's)
+1	419	27.147	.0762	.0247
+2	130	34.661	.0856	.0241
+3	22	39.740	.0883	.0281
-1	342	31.656	.0683	.0191
-2	68	37.842	.0624	.0145
-3	12	33.990	.0599	.0118
-3	2	28.274	.0968	.0214

Absolute Change	N	$\bar{x}$	$a_{\bar{v}}$ (g's)	$a_{\bar{t}}$ (g's)
1	761	29.172	.0727	.0022
2	198	35.570	.0776	.0208
3	34	37.710	.0783	.0224
4	2	28.274	.0968	.0214

Upward Change: 29.339

Downward Change: 32.694

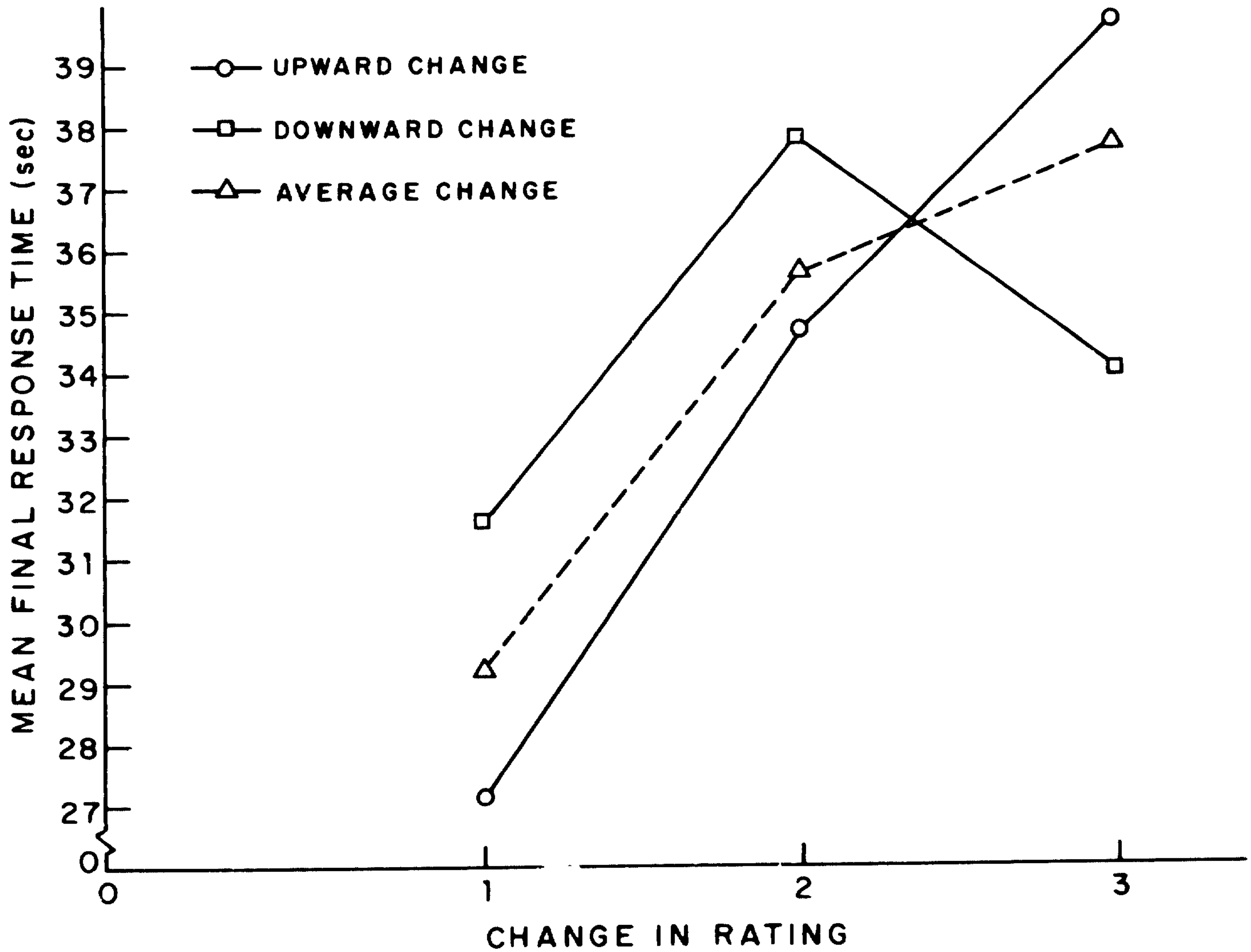

Fig. 12. Mean final response time in seconds as a function of change in comfort rating.

would seem to suggest that a subject initially responds more quickly to conditions associated with large changes in comfort but the final choice in comfort rating involves more of a decision time the larger the change.

Tables 7 and 8 and Figs. 13 and 14 show the relationship between the change in comfort rating and vertical and transverse accelerations. There appears to be, in general, an increase in acceleration for both first and final responses the greater the upward change in response rating and a decrease the greater the downward change.

The values for a change in rating of three were omitted for the first response as there were too few observations. In the case of the first response there were only five observations for the upward change and two for the downward change. In the case of the final response there were 22 for the upward and 12 for the downward change. A 7-point and 9-point scale should yield data more relevant to this problem.

Conclusions

Generally speaking, response times of changes in comfort (both first and final response times) as a result of changes in aircraft motion appear to be a decreasing function of intensity, in both the vertical and lateral directions. In addition, there also seems to be a monotonic relationship (decreasing for first and increasing for final response times) between comfort response times and the relative change in aircraft motion. These results suggest that there might be a parallel between the large body of data on human reaction time collected in the laboratory (Frost, 1972; Postman & Egan, 1949; Underwood, 1966; Woodworth & Schlosberg, 1954) and the data on response times of changes in comfort collected in the field situation. Although much data have been collected

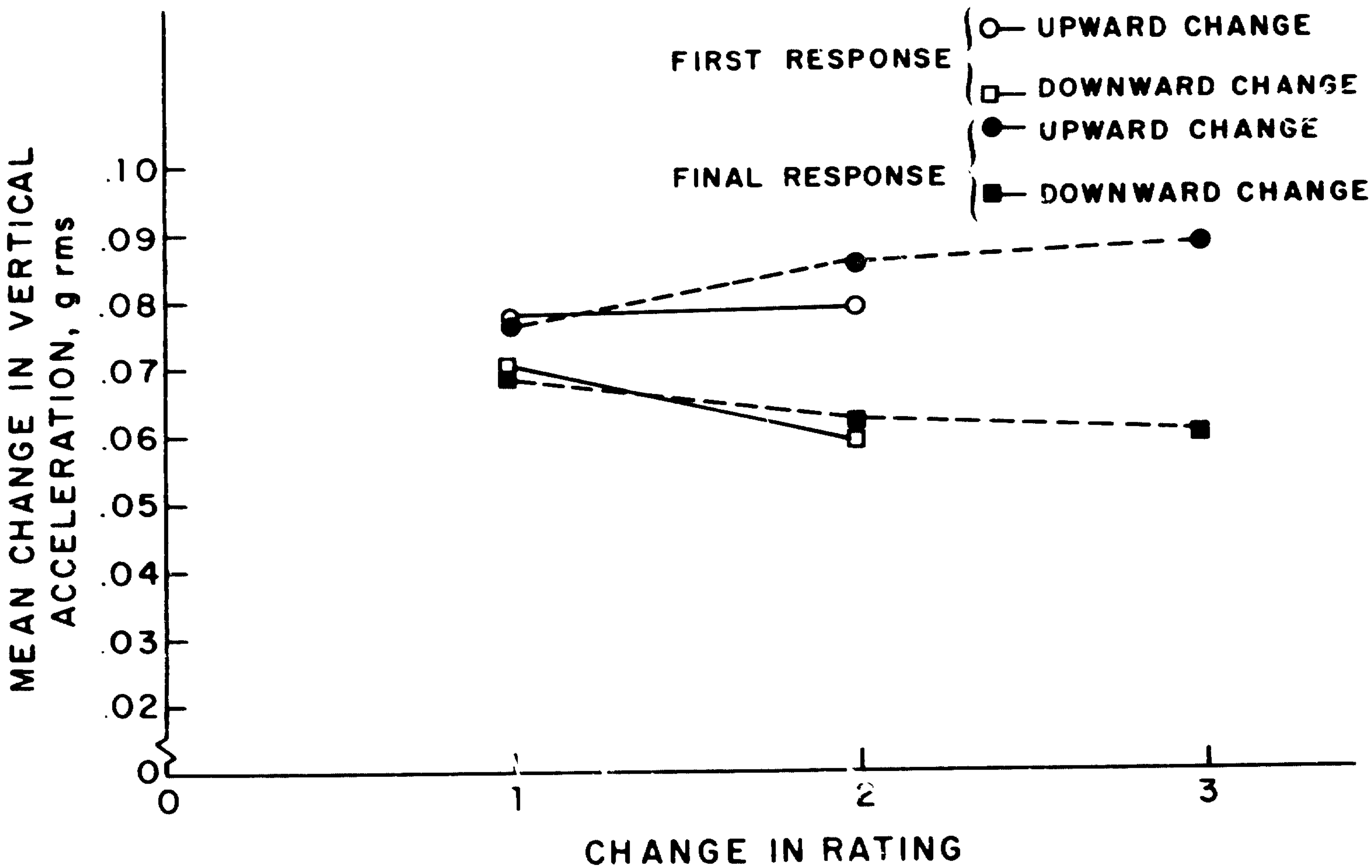

Fig. 13. Mean vertical acceleration as a function of change in rating for both first and final response times.

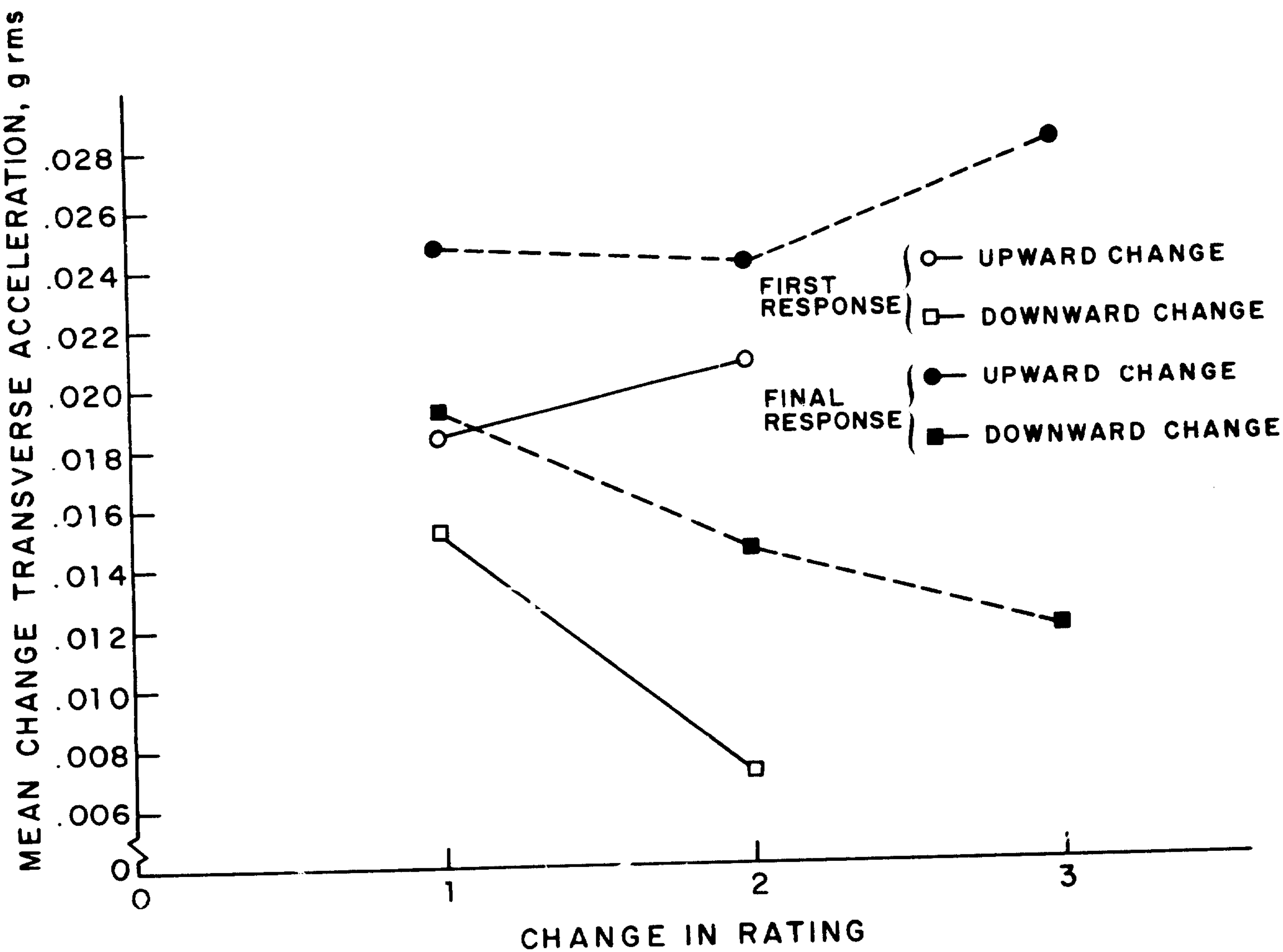

Fig. 14. Mean transverse acceleration as a function of change in rating for both first and final response times.

on the effects of vibration on human reaction time tasks, little or no data exists concerning the reaction or response time to vibration itself or changes in comfort resulting from vibration or from aircraft motion (Hornick, 1973). The results obtained in the research reported here would seem to indicate that we might conceive of some aspects of comfort response times in relation to the familiar human reaction time data. The relationship between field and laboratory results suggests that further research might be able to be conducted in a ground-based simulator as well as in an in-flight simulator. In a ground-based simulator empirical relationships might then be established between comfort response times and aircraft motions with a significant savings in time, effort, and money. This of course assumes that there is a sufficient degree of fidelity of simulation for the ground-based simulators.

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APPENDIX A

UNIVERSITY OF VIRGINIA DATA REQUEST TO FRC

Terminology

A segment refers to either:

a. each discrete level of motion while the GPAS system is engaged (usually 20 segments/flight)

or

b. each test turn (usually 2 segments/flight)

An interval refers to each subdivision of a segment. For the current analysis, this interval will be 5 seconds in duration.

Definitions of Variables of Interest

Linear accelerations:	Vertical (V_1), Lateral (V_2), Longitudinal (V_3)
Angular rotation rates:	Pitch (V_4), Roll (V_5), Yaw (V_6)
Angular accelerations:	Pitch (V_7), Roll (V_8), Yaw (V_9)
Subject responses:	Front seat (R_1), Rear seat (R_2)
Times:	Start time of each segment (T_S)
	Start time of each interval (T_1)
	Time each subject changes response (T_{R_1}, T_{R_2})

Data Requested

Description

For each flight

1. Identify each flight by number, including a code to indicate subject identification (if available).

2. Calculate means and standard deviations for each variable, $V_1 \rightarrow V_9$ for each 5-second interval.

3. For each segment, calculate cumulative means and standard deviations at end of each 5-second interval for each variable, $V_1 \rightarrow V_9$.

4. Calculate time line of subject response (i.e., response of subjects at start of segment plus time of response and response level for each change within the segment).

Single time

One power spectra 0-12 Hz of each variable V_i (i = 1,9) for each segment reduced from the on-board data tape. Only one such set is needed for each differing GPAS driving tape. For instance, a GPAS driving tape may have been used for 8 flights. Power spectra are requested for one flight only.

For each segment

Tapes should contain records as follows.

Once per segment:

ID No., T_S, R_1(at T_S), R_2(at T_S), No. of intervals (in this segment)

Once per interval:

M_i(i=1,9), σ_i(i=1,9), M_{C_i}(i=1,9), σ_{C_i}(i=1,9)

$T_{R_{11}}$ (1st change of subject 1), R_{11}(level at $T_{R_{11}}$),

$T_{R_{21}}$ (1st change of subject 2), R_{21}(level at $T_{R_{21}}$),

$T_{R_{12}}$ (2nd change of subject 1), R_{12}(level at $T_{R_{12}}$),

$T_{R_{22}}$ (2nd change of subject 2), R_{22}(level at $T_{R_{22}}$),

$T_{R_{13}}$ (3rd change of subject 1), R_{13}(level at $T_{R_{13}}$),

$T_{R_{23}}$ (3rd change of subject 2), R_{23}(level at $T_{R_{23}}$)

Notes:

ID No.	→	includes flight no., subject codes
M_i	→	mean of variable V_i for each interval
σ_i	→	standard deviation of variable V_i for each interval
M_{C_i}	→	cumulative mean of variable V_i from beginning of each segment through the end of each interval
σ_{C_i}	→	cumulative standard deviation of variable V_i from beginning of each segment through the end of each interval
T_S	→	start time for each segment
R_1	→	subject 1 response level at T_S
R_2	→	subject 2 response level at T_S
*$T_{R_{11}}, T_{R_{12}}, T_{R_{13}}$	→	times of subject 1 first, second, and third change of response within an interval
*R_{11}, R_{12}, R_{13}	→	subject 1 response level at $T_{R_{11}}, T_{R_{12}}, T_{R_{13}}$
*$T_{R_{21}}, T_{R_{22}}, T_{R_{23}}$	→	times of subject 2 first, second, and third change of response within an interval
*R_{21}, R_{22}, R_{23}	→	subject 2 response level at $T_{R_{21}}, T_{R_{22}}$, $T_{R_{23}}$, respectively

*It is unlikely that subjects will respond three times within each interval. Each unused record of time and response should be filled with zeros.

Tape Format

7-track magnetic tape

Binary using unformated Fortran write statements

Unlabeled

556 bpi

3000 - 5000 characters (frames) per physical record

60-bit word length

Two consecutive tape marks at end of data

Additional Requests

1. Send a copy of the write (or bufferout) statements used to create the tape.

2. Prior to reducing all the data, please send a tape with a full printout, instructions, and variable identification.

3. After verifying that we have properly described the data we want, and that we are able to read the tape, the remaining data can be reduced with abbreviated printout.