Return to Sussman

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UNITED STATES - FEDERAL REPUBLIC OF GERMANY COOPERATIVE STUDY OF PLANNED MAGNETICALLY LEVITATED VEHICLE RIDE QUALITY

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PROJECT MEMORANDUM

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U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

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1. BACKGROUND

The experiment described in this memorandum is the second phase of an investigation of the ride-comfort and acceptability characteristics of proposed magnetically levitated, advanced high-speed, ground transportation systems. The study is sponsored jointly by the U.S. Department of Transportation and the Federal Republic of Germany's (FRG) Ministry of Research and Development. It is being carried out in the United States by the Transportation Systems Center under the Transportation Advanced Research Project sponsored by the Office of Systems Technology, with the support of the National Aeronautics and Space Administration/Langley Research Center (NASA/LRC). The FRG portion of this effort is being performed by Dornier Systems GmbH , Messerschmitt Bolkow, Blohm (MBB) GmbH, and Machinen Fabrikan Augsburg-Nurnberg A.G. (Man). This U.S./FRG effort is covered under a cooperative research agreement initiated in May, 1978.

In the first phase of this study, the relative comfort associated with various speed-guideway configurations for a proposed magnetically levitated vehicle (Figure 1) and for a currently operating Bundesbahn rail-coach were determined. The ride-environment of the two vehicle types was simulated using the NASA Langley Research Center's (NASA/LRC) Passenger Ride Quality Apparatus (PRQA). The simulation was based on vehicle and guideway dynamics models which depict the motion environments in terms of "bounce" or motions along the Z-axis, "sway" or motions along the X-axis, and "roll" or rotational motions about the Y-axis. Paid subjects, chosen to achieve a balance between sex & age, were exposed to brief samples of the motion environments accompanied by appropriate levels of acoustic noise. The subjects were asked to rate the comfort level of each motion sample and, in cases where the ride was perceived to be uncomfortable, were asked to identify the motions which were most disturbing.

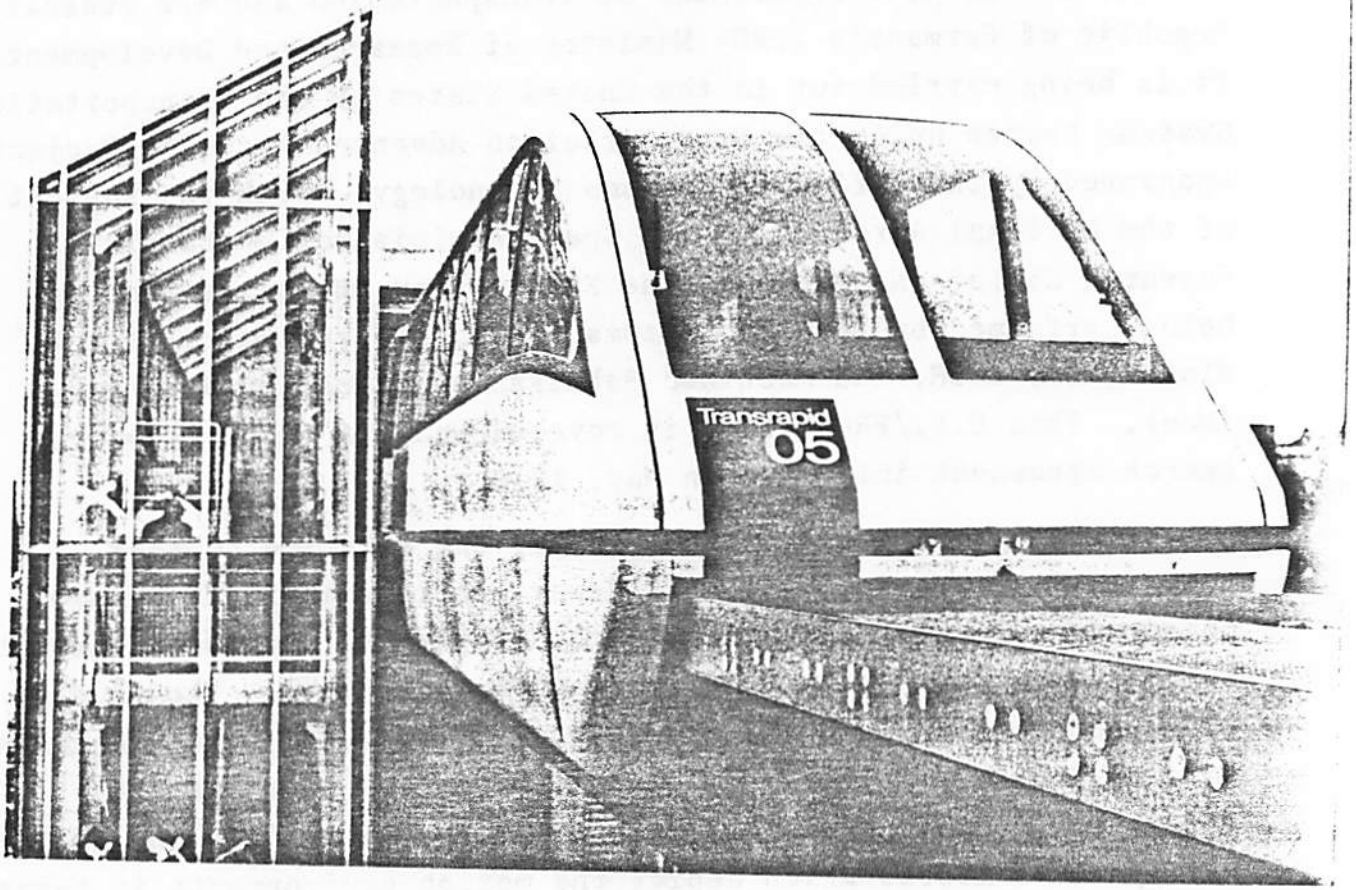


FIGURE 1. PROTOTYPE MAG-LEV VEHICLE

The results of the first phase indicated that at speeds up to 300 k/h, the magnetically levitated vehicle system would provide a ride equal to or better than the conventional rail system operating for the simulated, guideway configurations at speeds up to 160 k/h. The results also showed that the most disturbing aspect of the magnetically levitated vehicle's ride was the lateral acceleration or sway,while the most disturbing motions for the rail-coach were the vertical accelerations or bounce.

No effort was made during the first phase to simulate actual trips. The purpose was to obtain relative subject comfort ratings using brief (two minute) motion and noise simulations.

The major goal of the second phase was to estimate the absolute comfort levels which would be associated with actual travel on highspeed, interurban, fixed-guideway, transportation systems. To accomplish this goal, the study design incorporated many of the features to be found in such travel including realistic trip durations, simulations of the visual aspects of the countryside, control of subject expectation through descriptions of the characteristics of the vehicles simulated, and subject performance of activities analogous to those actually carried out during travel. Forty-five minute trip lengths (approximately the duration planned for the mag-lev systems) were used and during these trips, passengers were exposed to five eight-minute trip segments which represented different speed-guideway configurations. The "trips" and the segments they were composed of were presented with synchonized moving pictures depicting the view which would be seen from surface vehicles traveling at the speeds being simulated. The color movies used to provide the subjects with a distinct feeling of forward motion, allowed them to estimate the simulated speed, enhanced the impression that a trip was being taken, and gave the subjects something to look at then they were unoccupied.

The description of the systems being simulated serve to focus subject expectations. This was very important because the PRQA is configured to resemble an airliner cabin, and it was

essential that the subjects judge the rides based on their experiences with other surface-systems rather than the generally smoother-riding jet aircraft. Finally, the subjects were required to perform simple reading and writing tasks similar to those ordinarily carried out during intercity travel. This served to reduce subject boredom, permitted subjects to determine effect-estimates of ride-motion interference with such tasks and allowed the determination of the actual impact of the ride variations on reading and writing performance.

2. METHOD

2.1 DESIGN

The experimental design included three variables: type of vehicle, speed, and level of perturbation. The two vehicle types were magnetically-levitated and steel wheel-steel rail (rail coach). For each vehicle type, three variations in speed were tested. The speeds chosen for the magnetically levitated vehicle were 200, 300, and 400 k/h, and the speeds chosen for the rail coach were 125,200 and 265 k/h. There the levels of perturbation were high, low, and reduced. The perturbations used were simulations of ride irregularities caused by factors such as pier misalignment, guideway flexibility, and vehicle aerodynamics.

The three levels of perturbation could be varied for sway, bounce, and rail vibrations, and a factorial design incorporating the total number combination of all levels of the three variables would result in 162 conditions. Since the cost of running all the conditions was prohibitive, and the information most of the results would provide would not be useful for vehicle design (as they do not represent realistic operating conditions), no attempt was made to run them. Another reason for not using the factorial design was that more information was needed about magnetically levitated vehicles than about rail coaches. Therefore, it was decided at a joint meeting of the U.S. and German participants, to test ten magnetically levitated and five rail coach conditions as shown in Table 1. These conditions had the greatest potential for providing information about vehicle-guideway design.

The noise level within the PRQA cabin was varied systematically in coordination with the speed, vehicle type, and guideway-induced perturbations which characterized each ride segment. The noise-input levels were derived from estimates of turbulence-produced, jet-aircraft, cabin noise provided by NASA staff. However, the major source of noise-level variation experienced by the subjects was produced by their own conversations and movements within the PRQA. Therefore, the analyses performed were based on

TABLE 1. EXPERIMENTAL RIDE CONDITIONS

	CODE	CONDITION	AXIS Z-LINEAR (rms g)	AXIS Y-LINEAR (rms g)	W AXIS ~~X-ANGULAR~~ (rms rAd/s^2)	NOISE dB.A
TRAIN	1	125 LOLOLO	0.0056	0.0059	0.0451	57
	2	265 LOLOLO	0.0072	0.0059	0.0658	63
	3	200 HIHIHI	0.0112	0.0082	0.1431	63
	4	125 USUSUS	0.0150	0.0204	0.2005	65
	5	200 LOLOLO	0.0059	0.0059	0.0594	63
MAG-LEV	6	300 LOLORD	0.0230	0.0180	0.0587	58
	7	300 LORDLO	0.0230	0.0130	0.0626	58
	8	200 HIHIRD	0.0210	0.0140	0.0582	55
	9	400 LORDRD	0.0360	0.0210	0.0795	63
	10	400 LOLORD	0.0360	0.030	0.0795	63
	11	400 LORDLO	0.0350	0.0210	0.0813	63
	12	200 HIHIHI	0.0200	0.0140	0.0709	55
	13	400 LOLOLO	0.0350	0.0300	0.0858	63
	14	300 LOLOLO	0.0200	0.0180	0.0587	58
	15	200 LOLOLO	0.0130	0.0090	0.0568	55

NOTES: LO = LOW PERTURBATION
HI = HIGH PERTURBATION
RD = REDUCED PERTURBATION

the noise measurements made in the PRQA cabin during each segment. As these varied widely between similar ride segments, the dbA weighted noise-output levels listed were derived by averaging the noise levels recorded during the repetitions of each condition.

2.2 EQUIPMENT

Analog magnetic tapes with signals simulating the accelerations along the Y-axis (sway), along the Z-axis (bounce), and about the X-axis (roll), as well as acoustic noise were produced by MBB for the magnetically levitated vehicle. For the steel wheel-steel rail vehicle, the tapes were prepared by ~~MBB~~ MAN from ~~measured values taken on actual rail cars~~ simulations of the ride of the MAN 1003 railcar. These tapes were used to drive the NASA/LRC Passenger Ride Quality Apparatus (PRQA). The PRQA is a motion-simulator configured to resemble a cabin section of a jet passenger aircraft. The vibration and acoustic noise levels produced in the simulator from the tapes under each of the experimental conditions are summarized in Table 1.

Under the direction of Dornier, 16 mm motion pictures of the Bavarian countryside along the Bundesbahn tracks were prepared. These films were taken from the side of a moving rail car and then optically processed and edited to depict the view which a passenger would see at speeds of 125, 200, 265, 300, and 400 k/h. The films were projected using a reflex-projection system onto a back-projection screen adjacent to the PRQA cabin. The screen was located so that the subjects could see the projected images through the PRQA windows, but could not see the screen edges.

2.3 SUBJECTS

Eight groups of six subjects totaling 48 people participated in the study. The subjects were recruited for NASA/LRC by Biometics, Inc. The subjects, chosen to achieve a balance between age and sex, were briefed and medically screened by the NASA participants prior to the experiment. The subjects were paid approximately 15 dollars for their participation.

2.4 PROCEDURE

Each of the 48 subjects was exposed to ten of the ride conditions during the course of the experiment. The eight-minute ride conditons were presented as segments of similated trips with each group of six subjects receiving two 45-minute trips with a rest break in between. Each of the 45-minute trips was composed of five segments. Table 2 shows the order in which the ride segments were presented and illustrates the counterbalancing used to reduce the effects of factors such as time or order of presentation.

On each day the experimented was conducted, each subject was briefed on the operation of the simulator by NASA staff, and then they were briefed on the nature, purpose, and background of the study by TSC staff. The subjects then entered the simulator cabin, and were given instrucitons on the rating procedures and the performance of the reading and writing tasks. The subjects were given samples of the tasks, and their performance on these tasks was used to ascertain their comprehension of the instructions. The test began once the experimenters determined that the subjects understood the instructions. The responses for each 45-minute trip were collected using the test booklet.

During the tests, the sway, bounce, roll accelerations, cabin temperature, and level of accoustic noise for each segment of each of the simulated trips were recorded and retained for use in the subsequent analysis.

The subjects rated the ride segments in terms of perceived confort and perceived difficulty of reading and writing. They rated each condition of the three above mentioned characteristics on a scale of 1-7 with 1 representing "very comfortable" or "very easy", and 7 representing "very uncomfortable" or "very difficult."

The performance segment measures (the scales were provided in the Phase I Memorandum) included three tests: 1) an adaptation of the Carver-Darby Chunked Reading Test, 2) a word-copying test, an

TABLE 2. ORDER OF CONDITIONS

SESSION 1		SESSION 3		SESSION 5		SESSION 7	
TRIP	SEGMENT	TRIP	SEGMENT	TRIP	SEGMENT	TRIP	SEGMENT
A	1,2,3,4,5	A	15,14,13,12,11	A	11,12,13,14,15	A	5,4,3,2,1
B	10,9,8,8,6	B	10,9,8,7,6	B	6,7,8,9,10	B	6,7,8,9,10
SESSION 2		SESSION 4		SESSION 6		SESSION 8	
TRIP	SEGMENT	TRIP	SEGMENT	TRIP	SEGMENT	TRIP	SEGMENT
A	5,4,3,2,1	A	15,14,13,12,11	A	11,12,13,14,15	A	1,2,3,4,5
B	6,7,8,9,10	B	10,9,8,7,6	B	6,7,8,9,10	B	10,9,8,7,6

3) a number-copying test. In the Carver Darby test the subjects' ability to read and comprehend complex material was tested; the other two tests measured reading and writing skills. The tests used and the instructions for their use are copyrighted, but reproductions of the cover sheet and test instructions can be found in the Appendix.

3. RESULTS

Figure 2 depicts the mean-comfort ratings provided by the subjects of the simulated train rides. It should be noted that the only ride condition which has a mean-comfort score worse than neutral (C=4.0) is the score corresponding to a German rail car simulated on an AMTRAK rail at 125 k/h. The relatively poor rating may be due largely to the artificial combination of a vehicle designed for one rail system with a rail system built to entirely different standards.

To understand the implications of the mean-comfort ratings better, a binomial expansion procedure, as described in a DOT report prepared by Peplar Vallerie, Jacobson Barber, and Richards (1977) has been applied. Through the use of this technique, it is possible to estimate the distribution of comfort-responses which would be given by the public for a particular ride segment based on the mean-ride comfort rating the subjects gave for the segment. Table 3, reproduced from the Peplar, et al. (1977) report, was used to estimate the percent of the public which could be expected to respond to a given ride segment with a comfort response up to and including some predetermined value based on a mean-comfort response. In Figure 3, this technique was used to estimate the precent of riders which could be expected to rate the rail-car segments as neutral or better (C=4.0). For the most poorly rated segment, the German rail car on the American track, only 39 percent of potential users could be expected to rate the ride as neutral or better.

Figure 4 depicts the mean-comfort responses to the mag-lev segments. In examining this figure, it should be noted that a mean-comfort score of 3.75 indicates that 75 percent of the potential riders can be expected to rate the ride as neutral or better. Using this criteria, all of the 200 k/h segments provide acceptable rides; the 300 k/h segments, where roll and lateral motions have been reduced in amplitude, also provide acceptable

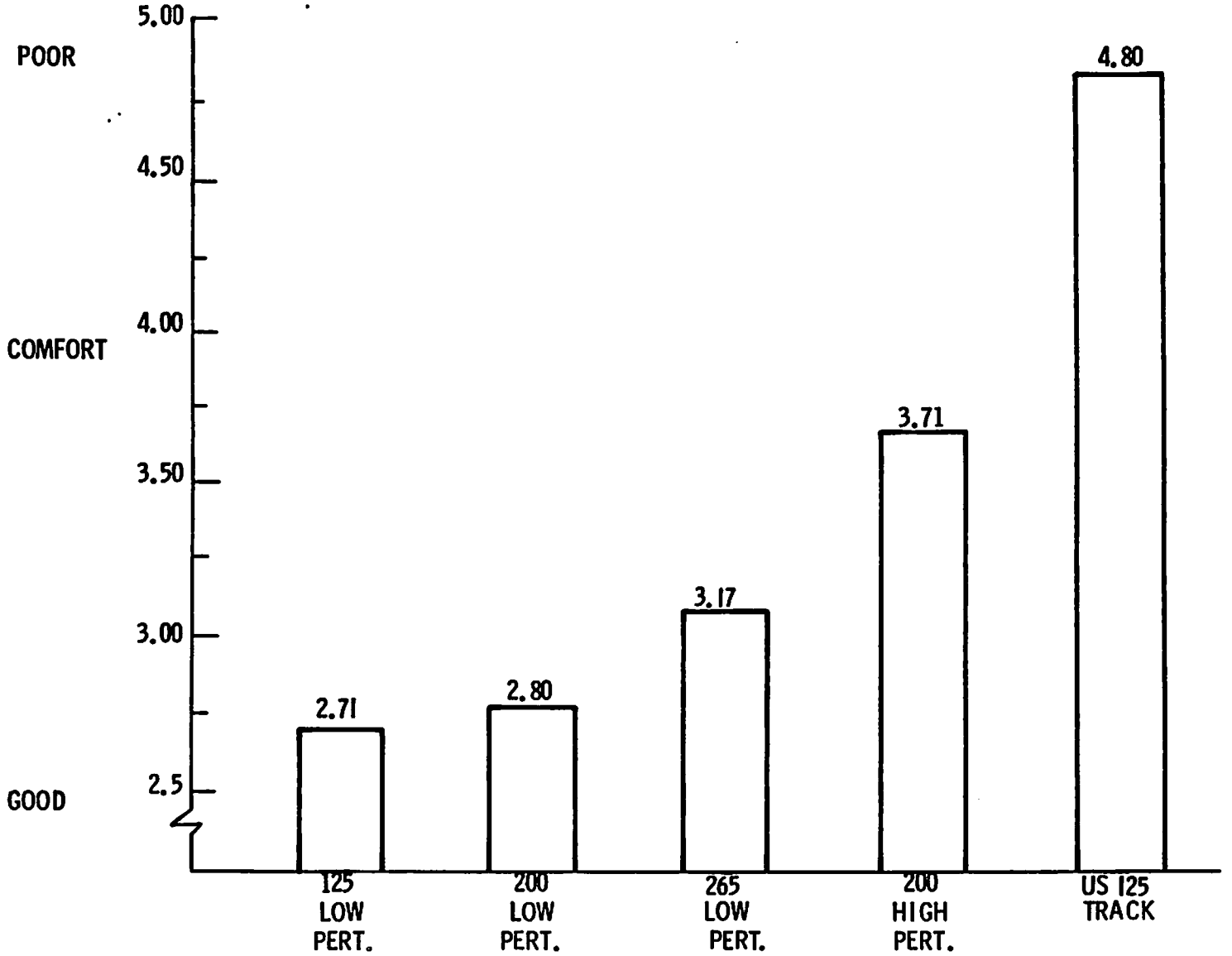


FIGURE 2. MEAN COMFORT RATINGS FOR TRAIN CONDITIONS

TABLE 3. PROBABILITY DISTRIBUTION OF PASSENGER RESPONSES AS A FUNCTION OF MEAN COMFORT VALUE

MEAN COMFORT	% ≤ 1	% ≤ 2	% ≤ 3	% ≤ 4	% ≤ 5	% ≤ 6	% ≤ 7
1.10	.90	1.00	1.00	1.00	1.00	1.00	1.00
1.20	.82	.98	1.00	1.00	1.00	1.00	1.00
1.30	.74	.97	1.00	1.00	1.00	1.00	1.00
1.40	.66	.94	.99	1.00	1.00	1.00	1.00
1.50	.59	.92	.99	1.00	1.00	1.00	1.00
1.60	.53	.89	.98	1.00	1.00	1.00	1.00
1.70	.48	.85	.98	1.00	1.00	1.00	1.00
1.80	.42	.81	.97	1.00	1.00	1.00	1.00
1.90	.38	.78	.95	.99	1.00	1.00	1.00
2.00	.33	.74	.94	.99	1.00	1.00	1.00
2.10	.30	.70	.92	.99	1.00	1.00	1.00
2.20	.26	.66	.90	.98	1.00	1.00	1.00
2.30	.23	.61	.88	.98	1.00	1.00	1.00
2.40	.20	.57	.86	.97	1.00	1.00	1.00
2.50	.18	.53	.83	.96	1.00	1.00	1.00
2.60	.16	.49	.80	.95	.99	1.00	1.00
2.70	.14	.46	.77	.94	.99	1.00	1.00
2.80	.12	.42	.74	.93	.99	1.00	1.00
2.90	.10	.38	.71	.92	.99	1.00	1.00
3.00	.09	.35	.68	.90	.98	1.00	1.00
3.10	.08	.32	.65	.88	.98	1.00	1.00
3.20	.06	.29	.61	.86	.97	1.00	1.00
3.30	.05	.26	.58	.84	.97	1.00	1.00
3.40	.05	.23	.54	.82	.96	1.00	1.00
3.50	.04	.21	.51	.80	.95	.99	1.00
3.60	.03	.19	.48	.77	.94	.99	1.00
3.70	.03	.16	.44	.74	.93	.99	1.00
3.80	.02	.14	.41	.72	.92	.99	1.00
3.90	.02	.13	.38	.69	.91	.99	1.00
4.00	.02	.11	.34	.66	.89	.98	1.00
4.10	.01	.09	.31	.62	.87	.98	1.00
4.20	.01	.08	.28	.59	.86	.98	1.00
4.30	.01	.07	.26	.56	.84	.97	1.00
4.40	.01	.06	.23	.52	.81	.97	1.00
4.50	.01	.05	.20	.49	.79	.96	1.00
4.60	.00	.04	.18	.46	.77	.95	1.00
4.70	.00	.03	.16	.42	.74	.95	1.00
4.80	.00	.03	.14	.39	.71	.94	1.00
4.90	.00	.02	.12	.35	.68	.92	1.00
5.00	.00	.02	.10	.32	.65	.91	1.00
5.10	.00	.01	.08	.29	.62	.90	1.00
5.20	.00	.01	.07	.26	.58	.88	1.00
5.30	.00	.01	.06	.23	.54	.86	1.00
5.40	.00	.01	.05	.20	.51	.84	1.00
5.50	.00	.00	.04	.17	.47	.82	1.00
5.60	.00	.00	.03	.14	.43	.80	1.00
5.70	.00	.01	.02	.12	.39	.77	1.00
5.80	.00	.00	.02	.10	.34	.74	1.00
5.90	.00	.00	.01	.08	.30	.70	1.00
6.00	.00	.00	.01	.06	.26	.67	1.00
6.10	.00	.00	.01	.05	.22	.62	1.00
6.20	.00	.00	.00	.03	.19	.58	1.00
6.30	.00	.00	.00	.02	.15	.52	1.00
6.40	.00	.00	.00	.02	.11	.47	1.00
6.50	.00	.00	.00	.01	.08	.41	1.00
6.60	.00	.00	.00	.01	.06	.34	1.00
6.70	.00	.00	.00	.00	.03	.26	1.00
6.80	.00	.00	.00	.00	.02	.18	1.00
6.90	.00	.00	.00	.00	.00	.10	1.00
7.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

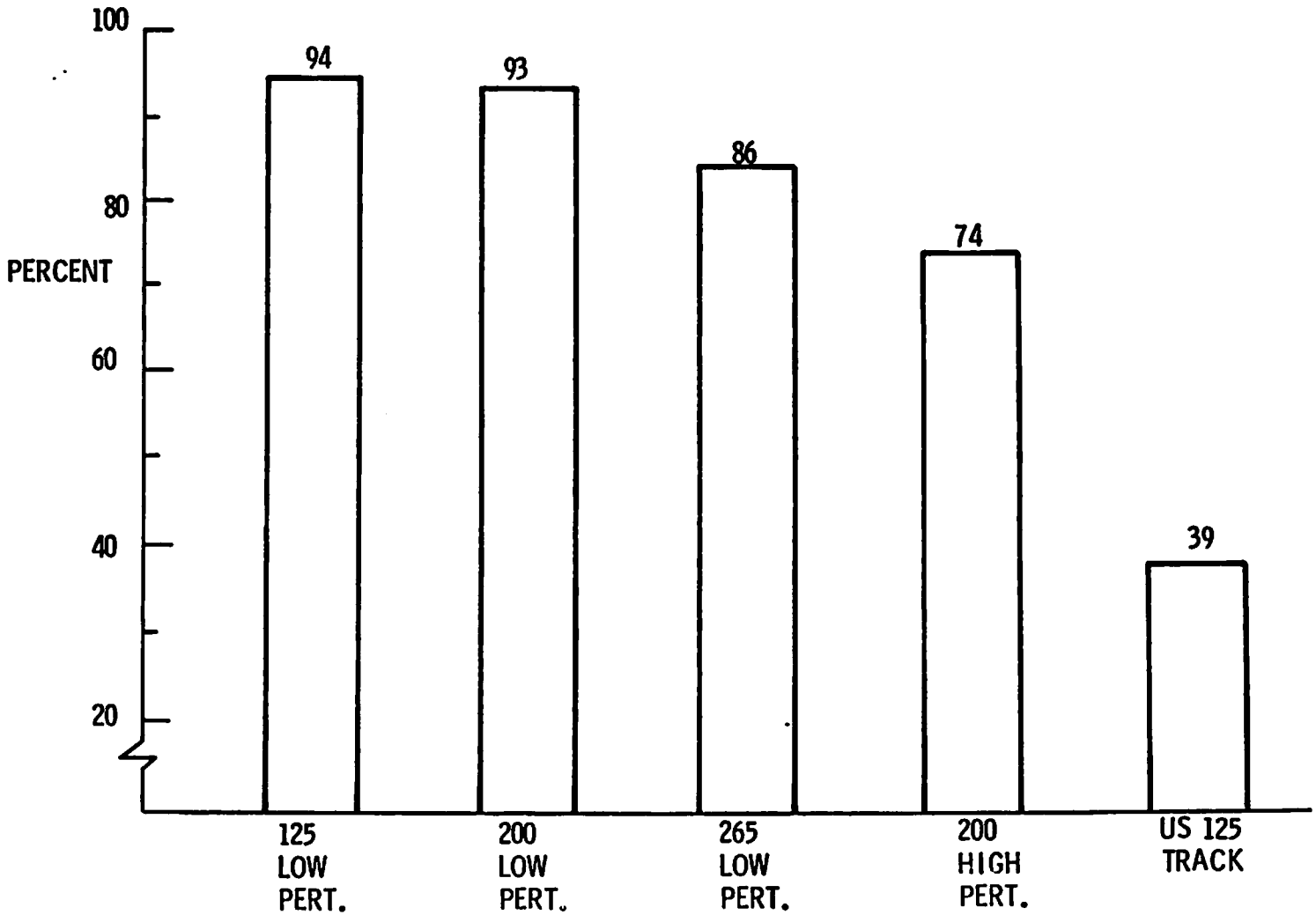


FIGURE 3. PERCENT RATING TRAIN RIDES NEUTRAL OR COMFORTABLE

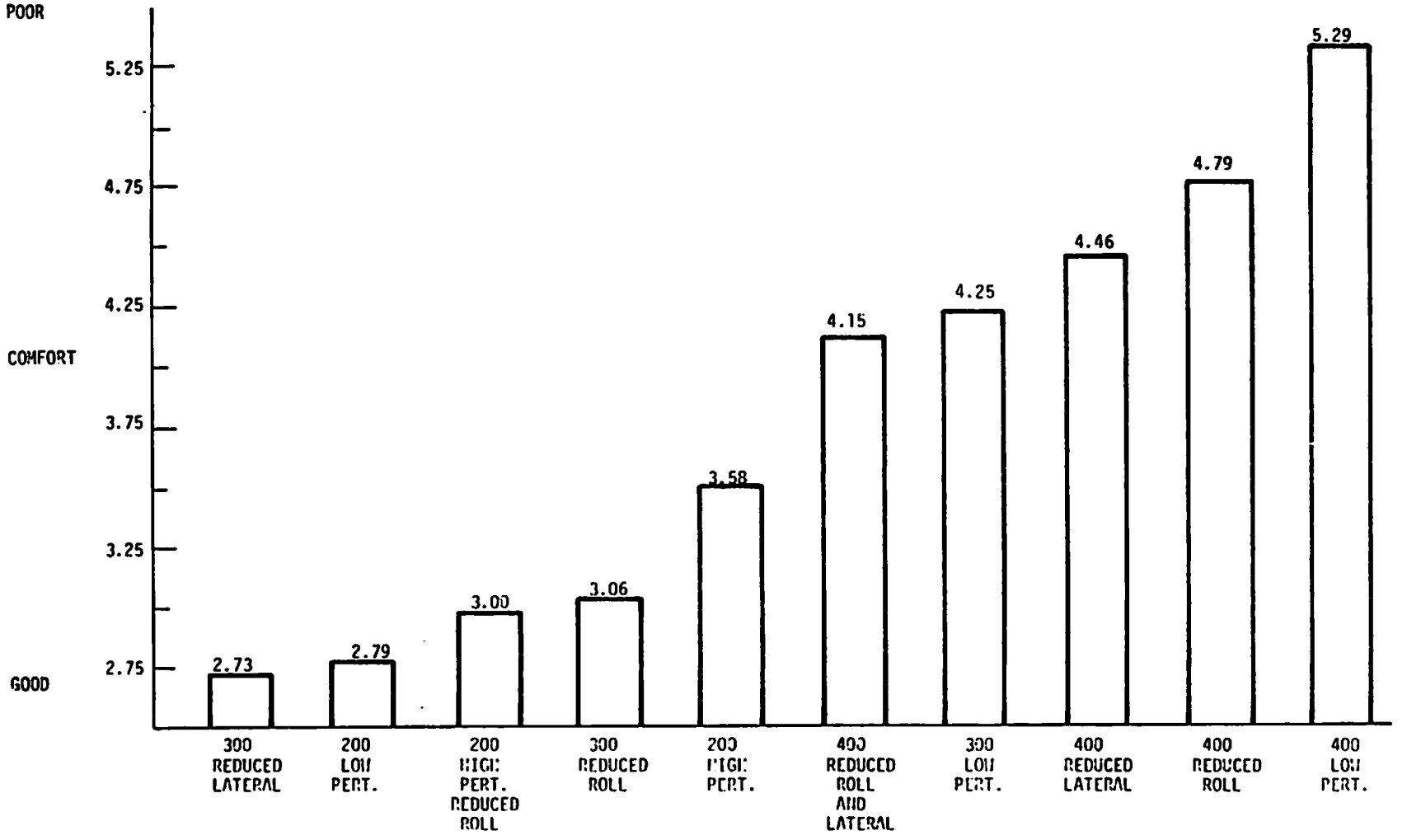


FIGURE 4. MEAN COMFORT RATINGS FOR MAG-LEV CONDITIONS

rides. The best rated mag-lev segment - 400 k/h with reduced roll and lateral motion, produced a mean-comfort response of 4.14, which indicates that 60.5 percent of the riders would rate the ride as neutral or better.

Figure 5 illustrates the effect of reducing the roll motions. In each case, the ride-comfort ratings were improved by simulating improved roll control. T-tests on the data pairs indicate that the roll reductions produced improvements that are significant, at least, at the $P<.10$ level. Figure 6 indicates the effect of reducing both lateral and roll motions. Again, significant ($P<.05$) improvements in comfort resulted. However, the improvement achieved by simulating both reduced lateral and roll motions is not as great as improvement achieved through reduction of lateral motion alone. The improvement measured by reducing roll motion and lateral motion ~~is~~ was found to be not statistically better than reducing just the lateral motion.

To evaluate the relative contributions of the physical variables to the subjects' comfort-responses, Pearson Product Moment Correlations were computed for the physical variable values, and between the physical variables and the comfort responses. For this statistic, the strength of the mathematical relationship is indicated by the absolute value of the statistic which can range from r = +1.00 (perfect positive relationship) through r = .00 (no relationship) to r = -1.00 (perfect inverse relationship), and the square of the correlation (r^2) indicates the proportion of the variance for which the relationship accounts. In the matrix depicted in Table 4,* the strongest relationship between any physical variable and comfort is with lateral motion (r - 0.80,

*These correlations are based on 62 scores. You will recall that there were 8 sessions of 10 conditions each in the simulator. For each of these 80 combinations, Langley measured the noise and three motion components. Unfortunately, the data is missing from several combinations. However, there are 62 cases where we have data on all variables.

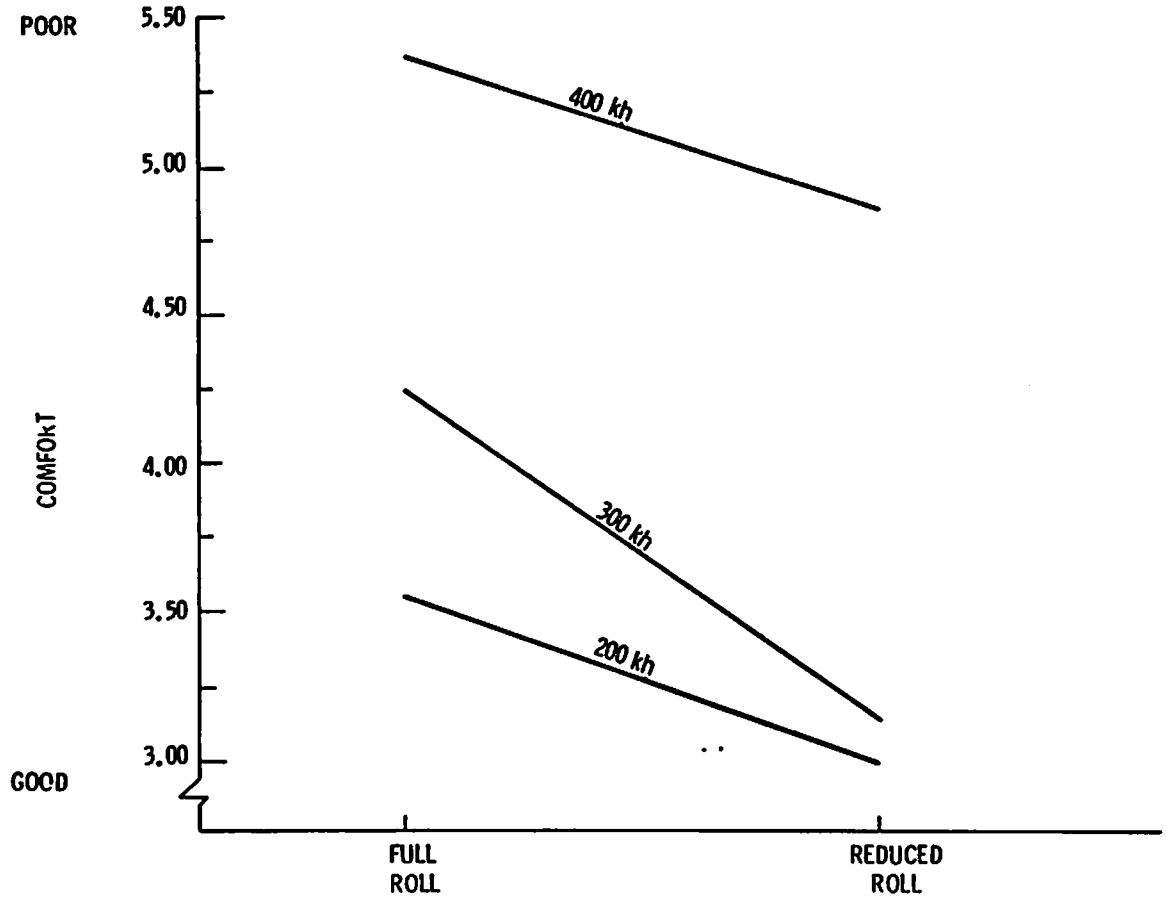


FIGURE 5. EFFECT OF REDUCED ROLL ON COMFORT FOR MAG-LEV VEHICLE

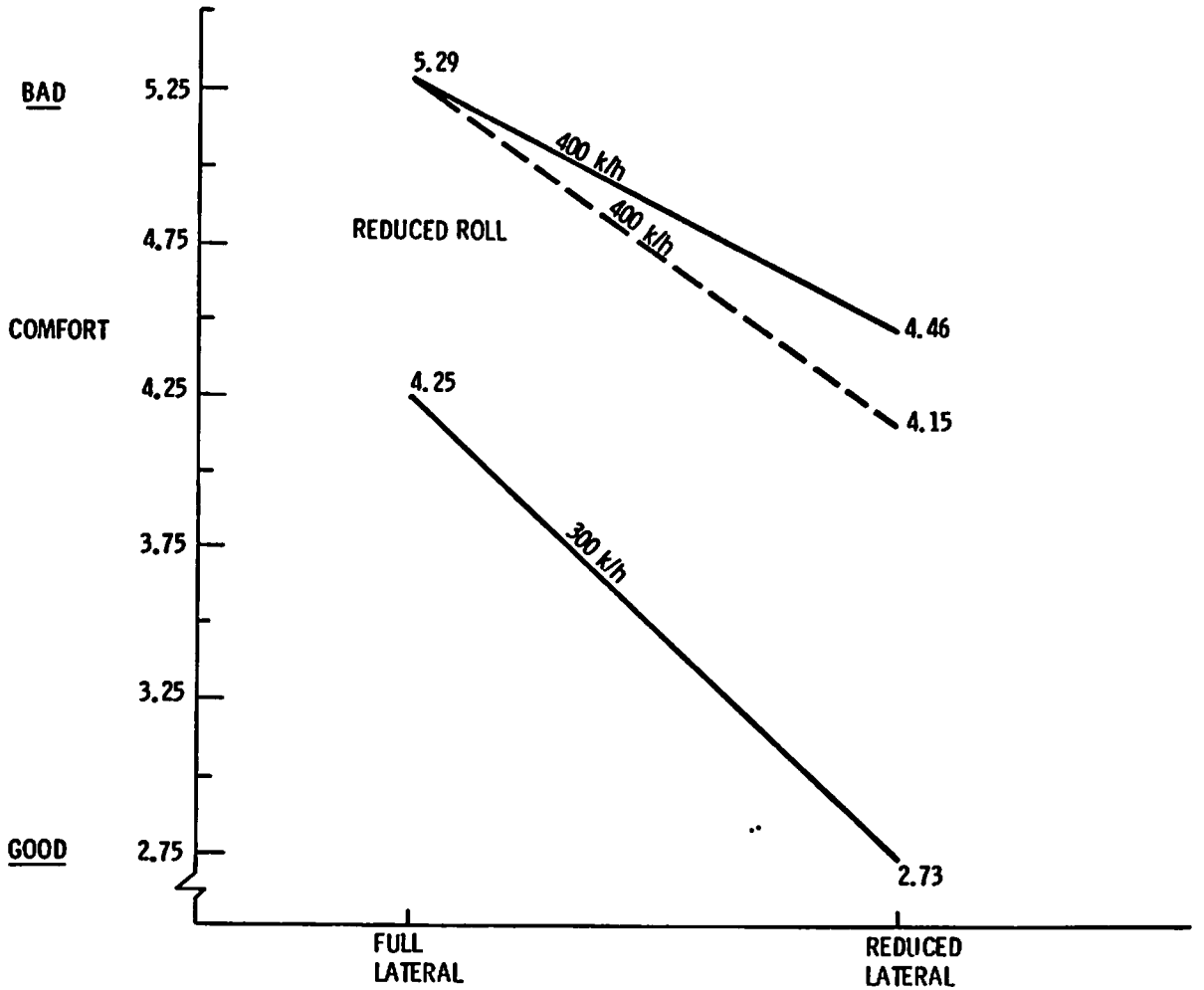


FIGURE 6. EFFECT OF REDUCED LATERAL AND ROLL ON COMFORT FOR MAG-LEV VEHICLE

TABLE 4. CORRELATIONS AMONG COMFORT RATINGS, MOTION VARIABLES, AND NOISE FOR ALL CONDITIONS

	COMFORT	NOISE	LATERAL	VERTICAL	ROLL
COMFORT	1.00				
NOISE	0.66	1.00			
LATERAL	0.80	0.48	1.00		
VERTICAL	0.65	0.39	0.86	1.00	
ROLL	0.45	0.40	0.21	0.00	1.00

N = 62

$r^2 = 0.64$), and the second highest is with noise ($r = 0.66$, $r^2 = 0.44$). While this second correlation is only slightly higher than the relationship between comfort and vertical motion, noise is less strongly correlated with the other physical variables making it more valuable as an independent predictor of comfort. This is particularly interesting as the low noise levels used in this study are generally believed to be below the threshold of discomfort.

Table 5 represents the same matrix. However, here the correlations are generated only from the mag-lev ride segments. All of the correlations are higher. This is probably due to two factors: the use of a set of simulated motion and noise variables which are highly intercorrelated themselves (a situation which is to be expected in the real world), and to a lesser extent, the use of fewer cases (62 for all segments as opposed to 48 for the mag-lev segments alone). It should be noted that a similar matrix was not computed for the rail segments alone due to the small number of available cases.

In order to determine whether the comfort ratings obtained using the PRQA simulator were likely to be similar to those expected in actual revenue service, a comfort model developed by Peplar, et al. (1977) from field tests on intercity trains, commuter buses, and various passenger aircraft was applied to the physical data recorded in the simulator. In this model, predicted comfort or $C' = 1.0 + 0.5w_R + 0.1\ [db(A)-65] + 17a_L + 17a_V$, ($\omega R$ = roll rate, L = sway, and V = bounce). Using the model, C' was predicted for each ride condition, and the predicted value was correlated with the actual ratings of the subjects. Table 6 depicts the correlation between "COMFORT" (C), the subject ratings, and "PRED" (C'). The correlation is quite high: $r = 0.73$, $r^2 = 0.53$. By assuming a greater sensitivity to noise than is provided in the model, the correlation can be further improved. For instance, if we postulate that a threshold of discomfort due to noise occurs as low as 60 dbA (Db60) or even 55dBA (Db55), we can increase the correlation to 0.76 or 0.78.

TABLE 5. CORRELATIONS AMONG COMFORT RATINGS, MOTION VARIABLES, AND NOISE FOR MAG-LEV CONDITIONS

	COMFORT	NOISE	LATERAL	VERTICAL	ROLL
COMFORT	1.00				
NOISE	0.76	1.00			
LATERAL	0.84	0.75	1.00		
VERTICAL	0.81	0.86	0.85	1.00	
ROLL	0.64	0.52	0.52	0.66	1.00

N = 48

TABLE 6. CORRELATIONS BETWEEN COMFORT RATINGS AND FIELD TEST DERIVED MODEL

	COMFORT	PRED.	DB60	DB55
COMFORT	1.00			
PRED.	0.73	1.00		
DB60	0.76	0.99	1.00	
DB55	0.78	0.97	0.99	1.00

N = 20

The high correlations between the predicted comfort scores and those provided by the subjects may be taken as strong substantiation that the results found with regard to the comfort ratings are realtistic.

The subjects' ratings of reading difficulty, writing difficulty, and comfort for trains and mag-lev vehicles respectively are depicted in Figures 7 and 8. In general, the subjects' rating indicate that they feel reading and writing were more seriously impaired by ride vibration and noise than by comfort.

Table 7 provides the matrix of intercorrelations between ratings of comfort, reading and writing difficulty, and physical variables that characterize the noise levels and motions for each segment. It is interesting to note that the correlation between noise level and comfort is higher than the correlation between noise level and writing difficulty ($r_{n-c} = 0.67$, $r^2 = 0.45$, vs. $r_{n-w} = 0.60$, $r^2 = 0.36$). This difference is statistically significant and has less than a 5 percent probability of being due to chance variation. Conversely, vertical and lateral motions have higher correlations with writing difficulty than does noise ($p < 0.05$). This may be interpreted as an indication that the major effect on acoustic noise is on passenger confort; whereas, physical motion that interferes with tasks, require hand-eye coordination such as writing.

Table 8 provides the correlations between physical-ride variables and subject performance on the tasks. It should be noted that there was little or no correlation between the writing tasks (questions answered, answered correct and percent correct) and the subjects perceived difficutly in reading. It may be hypothesized that the subjects compensated for the increased difficulty they reported while performing this purely cognitive task. Conversely, the correlations between the physical variables, particularly vertical and lateral motion, and performance on the writing tasks were substantial, suggesting that total compensation for tasks requiring significant motor-skills may be very difficult or even impossible.

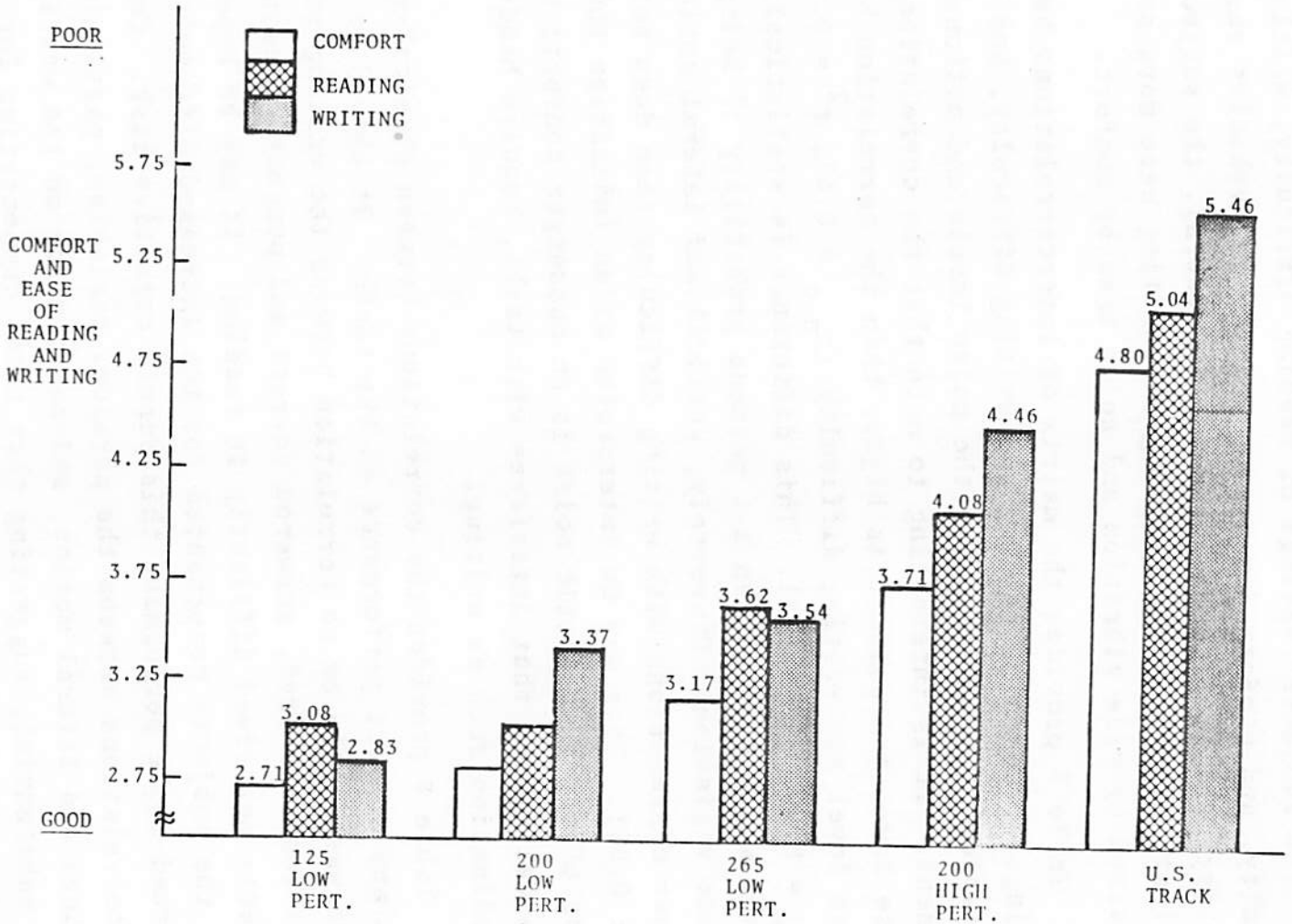


FIGURE 7. MEAN COMFORT AND EASE OF READING AND WRITING RATINGS FOR TRAIN CONDITIONS

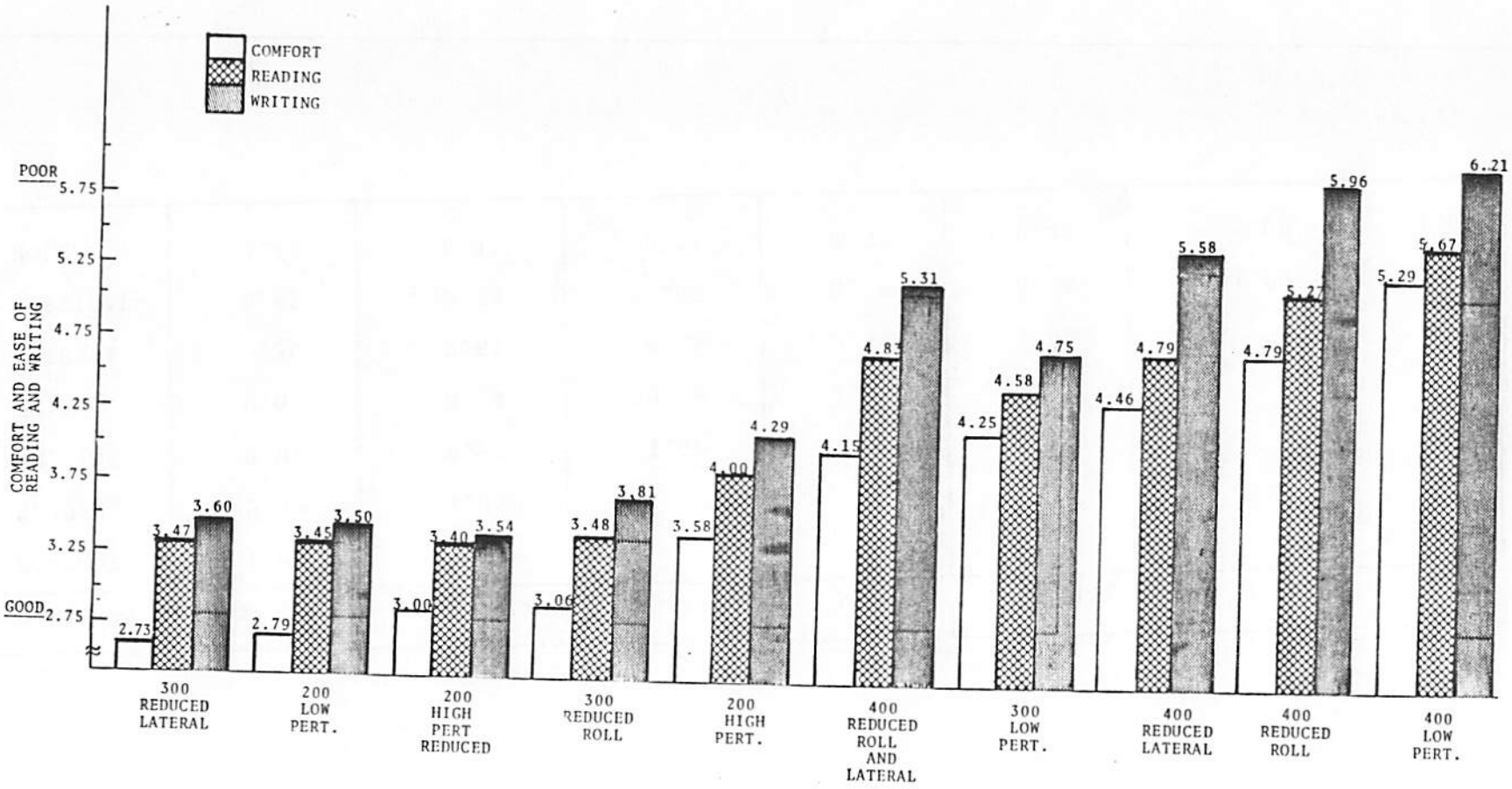


FIGURE 8. MEAN COMFORT AND EASE OF READING AND WRITING RATINGS FOR MAG-LEV CONDITIONS

TABLE 7. CORRELATIONS BETWEEN RATINGS OF COMFORT, RATINGS OF READING AND WRITING DIFFICULTY, AND NOISE AND MOTION LEVELS

CONDITION	COMFORT	READING	WRITING	NOISE	LATERAL	VERTICAL	ROLL
COMFORT	1.00						
READING	0.92	1.00					
WRITING	0.91	0.95	1.00				
NOISE	0.67	0.54	0.60	1.00			
LATERAL	0.80	0.81	0.85	0.48	1.00		
VERTICAL	0.65	0.73	0.77	0.39	0.86	1.00	
ROLL	0.45	0.41	0.41	0.37	0.21	0.00	1.00

TABLE 8. CORRELATIONS BETWEEN PERFORMANCE MEASURES AND NOISE, AND MOTION VARIABLES AND RATINGS

CONDITION	QUESTIONS ANSWERED	ANSWERS CORRECT	PERCENT CORRECT	WORDS COPIED	ERRORS	NUMBERS COPIED
NOISE	0.06	0.07	0.11	-0.25	0.41	-0.44
LATERAL	-0.06	-0.09	-0.06	-0.38	0.53	-0.57
VERTICAL	0.00	-0.02	-0.01	-0.28	0.52	-0.42
ROLL	-0.06	-0.04	-0.04	-0.14	0.18	-0.31
COMFORT	-0.14	-0.12	-0.05	-0.35	0.40	-0.57
EASE OF READING	-0.16	-0.12	-0.05	-0.35	0.42	-0.52
EASE OF WRITING	-0.12	-0.11	-0.04	-0.43	0.48	-0.52

Finally, the problem of the effect on comfort of the duration of exposure to vibration was examined. Prior work in this area has provided mixed results. The International Organization for Standardization's "Guide for the Evaluation of the Effects of Human Exposure to Whole Body Vibration" (Document 2631) indicates that the threshold of discomfort to vibration such as that experienced by the subjects in this study will decrease over periods as short as twenty minutes. However, no laboratory studies have ever provided data to support such a threshold decrease.

The current study, although not designed to definitively support or refute this "time-dependency hypothesis," does provide a sensitive test for periods up to 48 minutes in duration. Six of the ride conditions were presented half of the time at the beginning of a 48-minute ride, and half of the time at the end of the ride. If the time-dependency hypothesis is correct, the vibrations preceeding the trial presented at the end of the ride should reduce the discomfort threshold and cause higher discomfort ratings than if the same trial is presented prior to exposure to any vibration. [Matched sample "t" tests were preformed on the subjects' comfort ratings. These are presented in Table 9. In no case was their a significant increase in discomfort attributable to exposure to vibration prior to the trial].

Table 9 shows the mean-comfort rating for each of the six conditions which occurred both first and last in the simulated ride. The values of the t-tests computed on each of the pairs is also shown. None of the t-values are statistically significant. Furthermore, in two tasks, conditions 10 and 15, the ride was rated as being more comfortable when it occurred at the end of the simulated trip. Their data clearly do not support the time-dependency hypothesis.

TABLE 9. EFFECT OF DURATION ON COMFORT RATINGS

CONDITION	FIRST	LAST	t-VALVE	Degrees of Freedom
1	2.58	2.83	0.32	22
5	2.50	3.08	0.69	22
6	2.83	3.29	0.92	46
10	5.08	4.50	0.94	46
11	4.25	4.67	0.64	22
15	3.00	2.58	0.51	22

APPENDIX

20 copies

INTRODUCTION AND GENERAL INSTRUCTIONS

We are conducting an experiment to determine your comfort under conditions which simulate the ride environments of proposed advanced transportation systems. The U.S. Department of Transportation and the National Aeronautics and Space Administration, in cooperation with the Ministry of Research and Development of the Federal Republic of Germany, are presently conducting research leading to the development of modern, high speed, ground transportation systems. These systems will probably take the form of passenger trains running between cities at speeds of 100-300 mph.

Our past research has shown that passenger satisfaction with transportation systems depends not only on over-all feelings of comfort, but also on how vibration, noise, and other environmental factors interfere with performance of activities people like to do while traveling, such as reading and writing. The study you are about to participate in will allow us to evaluate how the proposed ride environments of these new systems will affect passengers' comfort and ability to perform certain activities. Your participation and cooperation in this experiment will be critical, since your opinions and responses will directly influence the design of new transportation vehicles.

During this experiment, we ask that you imagine yourself on a ground transportation system of the future, traveling at speeds of 100-300 mph between two cities several hundred miles apart. The ride motions you will soon be experiencing simulate the environment expected to exist in high speed "train-like" vehicles which will be put into service between 1985-1995. Similarly, the noise you will be hearing in the course of your trip is our best prediction of how these vehicles will sound to passengers inside the vehicle. We will also attempt to portray how the scenery will look out the window of these vehicles, in movies to be projected on a screen outside the windows of the simulator all during the ride.

In the next 90 minutes, you will experience two 40 minute trips, separated by a 10 minute rest break. Each trip actually consists of five 8 minute ride segments having different vibration and noise characteristics, which have been joined together so that you will experience one continuous 40 minute ride. During each 8 minute segment, you will be asked to do a reading test and a writing test according to instructions I will give you later. At the end of each ride segment, you will also be asked to determine how comfortable you felt over-all and how easy it was to do the reading and writing tasks under the vibration and noise conditions in that part of the ride.

NOTES USED BY NARRATOR

PRACTICE READING TEST

Please open your test booklet to page 2 and read along with me the instructions for the reading test.

On this test, there are five reading passages with a test on each passage. Before taking each test, you will read a passage through once completely, then go on immediately to the test on the next page. The test consists of the same passage retyped in columns. Your task will be to read the passage in the retyped form and identify the groups of words which change the meaning of the original passage. Please read to yourself as I read aloud the example passage and the example test below.

EXAMPLE PART PASSAGE

The third concert of the subscription series was given last evening, and a large audience was in attendance. Mr. Edward Appleton was the soloist, and the Boston Symphony Orchestra furnished the instrumental music. The former showed himself to be an artist of the first rank, while the latter proved itself fully deserving of its high reputation.

EXAMPLE TEST ITEMS

I. (A) The third concert
*(B) of the summer festival
(C) was given
(D) last evening
(E) and a large audience

II. (A) was in attendance.
(B) Mr. Edward Appleton
*(C) conducted
(D) and the Boston Symphony Orchestra
(E) furnished

III. (A) the instrumental music.
(B) The former
(C) showed himself
(D) to be
(E) completely undeserving

IV. (A) of the first rank,
(B) while the latter
(C) was not superb, but
(D) fully deserving
(E) of its high reputation.

Notice that in each test item, one of the five groups of words did not appear in the original passage. In Item I the test phrase "of the summer festival" has replaced the passage phrase "of the subscription series." Thus, the answer to Item I is B. In Item II, the word "conducted" in the test replaced the phrase "was the soloist" in the original passage. Now please look at Items III and IV and answer these to yourself.

Please listen carefully from this point on, as the rest of the instructions are not in your test booklet.

The answer to Item III is B; the answer to Item IV is C. It is very important that you notice that the correct answers to the above items are groups of words which are different in meaning from the groups of words which they replaced. That is, the words which you must identify are not simply minor wording differences, but represent major changes in meaning from the original passage.

You will have 4 minutes to work on each of the five reading tests. Each passage will contain 20 items like the four in the example test above. When you have finished reading a passage, turn directly to the test on the following page and begin answering the questions. An annoucement will be made after 2 minutes has elapsed. If you have not finished reading a passage at this point, you should make a slash in the text indicating how much you have completed and begin answering the questions on the next page. You may write directly in the test book. Use an X-mark to indicate your answer. Remember the test has been designed so that most people will not be able to complete the passages in the allotted time. Once you have turned to the test page for any reading passage you may not turn back and reread the passage. Do not cross out any answers, as these will automatically be considered errors. I will announce the beginning, 2 minute mark, and end of each reading test.

We will now read a practice passage and do a practice test. I will announce the start, 2 minute mark and the finish, at which time you should stop answering questions and wait for further instructions. Are there any questions? Ready, turn to page 5, and start.

Time 2'. 2 minutes. If you are still reading, mark with a slash in the text to show how much you have read and go on to questions on the next page ~~if you have not already done so~~

Time 2'. Stop.

PRACTICE WRITING TEST

After each reading test, there is a writing test on the following pages of your test booklet. It consists of a prose passage and a list of numbers which you will be asked to copy. You will be given 1 minute to copy as much of the prose as you can. You should mark your place in the paragraph with a slash when I say stop. Then you will be told to turn the page, and you will be given 1 minute to copy as many numbers as you can. You should mark your place in the number list with a slash when I say stop. I will tell you when to start, stop, and turn the page for each part of this test. You will be scored on the number of words and numbers you have copied, and the accuracy and legibility of your writing.

on the page underneath

We will now do a practice writing test. I will announce the start and finish of each part and when to turn the page. Are there any questions?

START.

TIME 1'. STOP. Mark with a slash where you have stopped. Turn the page. When I say start, begin copying the numbers.

START

TIME 1'. STOP. Mark with a slash where you have stopped.

SUBJECTIVE SCALES

After the writing test, you will see a page containing three questions regarding your over-all comfort and ease of reading and writing during this test segment. Please check a point on the 7 point scale for each question. Remember that these questions refer to how the ride environment affects your comfort and activity performance. They do not refer to the difficulty of the reading and writing tests themselves. You may do this now for your present environment.

There will be 2 minutes of free time after these tests during which you may rest, look out the window at the scenery, or go back to finish your reading or writing tests. Do not look ahead to any of the later tests. Also, do not cross out your previous answers, as any changes will automatically be scored as errors. Remember, your scores will not be compared with those of any other subject in this study. We are only interested in how your performance changes over different ride conditions. Are there any questions?

PART I - EXPERIMENT II

We will now begin the experiment. Please have your reading test booklet open to page 8. The ride is about to begin.

(RING BELLS. TIME 15".)

Now turn to page 9 and begin reading PASSAGE 1

(TIME 2'.) Two minutes. Mark a slash in the text and turn to Test 1 on page 10 if you have not already done so.

(TIME 2') STOP. Writing Test 1B on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, Start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax or go back and finish your reading and writing tests!

2 A

It is time to begin reading PASSAGE 2.
Turn to page 11 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 2 on page 12 if you haven't already done so.

(TIME 2') STOP. Writing Test 2A on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

23

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

20"

3

11

It is time to begin reading PASSAGE 3.
Turn to page 13 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 3 on page 14 if you haven't already done so.

(TIME 2') STOP. Writing Test 3A on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

.143

16

19

4 .

4

It is time to begin reading PASSAGE 4.
Turn to page 15 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 4 on page 16 if you haven't already done so.

(TIME 2') STOP. Writing Test 4A on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

09

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

19

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

5

A

It is time to begin reading PASSAGE 5.
Turn to page 17 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 5 on page 18 if you haven't already done so.

(TIME 2') STOP. Writing Test 5A on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

19

23"

The first ride is now over. We will take a 10 minute break. Please bring your test materials with you upon leaving the simulator.

PART II - EXPERIMENT II

We will now continue the experiment. Please take the same seat you had before the break. Turn to page 7 in your new test booklet. The ride is about to begin.

(RIDE BEGINS)

It is time to begin reading PASSAGE 1.
Turn to page 9 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 1 on page 10 if you haven't already done so.

(TIME 2') STOP. Writing Test 1A on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

22.

B

√ It is time to begin reading PASSAGE 2.
Turn to page 11 of your Reading Test. Ready, start.

√ (TIME 2') Two minutes. Mark a slash in the test and turn to Test 2 on page 12 if you haven't already done so.

√ (TIME 2') STOP. Writing Test 2B on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

10"

√ (TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

20

√ (TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

√ (TIME 30") You may now relax, or go back and finish your reading and writing tests.

20"

3

B

It is time to begin reading PASSAGE 3
Turn to page 13 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 3 on page 14 if you haven't already done so.

(TIME 2') STOP. Writing Test 3B on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

21"

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

31"

4

B

It is time to begin reading PASSAGE 4
Turn to page 15 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 4 on page 16 if you haven't already done so.

(TIME 2') STOP. Writing Test 4B on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

11"

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

21"

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

20"

5 B

It is time to begin reading PASSAGE 5.
Turn to page 17 of your Reading Test. Ready, start.

(TIME 2') Two minutes. Mark a slash in the test and turn to Test 5 on page 18 if you haven't already done so.

(TIME 2') STOP. Writing Test 5B on the facing page is about to begin. You have 1 minute to copy the passage. Ready, start.

10"

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of numbers underneath. You have 1 minute to copy the numbers. Ready, start.

20"

(TIME 1') STOP. Mark with a slash where you left off. Turn to the page of questions underneath, and answer 1, 2, and 3.

(TIME 30") You may now relax, or go back and finish your reading and writing tests.

19°

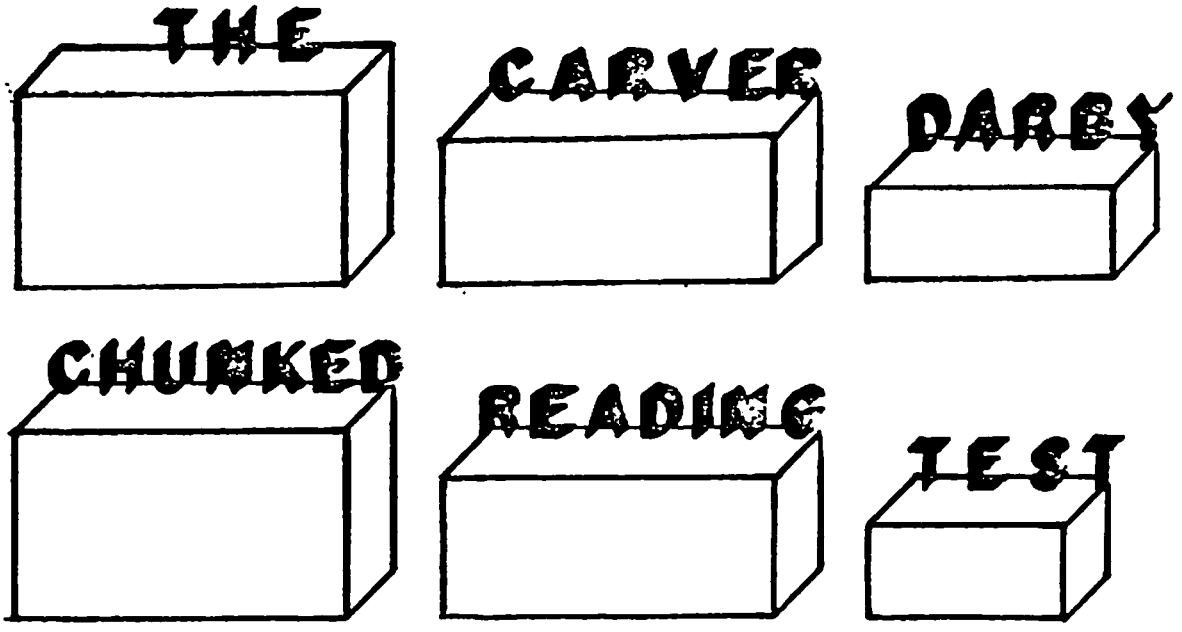
45"

The experiment is now over. Thank you for your participation.

REUSABLE TEST BOOKLET

FORM

A



For High School, College Students, and Adults

by

Ronald P. Carver and Charles A. Darby, Jr.

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