both the maximum ballast and subgrade stresses and a ratio of maximum to minimum stress as a measure of stress variation are recommended as critical factors for track design. Increasing tie spacing causes a relatively large increase in pressure ratio along the track, but the pressure variations under ties are higher and are therefore the more critical design problem. Track design data generated with the MULTA program can be used to evaluate the effects of changing ballast depth, tie size, and tie spacing on roadbed stresses. The parametric study showed that a track system with various combinations of synthetic tie size, tie spacing, and ballast depth gave equal or superior roadbed stress conditions when compared to a track structure with wood ties.

Results from the parametric evaluation of vertical rail fastener stiffness showed that the distribution of track loads can be improved by using a flexible fastener with a vertical stiffness less than about 500 000 lb/in. Other studies show that a flexible fastener can also reduce impact loads from wheel flats and rail joints and thereby can compensate for the normal increased stiffness of concrete over wood tie track. European and Russian fastener development efforts have been concentrated on designing more flexible rail fasteners. This trend has been largely ignored in the United States, where all fasteners currently used with concrete ties are rigid relative to the track. Maintaining adequate lateral restraint against gauge spread and rail rollover is the major design problem in developing a fastener with a lower vertical stiffness. However, the reduction in impact loads and the improved load distribution that can be obtained with more flexible fasteners should be adequate to encourage additional development efforts by the industry.

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Effects of Ride Environment on Intercity Train Passenger Activities

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The ability to read, write, talk, and sleep on a transit vehicle has been cited frequently 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 relation 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 at the same time as observations of passenger activity were made aboard 77 Amtrak vehicles on 14 trains between Newark, New Jersey, and Washington, D.C. Rotational vibration rates (1-20 Hz) were found to be negatively correlated with the 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 that predict approximately 20 percent 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 factors for passenger activity performance in the design of advanced transportation systems.

The ability to read, write, talk, and sleep on a transit vehicle has been cited frequently 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, with 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 guidelines for evaluation of human response to whole-body vibration, International Organization for Standardization (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.

Although passenger activities have received some recognition as human response patterns that might depend on 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 relations is currently available. If comfort does depend on the ability to perform activities, then quantifying the relations between the physical ride environment and levels of activity could provide a tool that would enhance passenger satisfaction.

The majority of studies in the ride quality and vibration research literature are concerned with either (a) the subjective effects of vibration on human sensation, as measured by using psychophysical methods or rating scales in laboratory experiments or through controlled field studies of passenger comfort (4-7), or (b) the objective effects of vibration on human performance, as measured by using task-specific dependent variables in highly controlled laboratory experiments (8-10). The question remains, however, as to the effect of vibration and other environmental variables on passenger performance of activities such as reading, writing, and sleeping in various transportation environments.

Some information regarding the subjective importance and difficulty of performing various passenger activities is available from studies of passengers on short takeoff and landing (STOL) airplanes (11-14). 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. The passenger activity data from these surveys, however, consist solely of passengers' subjective reports of their own behavior. Because 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 if the relations between levels of activity and the environment could be 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 and ride quality relations and to describe them in a quantitative form that 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.

Apparatus

Linear ride vibrations in three degrees of freedom (X=longitudinal, Y=lateral, and Z=vertical) were measured using the battery-operated portable accelerometer set developed by the National Aeronautics and Space Administration's (NASA) Langley Research Center (15). This unit consisted of three independently calibrated, seismic mass piezo-resistive accelerometers (0-100 Hz bandwidth) that were mounted in three mutually perpendicular directions. Rotational motions were measured by attaching three independently calibrated Unholtz-Dickie PA-1000 accelerometers to the outer casing of the NASA accelerometer package. The sensitivity of the PA-1000 accelerometers was set at 3.33 V/g, and their maximum response range was 0.1 to 2000 Hz. The six independent motion signals (three linear, three rotational) were recorded on a Lockheed eight-channel FM tape recorder (Model No. 4170).

Instrumentation used to measure nonmotion 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.

Procedure

Prior to the actual data-collection efforts on the trains, track charts of the Washington-Newark section of the Northeast Corridor were analyzed to select a number of internally homogeneous segments that might be sampled during the tests. To represent straight and curved track over uphill, downhill, and undulating terrain, 32 nonoverlapping segments were chosen.

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 and 13, 1977. Data were collected on two trains each day: the Patriot (no. 172) from Washington to Newark (9:00 a.m.-12:41 p.m.) and the Colonial (no. 169) from Newark to Washington (1:15 p.m.-5:00 p.m.). Each train had approximately six Amfleet vehicles, including several Amcoach cars and at least one Amcafe snackbar car.

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 through the rear vehicle. The equipment for measuring the environmental variables was set up at a reserved pair of center seats and the accelerometer package was placed 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. When a hand signal was given by the assistant to indicate the beginning of a recording period, the observer walked through the vehicle, unobtrusively observing and recording the activity of each passenger on a preprinted coding sheet. At the center of the vehicle, the observer also made an ambient light measurement in the center aisle. 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-s test interval. 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 was developed in the course of an earlier pilot study involving observations of the activities of 850 Northeast region Amtrak passengers (16). Because almost all seats on the trains faced forward (in the direction of motion), it was convenient to progress from the rear of the train toward the head end in performing the test. In this way, the observer could approach the passengers from behind, determine their activity, and record it, usually without attracting the passengers' attention. Also, the equipment could be transported between vehicles 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 these 12 operationally defined categories: high effort—writing, reading, drinking, eating; medium effort—handcrafts, games, talking-listening; low effort—viewing, smoking, sleeping, doing nothing; and other unranked activity. Behavior was coded according to the activity the passenger performed at the exact time of observation. Thus, a passenger with a book open but who was 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 of activity difficulty noted above. The activities were ranked according to the sum of their scores on six behavioral criteria suggested in the ride quality and vibration research literature as important in performing activities on moving vehicles. These included balance, eye focus, sustained visual attention, eye-hand coordination, hand-mouth coordination, and extraordinary compensation for vibration and noise.

DATA REDUCTION

For each test segment, the analogue data measured by each accelerometer were 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 for human response 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 values were then generated.

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

$$\text{linear acceleration} = \sqrt{(1.4a_x)2 + (1.4a_y)^2 + (a_z)^2} \qquad (1)$$

where

a_x = longitudinal acceleration,
a_y = lateral acceleration, and
a_z = vertical acceleration.

Rotational acceleration indexes were computed by using the formula:

$$\text{rotational acceleration} = \sqrt{\alpha_x^2 + \alpha_y^2 + \alpha_z^2} \qquad (2)$$

where

α_x = roll acceleration,
α_y = pitch acceleration, and
α_z = yaw acceleration.

Rotational rate indexes were computed by using the formula:

$$\text{rotational rate} = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} \qquad (3)$$

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 indexes by using the revised American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) comfort chart (17). These effective temperatures, average noise levels in dB(A), average speed levels in miles per hour, and light levels in foot-candles (fc), in addition to the motion variables, were used as predictor variables in subsequent multiple regression analyses. (The study was conducted using customary measurements; thus, SI equivalents are not given.)

Because the actual vehicles varied in absolute seating capacity and also had different levels of occupancy when observations and measurements were made, the activity data for each test segment were converted from absolute frequencies to percentages (relative frequencies). Handcrafts and games were combined into a single category because the relative frequency of each individual activity was so small and these behaviors were similar in purpose and effort.

RESULTS

Activity Distributions

The frequency distribution of the 11 activities is shown in Table 1. In general, the most frequently observed activities were reading, sleeping, and viewing; handcrafts-games, eating, and drinking occurred least often. The low percentage of passengers smoking is deceptively small because smoking often occurred simultaneously with other more effortful behaviors. These data are very similar to the activity distributions of 3300 passengers observed in previous efforts on Northeast Corridor trains (16).

The distribution statistics for the 11 activities 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

Table 1. Distribution statistics for activity percentages.

Activity	Total	Percentage of Total	Mean	SD	Range
Doing nothing	128	4.5	4.5	4.7	0-22.2
Sleeping	565	20.0	20.0	10.7	0-48.3
Smoking	19	0.7	0.7	1.9	0-9.4
Viewing	575	20.3	20.3	10.0	0-64.3
Talking-listening	368	13.0	13.0	9.3	0-40.7
Handcrafts-games	42	1.5	1.5	2.7	0-15.0
Eating	83	2.9	2.9	3.9	0-23.1
Drinking	75	2.7	2.7	3.9	0-16.7
Reading	719	25.4	25.4	9.2	7.1-50.0
Writing	121	4.3	4.3	4.3	0-23.5
Other	134	4.7	4.7	4.8	0-21.2
Total	2829	100.0			

Table 2. Statistical summary of ride motion data.

Ride Variable	Mean	SD	Range
Longitudinal (X) acceleration (RMS g)	0.007	0.002	0.005-0.014
Lateral (Y) acceleration (RMS g)	0.015	0.003	0.007-0.023
Vertical (Z) acceleration (RMS g)	0.021	0.004	0.013-0.036
ISO-weighted X-acceleration (RMS g)	0.003	0.001	0.001-0.007
ISO-weighted Y-acceleration (RMS g)	0.010	0.003	0.002-0.019
ISO-weighted Z-acceleration (RMS g)	0.009	0.002	0.005-0.015
Weighted ISO index	0.015	0.004	0.009-0.025
Roll (X) acceleration ($^\circ/s^2$)	74.94	29.14	20.57-150.49
Pitch (Y) acceleration ($^\circ/s^2$)	56.51	31.41	18.74-158.92
Yaw (Z) acceleration ($^\circ/s^2$)	51.43	20.14	10.56-105.59
Rotational acceleration index	110.39	38.74	42.43-226.40
Roll (X) rate (°/s)	2.56	2.04	0.08-10.57
Pitch (Y) rate (°/s)	1.69	1.93	0.02-10.67
Yaw (Z) rate (°/s)	1.66	1.15	0.05-5.39
Rotational rate index	3.79	2.65	0.10-12.22
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

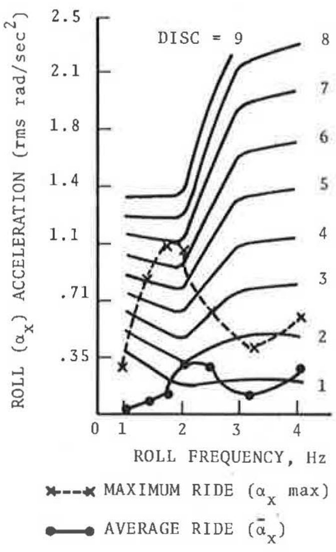

Figure 1. Comparison of roll accelerations measured on Amtrak trains (December 1977) with discomfort curves for roll vibration.

frequency data to percentages. The zero-value lower limits of some of the activity distributions result from the fact that these behaviors were not observed at all in some test segments.

Distributions of the Measured Environmental Variables

The distributions of the major motion and nonmotion variables recorded in this field study are described in Table 2. The statistics for motion variables were computed based on the data collected in 77 test segments for the frequency range of 1-20 Hz.

The linear motions experienced by passengers on these trains were quite small and in compliance with standards for reduced comfort boundaries (3) for daily 2.5-h exposures for lateral (Y-axis) vibration, and 8- and 16-h exposures, respectively, for Z- and X-axis vibrations. Rotational accelerations, however, were generally of much greater intensities. In Figure 1, 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. It is clear that the levels of motion recorded on the trains exceed the comfort threshold (DISC = 1) by a factor of almost 2 for a typical ride segment representing the mean RMS roll level of the 77 test segments and by a factor of 2 to 6 for the ride segment recorded with the maximum level of RMS roll acceleration.

Further evidence of the perceived severity of the rotational motions for passenger transportation may be derived by applying the intercity train comfort equation of Pepler and others (7) to existing data:

$$C = 0.73 + (N - 60) + 0.96\ \omega_x \qquad (4)$$

This empirically derived model may be used as a means of predicting passengers' comfort responses (C) 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 percent level of passenger satisfaction. Using this criterion, 72.7 percent of the ride segments measured in this study fall in the comfortable range ($C < 4$) and 27.3 percent in the uncomfortable ($C > 4$) range.

In terms of nonmotion environmental variables, the acoustic noise levels measured in this study are comparable to or lower than those measured in previous studies of intercity train environments (7) and are generally below the maximum recommended by the U.S. Environmental Protection Agency (18) for a 2-h daily exposure on this type of conveyance. However, compared with the speech interference level (SIL) curves (19), the mean noise level of 68 dB(A) is high enough to require very loud speech for communication between speakers separated by 0.6 to 1.2 m (2 to 4 ft), the approximate distance between passengers seated together on the trains. Comparison of the effective temperature levels recorded in this study with the ASHRAE (17) equal-comfort curves indicates that the mean effective temperature would be considered comfortable by approximately 80 percent of the population. Although the light levels measured in the vehicle aisles were low compared with those recommended by the Illuminating Engineering Society (20), illumination measured with the reading lights on at the seats attained levels of up to 130 fc, which is perfectly adequate for the performance of passenger activities.

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, however, a number of small but significant correlations between the activities and the rotational motions. In particular, many of the rotational motions were positively correlated with frequencies of sleeping ($r = 0.28$ with yaw, $p < 0.01$), smoking ($r = 0.25$ with pitch, $p < 0.01$), and doing nothing ($r = 0.17$ with roll, $p < 0.10$) and negatively correlated with frequencies of talking-listening ($r = -0.26$ with roll, $p < 0.01$), handcrafts-games ($r = -0.16$ with pitch, $p < 0.10$), eating ($r = -0.21$ with roll, $p < 0.05$), and writing ($r = -0.20$ with the rotational rate index, $p < 0.05$). 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 nonmotion environmental variables. Noise was significantly correlated only with the relative frequency of talking-listening ($r = 0.27$, $p < 0.05$). As effective temperature increased, levels of doing nothing increased ($r = 0.20$, $p < 0.05$), and the relative frequencies of smoking and viewing decreased ($r = -0.20, -0.18$, respectively; $p < 0.05$). As the level of illumination increased, doing nothing and handcrafts-games were observed less frequently ($r = -0.21, -0.18$, respectively; $p < 0.05$) compared with other activities; talking-listening was observed more frequently ($r = 0.20$, $p < 0.05$).

Correlations were also computed to determine any systematic relation 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 ($r = 0.18$, $p < 0.05$). Handcrafts-games and writing decreased with time into the day ($r = -0.23, -0.19$, respectively; $p < 0.05$). More smoking ($r = 0.25$, $p < 0.01$), talking-listening ($r = 0.25$, $p < 0.01$), and drinking ($r = 0.18$, $p < 0.05$) occurred in Amcafe cars than in Amcoaches, and less sleeping ($r = -0.16$, $p < 0.10$) and viewing ($r = -0.17$, $p < 0.10$). Sleeping increased ($r = 0.33$, $p < 0.01$) and eating and reading decreased ($r = -0.15, -0.16$, respectively; $p < 0.10$) as the level of vehicle occupancy (crowding) increased.

Because 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 on the previously defined effort categories in order to see how well these activity indexes might be correlated with the environmental and trip variables. Regrouping the activities in this way resulted in an increase in the size of the correlation coefficients for many of the same relations found previously; many frequencies of zero that entered into the correlations for individual activities were eliminated. The frequency of high-effort activities decreased as a function of roll-rate magnitude ($r = -0.22$, $p < 0.05$) and was marginally related in the same negative way to 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 ($r = -0.19, -0.21$, and -0.27 for roll; pitch, $p < 0.05$; and yaw, $p < 0.01$), while low-effort behaviors increased in frequency with increases in the rates of rotational motion (e.g., $r = 0.26$ with roll, $p < 0.01$). However, low-effort activities decreased marginally in frequency as a function of noise and were observed more often in Amcoach vehicles ($r = -0.23$, $p < 0.05$). Medium-effort activities were positively correlated with noise ($r = 0.26$, $p < 0.01$) and occurred more often in Amcafe snackbars ($r = 0.23$, $p < 0.05$).

Based on 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 physical exertion 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 require 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.

Rest behaviors were found to be positively correlated with roll ($r = 0.27$, $p < 0.05$) and yaw ($r = 0.23$, $p < 0.05$) rates. Motor activities decreased significantly in frequency with increases in roll and pitch rates ($r = -0.19, -0.22$, respectively; $p < 0.05$). Social-oral activities decreased marginally as roll and yaw rates increased and were positively correlated with noise ($r = 0.21$, $p < 0.05$), light ($r = 0.20$, $p < 0.05$), and vehicle type (i.e., Amcafe vehicles: $r = 0.32$, $p < 0.01$). Motor behaviors occurred more frequently in the morning than in the afternoon ($r = -0.26$, $p < 0.05$).

Multiple regression techniques were used to develop linear models to predict the levels of activity based on the environmental and trip variables measured and recorded in this study. Environmental and trip variables that 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 3 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 percent 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

Table 3. Linear multiple regression models for activity indexes (motion variables in 1-20 Hz range).

Activity Index (A)	Activity Model	F (df)	Multiple R	R^2	Significance
Low effort	$\%A = 1.04\omega_{XYZ} - 0.59N + 1971.43a_{XISO} - 6.61(V) + 3.69(T) + 78.62$ $(\sigma) = (0.56)\quad(0.42)\ (1387.26)\quad(4.10)\quad(2.96)$	3.05 (5, 71)	0.42	0.18	$p < 0.05$
Medium effort	$\%A = -1.09\omega_{XYZ} + 0.55N + 5.28(V) - 25.00$ $(\sigma) = (0.39)\quad(0.30)\ (2.93)$	5.52 (3, 73)	0.43	0.18	$p < 0.01$
High effort	$\%A = 1.03\omega_X + 1.42ET - 568.55a_X - 0.10(VO) - 2.18(T) - 46.70$ $(\sigma) = (0.65)\quad(1.25)\ (788.66)\ (0.08)\ (2.67)$	1.83 (5, 71)	0.34	0.11	NS
Rest	$\%A = 1.14\omega_X + 1.67\omega_Z - 5.44(V) + 24.99$ $(\sigma) = (0.60)\ (1.08)\ (3.28)$	3.55 (3, 69)	0.37	0.13	$p < 0.05$
Social-oral	$\%A = 0.50N + 0.40I - 0.79\omega_{XYZ} + 9.64(V) - 25.40$ $(\sigma) = (0.37)\ (0.22)\ (0.48)\ (3.61)$	4.33 (4, 71)	0.44	0.20	$p < 0.01$
Motor	$\%A = 0.50\omega_{XYZ} - 0.20I - 0.17N - 2.21(T) + 0.11(SP) + 15.02$ $(\sigma) = (0.23)\ (0.11)\ (0.17)\ (1.28)\ (0.09)$	2.78 (5, 67)	0.41	0.17	$p < 0.05$

Notes: a_* = linear acceleration (*axis); a_{*ISO} = ISO-weighted linear acceleration (* 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); and ω_{XYZ} = rotational rate index.

variable in the 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 is associated with a relative facilitation or increase in the relative frequency of activity. The variables in the equations are generally those with the highest simple correlations with the individual activities that 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 versus motor activities).

SUMMARY

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 that had the greatest effect on observed levels of activities were the rates of rotational motions, noise, vehicle type, and time of day. The variable that 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 about the importance of rotational motions for passenger comfort (7, 22). The above threshold discomfort levels of the roll accelerations measured in this study (Figure 1) and the neutral comfort index corresponding to only 80 percent passenger satisfaction as computed with the roll-base comfort equation of Pepler and others (7) contrast with the high level of acceptability of the linear vibrations as judged by 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 on angular motions, which are not addressed in the existing ISO guideline.

Some comment is necessary to explain the findings that measured noise levels were positively correlated with medium-effort social-oral activities and that the noise variable figured prominently in the linear equations generated to predict these behaviors. 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 interferential effects. The facts 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 $t = 1.89$, $df = 79$, $p < 0.05$). 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 relation, 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 this 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 in Table 3 could be used by a design engineer to specify the minimal levels of environmental variables that 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 that 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, for example, Amtrak's passenger-activity and ride-quality survey described in Wichansky (16) or in 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 percentage 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 relations that they describe. Second, only about 20 percent of the variance in activity may be accounted for by using the ride quality and trip variables recorded in this study. This 20 percent of the variance in activity is considered to be that proportion attributable to the interference or (relative) 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 (21, 23, 24). Also, the emergence of statistically significant relations in a field study of this type indicates at the very least that a great amount of effort is being expended on the passengers' part to perform the more complicated activities, probably resulting in increased levels of fatigue and passenger discomfort.

This 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 well 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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