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THE EFFECTS OF THE RIDE ENVIRONMENT ON INTERCITY TRAIN PASSENGER ACTIVITIES

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ABSTRACT

The ability to perform activities such as reading, writing, talking, and sleeping has frequently been cited in the ride quality literature as an important factor in passengers' comfort and satisfaction with transportation systems. A field study of passenger activities on intercity trains was conducted to quantify and describe the relationships between the relative frequencies of various passenger behaviors and the physical parameters of ride quality. Vibration in six degrees of freedom, acoustic noise, temperature, relative humidity, and illumination were measured while simultaneous observations of passenger activity were made aboard 77 Amtrak vehicles on 14 trains between Newark, NJ and Washington, DC. Rotational vibration rates (1-20 Hz) were found to be negatively correlated with observed performance of social and motor activities, and positively correlated with resting behaviors. Linear vibrations did not significantly affect observed activity frequencies. Noise levels resulting primarily from passengers' conversations were negatively correlated with frequencies of sleeping. Activity levels also varied with vehicle type and time of day. Multiple regression techniques were used to develop linear equations of physical ride quality and trip variables, which predict approximately 20% of the variance in activity levels. Individual differences are postulated to explain the remaining activity variance. The activity equations could be used to specify acceptable levels of ride quality parameters for passenger activity performance in the design of advanced transportation systems.

THE EFFECTS OF THE RIDE ENVIRONMENT ON INTERCITY TRAIN PASSENGER ACTIVITIES

Background

The ability to perform activities such as reading, writing, talking, and sleeping has frequently been cited in the ride quality literature as an important factor in passengers' comfort and satisfaction with various transportation systems. It has been suggested by Stone (1) that activity factors are among the most probable human factors elements associated with ride quality, and hence, comfort. Allen (2) indicates that the most common type of discomfort experienced by passengers is probably caused by interference with activity. The only internationally recognized guideline for evaluation of human response to whole-body vibration, ISO Document 2631 (3), also implicates activity interference as a source of discomfort in its description of the Reduced Comfort Boundary, which is "related to difficulties in carrying out such operations as eating, reading, and writing" (p. 5).

Although passenger activities have received some recognition as human response patterns which might depend upon ride quality and vary in some way with subjective assessments of comfort and willingness to use a transportation system on a regular basis, no systematic study of these relationships is currently available. If comfort does depend on the ability to perform activities, then quantifying the relationships between the physical ride environment and levels of activity could provide system designers with a tool which would allow them to design transportation systems that enhance passenger satisfaction.

The majority of studies in the ride quality and vibration research literature are concerned with either: 1) the subjective effects of vibration on human sensation, as measured using psychophysical methods or rating scales in laboratory experiments or controlled field studies (e.g., 4, 5, 6, 7); or 2) the objective effects of vibration on human performance, as measured using task-specific dependent variables such as reaction times and error rates in highly controlled laboratory experiments (e.g., 8, 9, 10). Research in the first category is often related to subjective passenger comfort in actual transportation situations, while research in the second category is directly applicable to operator performance in transportation and other multiple stress environments. The question remains, however, as to the effect of vibration and other environmental variables upon passenger performance in transportation situations, which include combinations of environmental variables such as vibration, noise, temperature, humidity, light, and space. Passenger performance in this case may be defined as the voluntary execution of various activities, such as reading, writing, eating, drinking, sleeping, and so on.

Some information regarding the subjective importance and difficulty of performing various passenger activities is available from studies of Short Take-Off and Landing (STOL) airline passengers (11, 12, 13, 14). The results of these surveys generally indicate that passengers' perceived ability to perform activities is significantly related to subjective assessments of comfort and satisfaction, and to objective measures of the ride environment. Ratings of activity difficulty were found to vary with ratings of ride comfort and satisfaction (6, 14). Thus, the more difficult the activity passengers wished to perform, the more uncomfortable and dissatisfied they were. Ratings of activity difficulty were also found to vary systematically with measured levels of the ride environment. For example, it was found that noise levels were positively correlated with perceived difficulty of conversation, while motion amplitudes were positively correlated with difficulty ratings for writing and dozing (14).

The passenger activity data from these surveys consists solely of passengers' subjective reports of their own behavior. Since actual behavior does not always correspond to self-reports of that behavior, it is usually preferable to obtain objective data whenever possible from observations, experimental performance measures, or other direct methods of behavioral assessment. If activities could be established as an objective behavioral correlative of the physical ride environment, and the relationships between levels of activity and the environment described in a quantitative form, then this quantitative description might be used as a tool to further specify ride environment variables at levels acceptable for the performance of passenger activities. Design of such an environment might in turn enhance passenger satisfaction. In the following field study, measurements of the ride environment and observations of passenger activities were made simultaneously aboard Amtrak intercity trains, in order to determine the nature and strength of activity/ride quality relationships, and to describe them in a quantitative form which might be used as a design and evaluation tool.

Method

Subjects

The subject sample consisted of 2829 revenue passengers observed on 14 Amtrak rides in the Northeast Corridor. These passengers were observed in 81 vehicles of trains traveling in both directions between Washington, DC and Newark, NJ, on weekdays between 9:00 a.m. and 5:00 p.m.

Apparatus

The instrumentation used to measure ride vibration is shown in Figure 1. Linear accelerations in three axes were

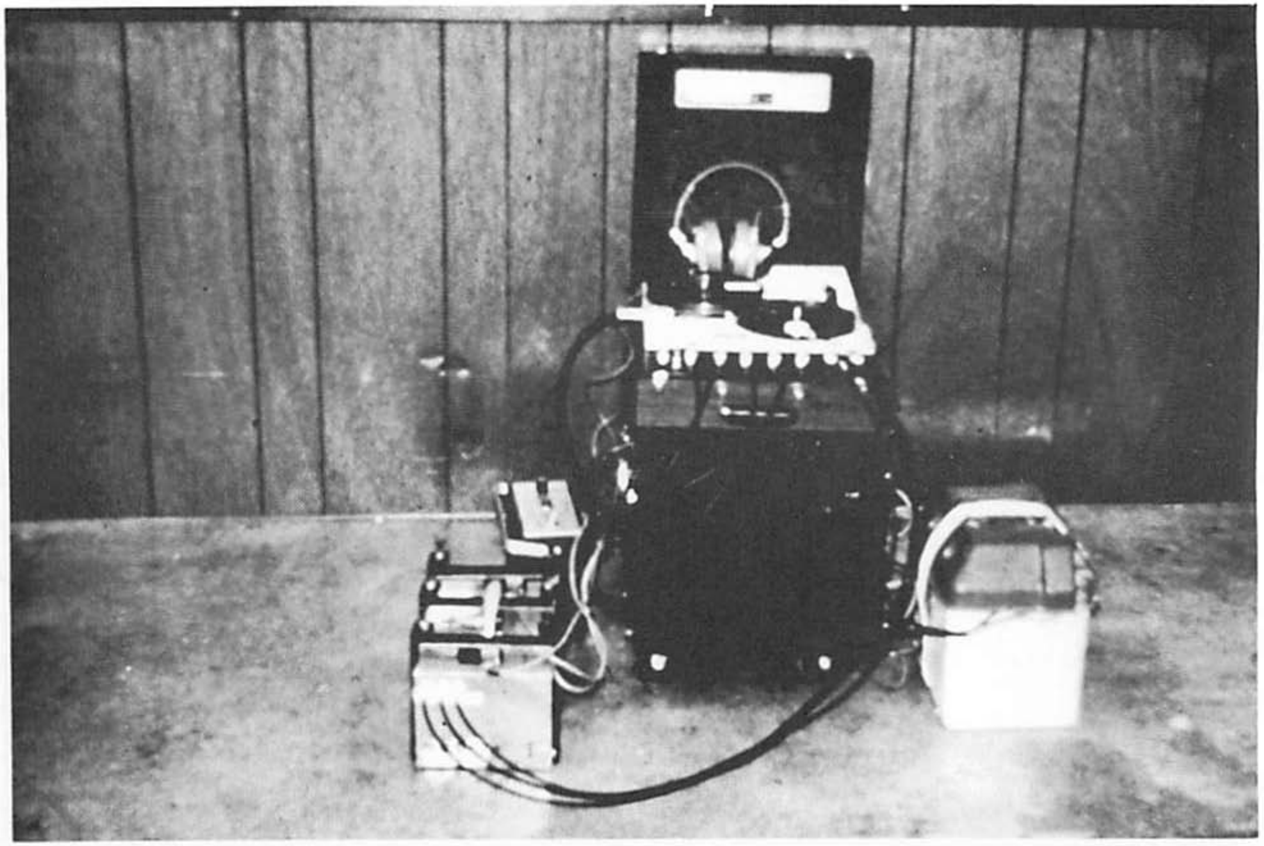

Figure 1. Equipment Used to Measure and Record Vibration on Northeast Corridor Amtrak Trains (Clockwise: Headphones, Tape Recorder, Power Source for Recorder, Modified NASA Accelerometer Package, Inverter Battery)

measured using the battery-operated portable accelerometer set developed by the NASA Langley Research Center (15). This unit consisted of three independently calibrated, seismic mass piezo-resistive accelerometers (0-100 Hz bandwidth), mounted in three mutually perpendicular directions corresponding to the X (longitudinal), Y (lateral), and Z (vertical) axes of vibration. Rotational motions were measured by attaching three Unholtz-Dickie PA-1000 type accelerometers to the outer casing of the NASA accelerometer package. Each accelerometer was separately calibrated. The sensitivity of the PA-1000 accelerometers was set at 3.33 volts per g, and their maximum response range was 0.1 to 2000 Hz. A power inverter connected to a 12 volt car battery was used to produce 120 volt, 60 Hz, AC power, which drove the signal conditioners associated with the PA-1000 sensors.

The six independent motion signals (three linear, three rotational) measured by the six accelerometers were recorded on a Lockheed eight channel FM tape recorder (Model No. 4170). The seventh channel was used for simultaneous voice commentary, and the eighth to record a 1 volt step signal for electronic decoding purposes.

Motion data were reduced from analogue to digital form suitable for subsequent statistical analyses using a Scientific Data Systems XDS Sigma 5 data processor.

Instrumentation used to measure non-motion environmental variables included a General Radio USA sound level meter

(Model No. 1565-B), an Abbeon certified hygrometer and temperature indicator (Model No. HTAB 169B), and a Gossen Luna-Pro light meter.

The behavioral coding form used to record passenger activity is shown in Figure 2.

Procedure

Prior to the actual data collection efforts on the trains, track charts of the Washington, DC - Newark, NJ section of the Northeast Corridor were analyzed to select a number of internally homogeneous segments which might be sampled during the tests. A total of 32 non-overlapping segments were chosen (16 in each direction between Washington, DC and Newark) to represent straight and curved track over uphill, downhill, and undulating terrain. Arrangements were also made with Amtrak to reserve seats in the center of every car of each train to be used in the course of the study.

Measurements and observations were recorded over a total of 81 test segments on 42 different vehicles of 14 trains during seven weekdays of testing between December 5-13, 1977. Data was collected on two trains each day: The Patriot (#172) from Washington, DC to Newark (9:00 a.m. - 12:41 p.m.) and The Colonial (#169) from Newark to Washington, DC (1:15 p.m.-5:00 p.m.). Each train was composed of approximately six Amfleet vehicles, including several Amcoach cars and at least one Amcafe snackbar car.

Car No.:	Mileposts:	Day:	Train No.:
Car Type:	Head Ct.:	Time:	Seating Cap:

READING (R)

VIEWING: Out Window (LW)
In Train (LT)
At Experimenter (LE)

SMOKING (S)

SLEEPING (Z)

WRITING (W)

EATING (E)

DRINKING (D)

HANDCRAFTS (H)

LIGHT LEVEL:

DOING NOTHING (N)

		2	3	4
TALKING & LISTENING (TL)	Adjacent			
	Across			

		2	3	4
PLAYING GAMES (P)	Adjacent			
	Across			

OTHER (O)

Figure 2. Behavioral Coding Form Used to Record Passenger Activities

The experimental procedure involved the simultaneous observation of passenger activities by the observer and measurement and recording of ride environment variables by two test assistants. The test team boarded each train in the rear vehicle and set up the equipment for measuring the environmental variables in a reserved pair of center seats (Figure 3), placing the accelerometer package on the floor underneath. This test location was chosen because it was close to the pitch and roll center of the vehicle. Once the train was in motion, the test assistants determined the milepost location by contacting a technician riding in the locomotive at the head end via walkie-talkie. As the train approached a predetermined test track segment, the observer proceeded to the rear of the vehicle. Upon hand signal by the assistant, which indicated the beginning of a recording period, the observer walked through the vehicle, unobtrusively observing and recording the activity of each passenger on the form shown in Figure 2. At the center of the vehicle, the observer also made an ambient light measurement in the center aisle halfway through the vehicle. At the same time, measurement and recording of the ride motion variables were made by one test assistant, while the other monitored and recorded the ranges of noise, temperature, and humidity on the smaller instruments, and kept track of the mileposts via walkie-talkie during the 100 sec test interval. The technician in the locomotive also recorded speed information for each mile of each

Figure 3. Measurement and Recording of Vibration on Northeast Corridor Amtrak Trains

test segment. At the end of each test, the equipment was moved to the next car forward and the test procedure was repeated.

Observational Technique

The observational methodology used in the present study was developed in the course of an earlier pilot study involving observations of the activities of 850 northeast region Amtrak passengers (16). Since almost all seats on the trains faced forward (in the direction of motion), it was most convenient to progress from the rear of the train toward the head end in performing the tests. In this way, the observer could approach the passengers from behind, determine their activity, and record it, usually without attracting the passengers' attention before moving on. Also, the equipment could be transported from one vehicle to the next one forward without confronting passengers face-to-face, thus preventing undesirable disruption of passenger behavior.

The results of the pilot study showed that activities could generally be coded into 12 categories, listed and defined in Table 1. Behavior was coded according to the activity the passenger performed at the exact time of observation. Thus, a passenger with a book open on his lap who was nevertheless looking out the window at the time of observation was coded in the Viewing rather than Reading activity category.

Multiple activities were coded into the category of the more effortful behavior component, according to the ranking

Table 1

Descriptive Definitions of Passenger Activity Categories

Doing Nothing	-	sitting in semi-erect, relaxed position, looking in no particular direction but with eyes open, performing no other observable behavior; may also be described as "resting", "relaxing", or "thinking"
Sleeping	-	reclining in completely relaxed posture over one or more seats, or sitting semi-erect with head hung down or resting against wall or seat, or "curled up" with whole body on one seat, with eyes closed, and performing no other observable behavior
Smoking	-	lighting, puffing on, and extinguishing cigarette, pipe, or cigar, sometimes looking at or directing attention to smoking materials or ashtray
Viewing	-	looking directly out the window or at some object or person (other than the experimenter) in the train

Talking-Listening - engaging in conversation with one or more other persons seated or standing directly across from or adjacent to the subject; "eavesdropping" on other passengers' or crew members' conversation; non-verbal listening behaviors such as nodding the head

Handcrafts - knitting, crocheting, embroidery, hooking rugs, sewing, and related behaviors (cutting fabrics with scissors, threading needle, winding up yarn, etc.)

Games - playing cards, board games; coloring and drawing pictures; children's play activities with and without toys, including "make-believe", "peek-a-boo", "hide and seek" or symbolic play with dolls or other objects

Eating - consuming food (chewing, swallowing) and related behaviors (unwrapping sandwiches, cutting meat, applying condiments, etc.)

Drinking - consuming beverages (lifting cup to mouth, swallowing) and related behaviors (adding sugar to coffee, stirring cocktails, etc.)

Reading - looking at books, magazines, train schedules, or other printed or pictorial materials; turning pages

Writing - marking papers, books, letters, or other materials with writing instruments such as pens, pencils, highlighters, or crayons for the purpose of recording numbers, words, or other language symbols; underlining in printed materials; does not include drawing or coloring pictures (see Games)

Other - engaging in any behaviors not listed above, including, for example, going through a handbag or suitcase; grooming behaviors such as combing hair, polishing fingernails; and infrequently occurring activities such as listening to a radio or playing a musical instrument of activity difficulty shown in Table 2. The activities were ranked according to the sum of their scores on six behavioral criteria which the ride quality and vibration research literature suggested to be important in performing activities on moving vehicles. These include balance, eye focus, sustained visual attention, eye-hand coordination, hand-mouth coordination, and extraordinary compensation for vibration and noise. Each of the 12 activities received a score from 0 to 3 points for each of these six criteria, depending upon how important that criterion was for the successful performance of that activity. Doing Nothing, Sleeping, Smoking, and Viewing, which were ranked between 1 and 4 for effort, are designated as Low Effort Activities. Talking-Listening, Handcrafts, and Games, which were ranked between 5 and 7 for effort, are called Medium Effort Activities. Eating, Drinking, Reading, and Writing, which received the highest effort ranks, are called High Effort Activities.

Data Reduction

For each test segment, the analogue data measured by each accelerometer was digitally sampled, and a set of data sequences for rotational acceleration in each axis was computed by subtractive methods (16). A discrete Fourier transform process was applied to the data points in each axis to calculate the frequency content of all test records. The three linear accelerations were then frequency-weighted according to the ISO guideline Document 2631 for human response

TABLE 2

Classification of Activities According to Effort Criteria

ACTIVITY	CRITERIA						TOTAL	EFFORT RANK	
	Balance	Eye Focus	Sustained Visual Attention	Eye-Hand Coordination	Hand-Mouth Coordination	Vibration & Noise Compensation			
Doing Nothing	1	0	0	0	0	0	1	1	LOW
Sleeping	1	0	0	0	0	2	3	2	
Smoking	1	1	0	1	1	0	4	3	
Viewing	1	2	2	0	0	0	5	4	
Talking-Listening	1	2	1	0	0	3	7	5	MEDIUM
Games	2	2	1	2	0	2	9	6	
Handcrafts	2	3	2	2	0	0	9	7	
Eating	2	1	1	2	3	1	10	8	HIGH
Drinking	3	1	1	2	3	1	11	9	
Reading	2	3	3	1	0	2	11	10	
Writing	2	3	3	3	0	2	13	11	

3 = much 2 = moderate 1 = some 0 = none

to whole-body vibration (3). One-third octave band root mean squares (rms) were computed for the rotational data sequences, the original, unweighted linear accelerations, and the ISO-weighted linear accelerations. The rotational acceleration data sequences were integrated to produce rotational rates, from which rms g values were then generated.

For each test segment, ISO-weighted linear acceleration indexes were computed using the formula:

$$\sqrt{(1.4a_x)^2 + (1.4a_y)^2 + (a_z)^2}$$

where a_x = longitudinal acceleration, a_y = lateral acceleration, and a_z = vertical acceleration. Rotational acceleration indexes were computed using the formula:

$$\sqrt{\alpha_x^2 + \alpha_y^2 + \alpha_z^2}$$

where α_x = roll acceleration, α_y = pitch acceleration, and α_z = yaw acceleration. Rotational rate indexes were computed using the formula:

$$\sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2}$$

where ω_x = roll rate, ω_y = pitch rate, and ω_z = yaw rate.

Temperature and humidity data for each test segment were converted to effective temperature indices using the Revised ASHRAE Comfort Chart (17). These effective temperatures, average noise levels in dB(A), average speed levels in mph, and light levels in foot-candles (fc), in addition to the motion variables, were used as predictor variables in subsequent multiple regression analyses.

Since the vehicles used in different test segments varied in absolute seating capacity and also had different levels of occupancy at the time observations and measurements were made, it was felt that the relative rather than absolute frequencies would be more useful for direct comparison of activity levels between test segments. The activity data for each test segment were therefore converted from absolute frequencies to percents (relative frequencies) for each activity category described in Table 1. Handcrafts and Games were combined into a single category, since the relative frequency of each individual activity was so small and since these behaviors were similar in purpose and effort.

Results

Activity Distributions

The frequency distribution of the 11 activities is shown in Table 3. In general, the most frequently observed activities were Reading, Sleeping, and Viewing, while Handcrafts/Games, Eating, and Drinking occurred least often. The low percentage of passengers Smoking is deceptively small, since Smoking often occurred simultaneously with other more effortful behaviors. The present data are very similar to the activity distributions of 3300 passengers observed in previous efforts on Northeast Corridor trains (16).

Table 3
Distribution Statistics for Activity Percentages (December 5-13, 1977)

Activity	Total % (Total N)	Mean	Median	Mode	Range	Standard Deviation	Kurtosis	Skewness
Doing Nothing	4.5 (128)	4.5	3.8	0	0-22.2	4.7	1.5	1.2
Sleeping	20.0 (565)	20.0	19.8	0	0-48.3	10.7	0.0	.4
Smoking	0.7 (19)	0.7	0	0	0- 9.4	1.9	7.8	2.9
Viewing	20.3 (575)	20.3	20.2	20.0	0-64.3	10.0	3.3	1.0
Talking-Listening	13.0 (368)	13.0	12.6	0	0-40.7	9.3	-0.1	0.5
Handcrafts/Games	1.5 (42)	1.5	0	0	0-15.0	2.7	7.2	2.5
Eating	2.9 (83)	2.9	2.0	0	0-23.1	3.9	7.2	2.2
Drinking	2.7 (75)	2.7	0	0	0-16.7	3.9	2.2	1.6
Reading	25.4 (719)	25.4	24.6	25.0	7.1-50.0	9.2	0.1	0.4
Writing	4.3 (121)	4.3	3.7	0	0-23.5	4.3	4.0	1.6
Other	4.7 (134)	4.7	3.7	0	0-21.2	4.8	1.4	1.3
	100 (2829)							

The distribution statistics for the 11 activities (Table 3) were calculated based on the percentage values of each activity observed over all 81 test segments. The wide relative frequency range of most of the activities between test segments reflects not only the actual differences between activity distributions of different vehicles, but also the effects of converting the absolute frequency data to percents. The positive skewness of the activity distributions may be due to the fact that some activities were not observed at all in some test segments; this is also reflected by the zero modal values and lower limits of the percentage ranges for these behaviors.

Distributions of the Measured Environmental Variables

The distributions of the major motion and non-motion variables recorded in this field study are described in Table 4. The statistics for the motion variables were computed based upon the data collected in 77 test segments for the frequency range of 1-20 Hz. Problems with the tape recording equipment during four test segments precluded the recovery of these data for further processing. The statistics for the non-motion variables, however, were computed using the data recorded in 80 test segments.

The linear motions experienced by passengers on these trains were quite small and in compliance with the ISO 2631 (3) Reduced Comfort Boundaries for daily 2.5 hr exposures for lateral (Y-axis) vibration, and 8 and 16 hr exposures, respectively,

TABLE 4 STATISTICAL SUMMARY OF RIDE MOTION DATA

RIDE VARIABLE	MEAN	STANDARD DEVIATION	RANGE
Longitudinal (X) Acceleration (rms g)	.007	.002	.005-.014
Lateral (Y) Acceleration (rms g)	.015	.003	.007-.023
Vertical (Z) Acceleration (rms g)	.021	.004	.013-.036
ISO-Weighted X-Acceleration (rms g)	.003	.001	.001-.007
ISO-Weighted Y-Acceleration (rms g)	.010	.003	.002-.019
ISO-Weighted Z-Acceleration (rms g)	.009	.002	.005-.015
Weighted ISO Index (rms g)	.015	.004	.009-025
Roll (X) Acceleration (°/sec^2)	74.94	29.14	20.57-150.49
Pitch (Y) Acceleration (°/sec^2)	56.51	31.41	18.74-158.92
Yaw (Z) Acceleration (°/sec^2)	51.43	20.14	10.56-105.59
Rotational Acceleration Index (°/sec^2)	110.39	38.74	42.43-226.40
Roll (X) Rate (°/sec)	2.56	2.04	.08-10.57
Pitch (Y) Rate (°/sec)	1.69	1.93	.02-10.67
Yaw (Z) Rate (°/sec)	1.66	1.15	.05-5.39
Rotational Rate Index (°/sec)	3.79	2.65	.10-12.22
Acoustic Noise (dB.A)	67.7	3.5	60.0-80.0
Effective Temperature (°F)	68.1	1.06	65.9-72.8
Light (fc)	6	5	1-32

for Z- and X-axis vibrations. Rotational accelerations, however, were generally of much greater intensities. In Figure 4, the roll acceleration amplitudes from test segments in this study are broken down into one-third octave band frequency components and plotted against Discomfort Curves for roll acceleration (after 18). It is clear that the levels of motion recorded on the trains exceed the comfort threshold (DISC = 1) by a factor of almost two for a typical ride segment representing the mean rms roll level of the 77 test segments, and by a factor of two to six for the ride segment recorded with the maximum level of rms roll acceleration.

Further evidence of the relative severity of the rotational motions for passenger transportation may be derived by applying Pepler, et al.'s (7) intercity train Comfort Equation:

$$C = .73 + .1\ (N-60) + .96\ \omega_x \qquad (1)$$

to the present set of data. This empirically derived model may be used as a means of predicting passengers' comfort responses on a scale of 1 to 7, given roll rate (ω_x) and noise (N) levels. Calculation of the mean predicted comfort rating from the roll rates recorded in this study yields a neutral comfort value of C = 4, representing an approximate 80% level of passenger satisfaction. In all, 72.7% of the ride segments measured in this study fall in the comfortable range ($C < 4$) and 27.3% in the uncomfortable ($C > 4$) range, using this criterion.

In terms of non-motion environmental variables, the acoustic noise levels measured in this study are comparable to or

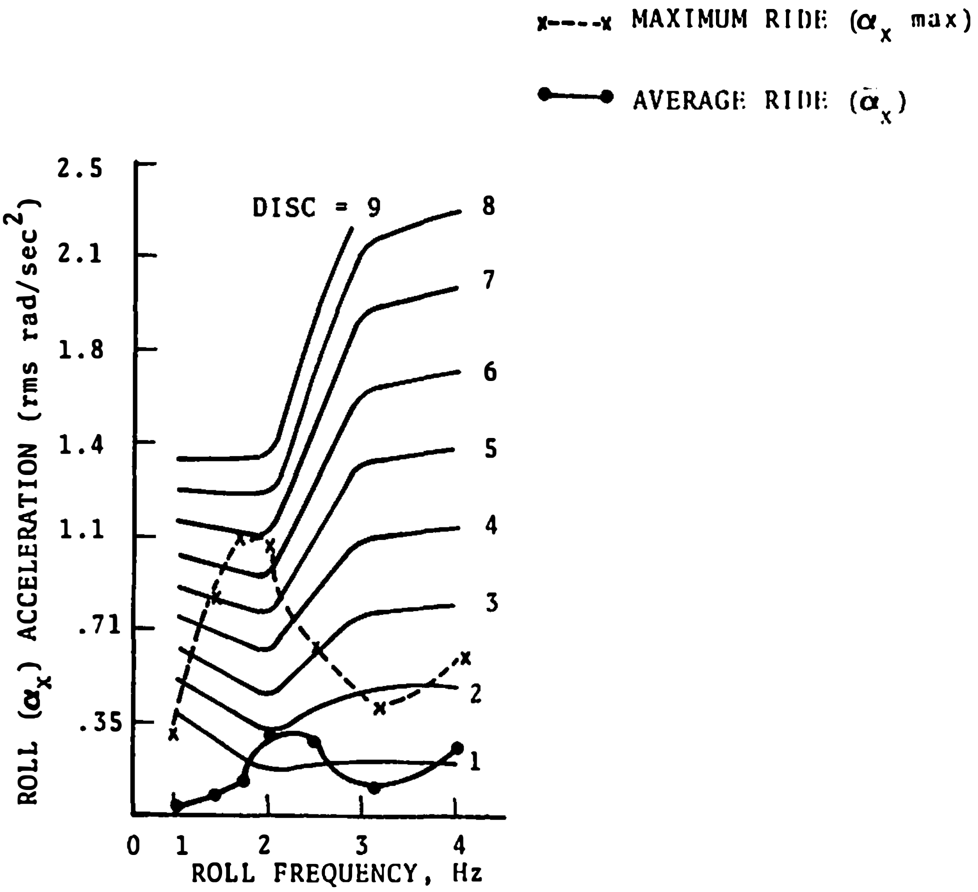

Figure 4. Comparison of Roll Accelerations Measured on Amtrak Trains (December, 1977) with Discomfort Curves for Roll Vibration (Leatherwood, et al., 1978)

lower than those measured in previous studies of intercity train environments (7,19), and are generally below the maximum of 76 dB(A) recommended by the U.S. Environmental Protection Agency (19) for a 2 hr daily exposure on this type of conveyance. However, compared with the Speech Interference Level (SIL) Curves (20), the mean noise level of 68 dB(A) is high enough to require very loud speech for communication between speakers separated 2 to 4 ft. Only at the minimum noise level observed (60 dB.A) is normal speech possible at 2 ft, which is the approximate distance between passengers seated next to each other.

Comparison of the effective temperature levels recorded in this study with the ASHRAE (17) equal comfort curves indicates that the effective temperatures on the trains were on the high side for winter comfort. However, the mean effective temperature would be considered comfortable by approximately 80% of the population.

Although the illumination levels measured in this study were low compared with those recommended by the Illuminating Engineering Society (21) for performance of various activities, these levels generally reflect only ambient illumination levels in the aisle from the overhead lighting fixtures and windows. Light levels measured with the reading lights on at the seats, however, attained levels of up to 130 fc, which is perfectly adequate for the performance of passenger activities.

The Effects of Environmental Variables on Activity Levels

Simple correlations were computed between the measured levels of the motion variables and the relative frequencies of the individual activities over all test segments. In general, there were no significant correlations between the activities and the linear accelerations. There were a number of small but significant correlations between the activities and the rotational motions, however, as shown in Table 5. In particular, it appears that many of the rotational motions are positively correlated with frequencies of Sleeping, Smoking, and Doing Nothing,and negatively correlated with frequencies of Talking-Listening, Handcrafts/Games, Eating, and Writing. Frequencies of Viewing and Reading, the two most popular activities, and Drinking were not significantly influenced by changes in rotational motion levels.

In general, there were few significant correlations between the activity levels and the non-motion environmental variables. Noise was significantly correlated only with the relative frequency of Talking-Listening ($r=.27$, $p<.05$). As effective temperature increased, levels of Doing Nothing increased ($r=.20$, $p<.05$), while the relative frequencies of Smoking and Viewing decreased ($r=-.20$, $-.18$, respectively; $p<.05$). As the level of illumination increased, Doing Nothing and Handcrafts/Games were observed less frequently ($r=-.21$, $-.18$, respectively; $p<.05$) compared to other activities, while Talking-Listening was observed more frequently ($r=.20$, $p<.05$).

Table 5
Simple Correlations Between Percent Observed Activities and Rotational Accelerations and Rates (1-20 Hz)

Rotational Motions	ACTIVITIES									
	Doing Nothing	Sleeping	Smoking	Viewing	Talking-Listening	Eating	Handcrafts/ Games	Reading	Drinking	Writing
Roll (X) Acceleration	(.17)	.14	.06	.01	-.14	-.21*	(.17)	-.09	.01	-.07
Pitch (Y) Acceleration	.02	.08	.25*	-.05	-.05	-.01	-.05	-.03	.14	(-.15)
Yaw (Z) Acceleration	.01	(.18)	.20*	-.01	(-.17)	-.13	.12	-.08	.02	.06
Rotational Acceleration Index	.11	(.19)	.20*	-.03	(-.16)	(-.15)	.09	-.09	.07	-.10
Roll (X) Rate	.04	.25*	0	.05	(-.17)	-.12	-.09	(-.16)	.06	(-.18)
Pitch (Y) Rate	.04	.12	.19*	.04	(-.18)	-.02	(-.16)	.04	.14	(-.17)
Yaw (Z) Rate	-.13	.28**	(.17)	-.03	-.26**	.00	-.07	-.03	.10	-.06
Rotational Rate Index	-.02	.28**	.10	.04	-.26**	-.08	(-.15)	-.07	.12	-.20*

( ): p<.10 *: p<.05 **: p<.01 n=77

Correlations were also computed to determine any systematic relationships between the relative frequencies of individual activities and trip variables such as time of day, vehicle type, and vehicle occupancy. Viewing increased from morning to afternoon ($r=.18$, $p<.05$), while Handcrafts/Games and Writing decreased with time into the day ($r=-.23$, $-.19$, respectively; $p<.05$). More Smoking ($r=.25$, $p<.01$), Talking-Listening ($r=.25$, $p<.01$), and Drinking ($r=.18$, $p<.05$) occurred in Amcafe cars than in Amcoaches, and less Sleeping ($r=-.16$, $p<10$) and Viewing ($r=-.17$, $p<.10$). Sleeping increased ($r=.33$, $p<.01$) and Eating and Reading decreased ($r=-.15$, $-.16$, respectively; $p<.10$) as level of vehicle occupancy (crowding) increased.

Since the correlations between individual activities and the environmental variables were generally small but significant, it was decided to combine the activities into three groups based upon the previously defined effort categories, to see how well these activity indexes might be correlated with the environmental and trip variables. Table 6 shows that grouping the activities in this way results in an increase in the size of the correlation coefficients for many of the same relationships found previously, since many frequencies of zero which entered into the correlations for individual activities have now been eliminated. The frequency of High Effort activities decreased as a function of roll rate magnitude, and was marginally related in the same negative way to

TABLE 6 SIMPLE CORRELATIONS BETWEEN PERCENT HIGH, MEDIUM, AND LOW EFFORT ACTIVITIES AND RIDE VARIABLES

	HIGH	MEDIUM	LOW
X-Linear Acceleration	(-.17)	.08	.08
Y-Linear Acceleration	.03	-.09	.07
Z-Linear Acceleration	.03	-.02	.00
X-ISO Linear Acceleration	-.07	-.13	.19*
Y-ISO Linear Acceleration	.04	(-.14)	.11
Z-ISO Linear Acceleration	.06	.04	-.07
Weighted ISO Index	.02	-.10	.10
Roll (X) Acceleration	(-.17)	-.09	.19*
Pitch (Y) Acceleration	-.03	-.07	.07
Yaw (Z) Acceleration	-.08	-.13	(.17)
Rotational Acceleration Index	(-.14)	-.13	.20*
Roll (X) Rate	-.22*	-.19*	.26**
Pitch (Y) Rate	.01	-.21*	(.14)
Yaw (Z) Rate	-.01	-.27**	.19*
Rotational Rate Index	-.12	-.30**	.27**
Noise	.03	.26**	(-.18)
Effective Temperature	(.18)	-.05	-.10
Light	.01	.13	-.07
Time	(-.14)	-.09	(.14)
Vehicle Type	.03	.23*	-.23*
Vehicle Occupancy	(-.15)	.07	0
Speed	.08	.07	(-.14)

**: p<.01 *: p<.05 ( ): p<.10 n = 77

the X-linear and angular accelerations, time of day, and vehicle occupancy. Medium Effort activities were negatively correlated with the magnitudes of the angular rates of motion in all three degrees of freedom, while Low Effort behaviors increased in frequency with increases in the rates of rotational motion. Low Effort activities decreased in frequency as a function of noise and were observed more often in Amcoach vehicles; Medium Effort activities were positively correlated with noise and occurred more often in Amcafe snackbars.

Based upon similarities in physical action components and common correlations with environmental and trip variables, the activities were regrouped into a second set of indexes. Rest activities, in which no exertion of physical action could be observed, included Doing Nothing and Sleeping. Social/Oral activities, involving hand-mouth coordination or interpersonal communication, included Eating, Drinking, Smoking, and Talking-Listening. Motor activities, which required hand-eye coordination and hand movements, included Handcrafts/Games and Writing. Reading and Viewing, which were not well correlated with any major environmental variables, were omitted from this second set of activity indexes.

Table 7 shows the correlations between the physical action indexes and the environmental and trip variables. Rest behaviors were positively correlated with roll and yaw accelerations and rates. Motor activities decreased significantly in frequency with increases in roll and pitch rates. Social/

TABLE 7 SIMPLE CORRELATIONS BETWEEN PERCENT REST, SOCIAL/ORAL, AND MOTOR ACTIVITIES AND RIDE VARIABLES

	REST	SOCIAL/ORAL	MOTOR
X-Linear Acceleration	.05	.06	.02
Y-Linear Acceleration	.06	-.01	.07
Z-Linear Acceleration	-.08	-.06	(.14)
X-ISO Linear Acceleration	.07	-.04	-.04
Y-ISO Linear Acceleration	.03	-.02	-.03
Z-ISO Linear Acceleration	-.04	-.09	.26*
Weighted ISO Index	.02	-.04	.05
Roll (X) Acceleration	.22*	(-.17)	.03
Pitch (Y) Acceleration	.09	.04	(-.14)
Yaw (Z) Acceleration	.19*	-.13	.11
Rotational Acceleration Index	.24*	-.12	-.03
Roll (X) Rate	.27*	(-.15)	-.19*
Pitch (Y) Rate	.11	-.06	-.22*
Yaw (Z) Rate	.23*	(-.14)	-.08
Rotational Rate Index	.28**	(-.18)	-.24*
Noise	-.09	.21*	-.11
Effective Temperature	.09	-.02	.09
Light	-.03	.20*	(-.14)
Time	-.03	-.02	-.26*
Vehicle Type	(-.16)	.32**	-.02
Vehicle Occupancy	.07	.02	.07
Speed	-.05	.03	.12

( ): p<.10 *: p<.05 **: p<.01 n=77

Oral activities decreased marginally as roll and yaw rates increased, and were positively correlated with noise, light, and vehicle type (i.e., Amcafe vehicles). Motor behaviors occurred more frequently in the morning than in the afternoon. The counterintuitive positive correlation between Motor activity and ISO-weighted Z-linear acceleration resulted from a similar simple correlation between this motion variable and Handcrafts/Games, and is believed to be spurious.

Multiple regression techniques were used to develop linear models to predict the levels of activity based upon the environmental and trip variables measured and recorded in this study. Environmental and trip variables which were significantly correlated with activity levels but relatively uncorrelated with other predictor variables were selected for inclusion in the stepwise regression process. The linear equations shown in Table 8 represent the best fit of the physical and trip variable data to the observed levels of activity.

It may be seen that levels of all types of activity except High Effort behaviors may be predicted to some appreciable level of significance by the environmental and trip variables recorded in this study. Except for the High Effort behaviors, linear combinations of five or fewer predictor variables may be used to account for approximately 20% of the variance in the various activity categories. The sign preceding the coefficient of each predictor variable in each equation reflects the direction of the correlation between the activity and the predictor variable. Thus, a negative sign before a particular factor indicates that the presence of that variable in the

Table 8
Linear Multiple Regression Models for Activity Indices
(Motion Variables in 1-20 Hz Range)

ACTIVITY INDEX (A)	ACTIVITY MODEL	F (d.f.)	MULTIPLE R	R^2	LEVEL SIGNI-FICANCE
Low Effort	$\%A=1.04\omega_{XYZ}-.59N+1971.43a_{XISO}-6.61(V)+3.69(T)+78.62$ $(\sigma)=(.56)\quad(.42)(1387.26)\quad(4.10)\quad(2.96)$	3.05 (5,71)	.42	.18	$p<.05$
Medium Effort	$\%A=\overline{1}.09\omega_{XYZ}+.55N+5.28(V)-25.00$ $(\sigma)=(.39)\quad(.30)(2.93)$	5.52 (3,73)	.43	.18	$p<.01$
High Effort	$\%A=-1.03\omega_{X}+1.42ET-568.55a_{X}-.10(VO)-2.18(T)-46.70$ $(\sigma)=(.65)\quad(1.25)\quad(788.66)\quad(.08)\quad(2.67)$	1.83 (5,71)	.34	.11	NS
Rest	$\%A=1.14\omega_{X}+1.67\omega_{Z}-5.44(V)+24.99$ $(\sigma)=(.60)\quad(1.08)\quad(3.28)$	3.55 (3,69)	.37	.13	$p<.05$
Social/Oral	$\%A=.50N+.40I-.79\omega_{XYZ}+9.64(V)-25.40$ $(\sigma)=(.37)(.22)(.48)\quad(3.61)$	4.33 (4,71)	.44	.20	$p<.01$
Motor	$\%A=\overline{.}50\omega_{XYZ}-.20I-.17N-2.21(T)+.11(SP)+15.02$ $(\sigma)=(.23)\quad(.11)\quad(.17)\quad(1.28)\quad(.09)$	2.78 (5,67)	.41	.17	$p<.05$

a_* = Linear Accel. (*axis)
a_{*ISO} = ISO-Weighted Linear Accel. (* axis)
ET = Effective Temperature (°F)
I= Illumination (fc)
N= Noise (dB.A)
σ= Standard Error of Coefficient
SP= Speed (mph)
T = Time (1=a.m., 2=p.m.)
V = Vehicle Type (1=Amcoach, 2=Amcafe)
VO = Vehicle Occupancy (%)
ω_* = Rotational Rate (*axis)
ω_{XYZ}= Rotational Rate Index

ride environment contributes to the inhibition or decrease in the activity level (% A) on the opposite side of the equation. A positive sign indicates that the presence of a given variable serves to facilitate or increase the relative frequency of activity. The variables in the equations are generally those with the highest simple correlations with the individual activities which make up the activity indexes. In some cases, a given variable may serve to facilitate one type of activity and inhibit another type (e.g., noise for Social/Oral vs. Motor activities).

Discussion

The results of this field study indicate that a small but significant proportion of the variance of passenger activity could be explained by combinations of physical ride quality and trip or situational factors. The variables which had the greatest effect upon observed levels of activities were the rates of rotational motions, noise, vehicle type, and time of day. The variable which influenced passenger activity levels the least was linear vibration.

The fact that rotational motions were found to play a more significant role than linear vibration in affecting the frequencies of passenger activity supports a growing body of evidence which shows the importance of rotational motions for passenger comfort (e.g., 7,18). The above-threshold discomfort levels of the roll accelerations measured in the present study (Figure 4) and the Neutral comfort index corresponding to only 80% passenger satisfaction as computed with the roll-based comfort equation of Pepler, et al. (7) contrast with the high level of acceptability of the linear vibrations as judged using the ISO 2631 (3) Reduced Comfort Boundaries. It is clear that both subjective estimates of passenger comfort and the ability to do activities involving anything more than a low level of effort (as evidenced through changes in the activities' relative frequencies) significantly depend upon angular motions, which are not addressed in the present ISO guideline.

The findings that measured noise levels were positively correlated with Medium Effort, Social/Oral activities and that the noise variable figured prominantly in the linear equations generated to predict these behaviors deserves comment. In general, it was expected that environmental noise coming from the train would be negatively correlated with the frequencies of most activities due to its disruptive and interferent effects. The fact that noise was generally uncorrelated with dominant vehicle motion levels, and that both noise and vehicle type were significantly correlated with Talking-Listening led to the hypothesis that the passengers were the chief source of noise in this study rather than the train itself. This hypothesis was supported by the finding that noise levels in Amcoach cars were lower than those in Amcafe snackbars, where more Talking-Listening was observed (one-tailed $t = 1.89$, $d.f. = 79$, $p < .05$). Thus, in this case, the environment was influenced more by the passengers' activity than the activity was influenced by the environment. Regardless of the causative direction of this relationship, noise remained the best environmental correlative of several types of activity and was therefore retained as a predictor variable when the linear equations of activity were generated.

A major goal of the present study was to provide a useful tool for designers and evaluators of transportation systems who wish to accommodate a certain level of passenger activity in order to increase passenger satisfaction. The activity equations shown in Table 8 might be used as such a tool. These models are similar in concept to the comfort equations generated by Jacobson and Richards (13) and Pepler, et al. (7) for predicting and evaluating the subjective comfort of aircraft, trains, and buses.

The activity equations in Table 8 could be used by a design engineer to specify the minimum levels of environmental variables which are required to allow a certain relative frequency level of performance for a particular type of activity. This could be done by "plugging in" the relative frequency value of activity the designer wishes to accommodate and then "trading off" or adjusting the values of the ride environment factors until both sides of the equation are equal. Information regarding a desirable level of activities for maximum passenger satisfaction might be obtained from passenger opinion surveys (e.g., Amtrak's passenger activity/ride quality survey described by Wichansky, 16) or other data sources. Conversely, a systems evaluator might wish to determine what level of passenger activity the existing ride quality and trip conditions on any given system might allow. This could be computed by " plugging in" the predetermined values of the ride environment and trip factors and solving for the percent activity (% A) value.

It is recommended, however, that the activity equations developed here be applied with caution. First, these models need to be validated on an independent sample of Amtrak system users to confirm the existence and accuracy of the activity/ ride quality relationships which they describe. Second, only about 20% of the variance in activity may be accounted for using the ride quality and trip variables recorded in this study. This 20% of the variance in activity is considered to be that proportion attributable to the interference or facilitation effects of vibration, noise, and other aspects of the ride environment, which are the factors at least theoretically under the control of the design engineer. The fact that physical ride quality and trip variables could influence even this much of the variation in activities is considerable, in light of the dominant role played by individual differences in the majority of ride quality-related research efforts.

While the observational design of the present field study did not permit the assessment of within- vs. between-subjects variance in the performance of activities, it is undoubtedly these individual differences which control the largest proportion of the variance in passenger activity. There is ample evidence in the literature that individual differences may be a most important factor in determining human response to whole-body vibration. A number of reviews and experimental studies have referred to individual differences in explaining the inconsistency of past research results in determining human response to whole-body vibration (e.g., 22, 23, 24). Individual differences in passengers' subjective comfort responses have already been found as a function of demographic variables such as sex (25) and age (7). Richard, et al. (25) also found certain individual differences in passengers' reported frequencies of performing various activities in flight. Thus, it is very likely that individual differences play an important role in passengers' preference and performance of activities in intercity train transit.

The present study clearly indicates the importance of ride quality and situational variables in determining relative frequencies of passenger activities. Further research is necessary to determine how <u>well</u> passengers are able to perform activities in transportation environments and how motivational factors influence the frequency and quality of activity performance. Use of the relative frequencies of behavior as dependent variables can only give a rough indication of passengers' difficulties in doing various activities in transit. The assumption that people will do what is the easiest for them to do (6) may be confounded by their varying motivations to perform different activities and the resulting level of effort they are willing to expend. These issues require experimental study in a controlled research environment, where individual differences between subjects may be more easily controlled.

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