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EFFECTS OF THE RIDE ENVIRONMENT ON PASSENGER ACTIVITIES: A Field Study on Intercity Trains

Anna M. Wichansky

U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

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16. Abstract A three-part field study of passenger activities (e.g. reading, writing, talking, sleeping) was conducted on intercity Amtrak trains in the northeastern United States to determine the relationships between the ride environment, subjective passenger comfort and satisfaction, and overt passenger behavior. From observations of 7000 revenue passengers over a one-year period, a stable relative frequency distribution of 12 categories of passenger activity in three effort classes was established. Reading and Viewing were observed most often; Handcrafts and Games were seldom observed. An Amtrak survey of ride quality and activity preferences was also conducted using over 800 revenue Northeast Corridor passengers. Although passengers rated the ride as comfortable, ride motions were perceived to interfere with performance of visual/motor tasks (e.g., Reading and Writing). Passengers' preferences for activities were also found to increase with trip distance. In order to quantify ride quality/activity relationships, observations of passenger activity were made simultaneously with measurements of vibration in six degrees of freedom, acoustic noise, temperature, relative humidity, and illumination aboard 77 Amtrak vehicles. Correlational analysis revealed that rotational (rather than linear) motions were associated with low frequencies of motor and conversational activity and high levels of rest behavior. 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 account for 20% of the variance in the relative frequencies of various types of activities.

17. Key Words Ride Quality, Passenger Activities, Passenger Acceptance, Angular Vibration, Noise, Effective Temperature, Northeast Corridor, Multiple Regression Models

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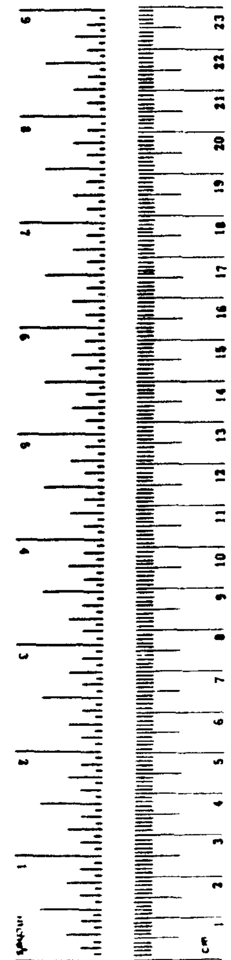
METRIC CONVERSION FACTORS

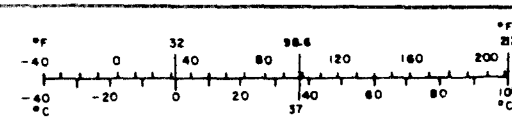
Approximate Conversions to Metric Measures

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



PREFACE

The ability to perform activities while traveling on long and intermediate distance trips may be an important factor in the passenger's acceptance of and satisfaction with a mode or particular system of transportation. Activities such as reading, writing, eating, drinking, and sleeping relieve boredom during travel and may be required behaviors for passengers wishing to conduct business during their trips. The present research effort was conducted to determine which activities passengers wish to do while in transit, and how the ride environment, which includes such factors as vibration, noise, temperature, humidity, illumination, and crowding, facilitates or inhibits passengers' performance of these behaviors.

The success of this series of passenger activity studies may be attributed to the effort and hard work of a number of people. Most special thanks go to E. Donald Sussman (DTS-532), Technical Monitor of the Behavioral Aspects of Transportation Systems Design Project (RS904 R9502), for his expert technical guidance and support. I also wish to thank Robert J. Ravera (DBP-50), past sponsor of the Transportation Advanced Research Project (TARP) of the Office of the Secretary, for his encouragement and guidance in the course of the work; Brooks Bartholow (DPB-25), the present sponsor of the Behavioral Design Project, for his programmatic support of this study; and Harold P. Bishop (DTS-

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The contributions of Anthony J. Healey, Joseph Priest, and Malcolm Dukler of Anthony J. Healey Associates, Austin, TX, in assisting in the measurement, recording, reduction, and analysis of the ride motion data used in this study are most gratefully acknowledged. Many thanks also go to Thomas Hayes (DTS-743), who was a most valuable member of the test team participating in this work.

Finally, this research could not have been conducted without the cooperation of Amtrak, the National Railroad Passenger Corporation. Special thanks go to Ross A. Higginbotham, Manager of Car Planning and Engineering, J. J. Schmidt, Vice President of Operations, and their train crews and trainmasters for their help and cooperation in facilitating the data collection efforts. I would also like to extend my appreciation to Leon Jackson, Manager of Quantitative Market Analysis, and to Alfred A. Michaud, Vice President of Marketing, for arranging the logistics of our test schedule and for the printing and dissemination of the passenger activity/ride quality questionnaire.

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1. INTRODUCTION

A common goal of federal transportation authorities and others involved in the implementation of advanced transportation systems is the development of a methodology for the design of cost-effective transportation systems which will provide an acceptable level of public satisfaction and utility. Passenger comfort and satisfaction with the ride environment have long been acknowledged in the field of transportation systems design to be important factors in determining the over-all acceptability and utility of such systems to the public (Solomon, Solomon, and Silien, 1968). In particular, passengers' comfort ratings of a system's ride environment have been found to be the factor most highly correlated with their willingness to ride again, which may be considered as an index of passenger satisfaction (Richards and Jacobson, 1975; Jacobson and Richards, 1976).

Cost analyses of recently implemented advanced transportation concepts, such as the San Francisco Bay Area Rapid Transit (BART) System and the Morgantown, West Virginia High Performance Personal Rapid Transit (HPPRT) System, have demonstrated the excessive costs involved in providing a high quality ride environment. These costs are largely attributable to the design and construction of the guideway. Since guideway design characteristics have been shown to play a dominant role in determining the ultimate ride quality of the system, significant efforts have been made by the U.S. Department of Transportation's

Transportation Advanced Research Project to develop cost/ride quality trade-off methodologies, which provide guidance for minimizing the expense of guideway design and construction while maximizing the resultant ride quality (Wormley, Hedrick, Eglitis, and Costanza, 1977).

The ride quality/cost trade-off problem may also be addressed from a complementary point of view; i.e., the question may be asked as to how smooth the ride must be to be acceptable to the passenger. Thus, the costs of providing technology to insure an adequate level of ride quality may ultimately be reduced through an accurate determination of the passenger response to various types of ride environments. Once the minimum level of ride quality which is judged as acceptable by the user population is determined, costs may then be held down by designing to meet the minimum acceptable level. Any expenditure to provide a more comfortable environment would not be cost-effective, since passenger satisfaction and ridership would not increase in proportion to any additional increment in ride quality.

In order to determine the minimum level of ride quality for passenger acceptance, a significant effort sponsored by the Transportation Advanced Research Program has been undertaken to define quantitative relationships between subjective passenger comfort responses and various aspects of the ride environment which contribute to ride quality in various modes of transportation. This effort has resulted in the development of mode-specific mathematical models of ride quality, incorporating such factors as vibration and noise to predict passenger comfort on intercity trains, city buses, and airplanes (Pepler, Vallerie, Jacobson, Barber, and Richards, 1978). These models allow the designers of advanced systems to trade off a number of physical ride quality variables and still have confidence that the resulting design will satisfy the ride quality requirements of whatever proportion of passengers they choose. This work is currently being extended to several other transportation modes, including luxury charter buses, hovercraft marine systems, high speed intercity trains, and rapid rail transit systems.

The linear models of passenger comfort are undoubtedly a giant step in the quantification of the psychophysical relationships between human response and the physical ride environment. These models, however useful they may be to the designers of advanced transportation systems technology, are limited in the sense that the dependent variable used to operationally define passenger satisfaction is based upon the subjective comfort rating of the passenger. Specifically, the models were developed from the correlations between the measured levels of the physical ride environment and subjects' comfort ratings on a seven-point scale.

The administration of subjective comfort scales to passengers in field experiments such as those conducted by Pepler, et al., (1978) to develop ride quality/comfort models is an extension of a traditional psychophysical methodology, adapted from earlier experiments on human response to whole-body vibration conducted in laboratory environments on shake tables and other, more sophisticated types of motion simulators. This type of methodology requires the previous consent and knowledge of the subject, who is required to behave as a "human accelerometer" and rate the ride. Subjects in such experiments are frequently self-selected, or come from specific groups recruited en masse by the experimenter to take a "free ride" if they are willing to participate in the experiment. Subjects may therefore arrive at the scene of the experiment with various preconceived notions of what the experimenter wants them to do, a classic example of subject bias. Furthermore, it is often the case that subjective opinions do not necessarily reflect actual behavior; thus, even if public opinion of a system is favorable, the public may not actually ride the system consistently, as in the case of BART in San Francisco (Lindsey, 1975). Therefore, it is important to investigate other behavioral correlatives of the physical parameters of ride quality besides the subjective comfort ratings, to obtain a more complete knowledge of human response to transportation ride environments.

Passenger activity has received some recognition in the ride quality literature as a human response pattern which might depend upon or be in some way related to comfort. The ability to perform these voluntary behaviors, including reading, writing, eating, drinking, and looking out the window, undoubtedly contributes to passengers' feelings of satisfaction and well-being during their trip. It has been suggested by Stone (1972) that activity factors are among the most probable human factors elements associated with ride quality, and hence, comfort. Allen (1975) 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 (International Organization for Standardization, 1974), 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).

Thus, it is generally agreed upon by the experts in the field of ride quality that passenger activities may play an important role in determining passenger comfort. Traditionally, however, passenger comfort has been related to subjective measures of human response to vibration or ride environments, while task performance, or activity, has been related to operator efficiency. The relationship between activity or task performance and the physical ride environment has not been sufficiently explored in either laboratory or field studies of ride quality to provide insights into its role in passenger satisfaction.

The following sections of this introduction will be devoted to a critical summary of past research on human response to whole-body vibration and other environmental variables, as these studies relate to passenger comfort and task performance in transportation situations. The few studies which have specifically addressed the issue of passenger activities will then be reviewed, and a systematic approach to the study of these behaviors in actual transportation systems will be outlined.

1.1 Assessment of Comfort in Vibration Environments

Extensive research has been conducted in both laboratory and field settings to determine human subjective response to whole-body vibration environments. A number of thorough literature reviews of this research (e.g., Shoenberger, 1972; Oborne, 1976; McCullough and Clarke, 1974; and Allen, 1971) have also been recently published in the psychological and human factors literature. This is fortunate, since many of the original studies of human response to whole-body vibration were published in the form of technical reports for private industries, which are not readily available to the general reader. The present discussion will deal with the major findings of this body of research and the more serious criticisms which have been levelled against many of these studies.

1.1.1 Laboratory Experiments on Human Response to Whole-Body Vibration. In general, there is little agreement between researchers in the field of vibration research regarding the levels of whole-body vibration which reliably elicit particular types of human subjective response (Allen, 1971; Shoenberger, 1972; Oborne, 1976). A number of early research efforts attempted to discover the amplitudes of vibration corresponding to the thresholds of perception, annoyance, discomfort, intolerability, and a number of other subjective responses. The scaling of such responses generally involved diverse semantic labels as descriptors of sensation, which often did not uniformly relate to a distinct psychological dimension. Furthermore, for any given semantic label, there were differences in the results of various studies in both the absolute level or amplitude of vibration related to that label, and in the shape of the response curve as a function of vibration frequency (Oborne, 1976). These differences may be attributed to variations in experimental design (Shoenberger, 1972).

Other experimenters took a more basic psychophysical approach to the problem of quantifying human response to vibration. These researchers were interested in identifying equal sensation or equal comfort relationships over various frequencies and intensities of vibration, to generate families of curves, power functions, and other quantitative descriptions of human response. Some of these studies were associated with particular subjective responses (e.g., the threshold curves of Miwa (1967) and the Dempsey and Leatherwood (1975) Discomfort Curves); others (e.g., Shoenberger and Harris, 1971) dealt simply with the scaling of equal sensations.

In general, the results of these experiments conflict regarding the frequency range of maximum sensitivity to vertical vibration. Some studies show maximum sensitivity between 6-15 Hz, with a slow decrease in sensitivity above and below these frequencies, while others show the maximum response between 4-6 Hz, with a rapid decrease in sensitivity beyond this range (Oborne, 1976). Most studies, however, show that human sensitivity is greatest to vibration between 1-20 Hz (Hornick and Lefritz, 1966), in the range of the major body resonances. The slopes of power functions developed to describe sensations resulting from whole-body vibration vary somewhat with the frequency of the stimulus (Shoenberger and Harris, 1971) but hover about a value of 1, reducing the psychophysical relationship between vibration and sensation to a simple logarithmic function.

The laboratory studies of human response to whole-body vibration using the psychophysical methods have been thoroughly analyzed and criticized for their contradictory results and methodological problems. In general, small numbers of subjects were used, sometimes repeatedly, as in the case of Miwa (1967, as described by Shoenberger, 1972). Sequence and order effects were often ignored, and vibration frequency and intensity levels confounded in naive experimental designs (Shoenberger, 1972). Motion parameters were often not fully specified or were specified in widely varying units. Finally, few experiments of the psychophysical type controlled or even made note of the amount of time subjects were exposed to vibration stimuli (Oborne, 1976), although exposure duration was widely acknowledged to be an important factor in subjective response to vibration (von Gierke, 1975).

In terms of the actual stimuli, almost all experiments used simple vertical sinusoidal vibration. Lateral vibration, which is a major motion component in ground transportation systems, and longitudinal motions have received little attention (Shoenberger, 1972). Similarly, random waveforms, which usually occur in transportation vehicle rides, were rarely used in these studies, although it has been argued that some of the results may be generalizable to situations of random motion (Shoenberger, 1972). Most important, the amplitudes or intensities of vibration used in the vast majority of these studies exceed, often by a factor of 10 or more, the levels of motion commonly encountered in modern ground transportation vehicles. The vibration amplitudes used in these studies may have been chosen on the basis of previous research, convenience, or limitations in the motions which the available equipment could produce. However, the fact that these motion stimuli used in the laboratory are so unlike those in actual vehicles severely limits the applicability of the results of these experiments to the specification of ride quality in actual transportation systems.

1.1.2 Field Studies of Comfort in Transportation Vehicles. Field studies of vibration in moving vehicles have also been undertaken by a number of researchers. Oborne (1976) has provided a review of some of the earlier studies (1930's-1960's) conducted in aircraft and automobiles which are not readily available in the literature. In general, although few experimental details were provided in the technical reports, the results of these studies are remarkably consistent in terms of the amplitudes and frequencies of vibration which were judged to have similar subjective effects. The results of these studies show that vibration levels exceeding about 0.1 g (.071 rms g) at frequencies up to 20 Hz are considered uncomfortable, rough, and unsatisfactory, while vibration levels lower than this value are considered comfortable, smooth, and satisfactory (Oborne, 1976). High positive correlations were also consistently found between measured vibration inputs from automobiles and subjective responses using cross-modality matching techniques and comfort rating scales.

More recent field studies conducted by the University of Virginia and Dunlap and Associates for the Transportation Advanced Research Project have extended the use of correlation analyses to develop a more sophisticated metric for evaluating ride quality in various modes of transportation. In a series of studies which began using Short Take-Off and Landing (STOL) aircraft flights, an attempt was made to determine, through the use of surveys administered to actual passengers and paid subjects on the ground and in the air, what factors were important in airline passenger comfort and satisfaction (Jacobson and Martinez, 1974). It was subsequently found that subjective ratings of comfort on a seven-point bipolar scale provided a stable measure of the subjective concept of comfort over the flying population. The ratings were not greatly influenced by individual differences such as age, sex, trip purpose, occupation, income level, or flight history. Furthermore, these comfort ratings were highly correlated with passengers' willingness to fly again, which was considered to be an index of passenger satisfaction (Richards and Jacobson, 1975).

Using standard least-squares techniques, linear and non-linear equations were developed for use as mathematical models to predict passenger comfort, based on the comfort responses of paid subjects who rated a number of different aircraft rides and physical measures of vibration made simultaneously (Jacobson and Richards, 1976). In general, it was found that vertical and transverse motions were the most important predictors of subject comfort. Further study of passenger comfort using a revised questionnaire on four types of short-haul aircraft revealed seat factors, noise, temperature, and motion to be the primary determinants of comfort as perceived by passengers (Richards and Jacobson, 1977). Rudrapatna (1977) later developed linear models of aircraft passenger comfort which included noise in addition to motion factors, significantly improving the predictability of subjects' comfort responses.

These modeling efforts were extended to intercity trains and city buses by Pepler, et al. (1978), using subjects selected to represent a cross-section of the population in terms of age, sex, and trip experience. In the initial phase of the bus study, the route was carefully selected to contain a representative cross-section of road surfaces, curvature, and terrain type. Subjects rated several 1 min ride segments on buses with both good and poor suspensions. Duration of vibration exposure and sequence effects were controlled in the experimental design. Motions in six degrees of freedom, temperature, speed, and noise were measured simultaneously during each test segment.

Multiple regression procedures were used to correlate subject responses with the physical variables. The comfort equation for straight and level roadways was:

$$C = .87 + 1.05\omega_R \qquad R = .76 \ (p<.001) \qquad (1)$$
$$\sigma = (.32) \quad (.13)$$

where C = mean comfort rating, ω_R = roll (X-axis rotational) rate (°/sec), and σ = standard error of the coefficient. This equation clearly indicates that roll rate was the most important factor in predicting comfort levels on the bus, accounting for 58% of the variance ($R^2 = .58$) in subjects' comfort ratings. Separate models were also developed for comfort on curved roadways.

A validation study was also conducted with revenue passengers who were allowed to ride for free on a reserved bus of the same type used in the initial study. The correlation between the actual responses of passengers in the validation study and "predicted responses", which were computed using the above comfort equation and the roll rates measured in the validation study, was .69 ($p<.00002$), which indicated significant agreement between the preliminary model and the validation data.

Similar studies were conducted using paid subjects and revenue passengers on Amtrak intercity trains. Two matched groups of subjects were used in the initial phase of this study to rate the comfort of a number of 1 min ride segments in four different passenger coaches varying in suspension characteristics between Stamford and New London, Connecticut. Since a fixed route was used, it was not possible to control track type to any great extent, although the authors maintain that the route contained "a good cross-section of track characteristics" (Pepler, et al., 1978, Vol. II, p.7). Subject selection and environmental measurement techniques were similar to those used in the bus studies.

Roll rate and noise were shown to be the dominant factors influencing ride comfort on trains, according to the following equation:

$$C = .73 + .10\ (\text{dB.A}-60) + .96\omega_R \qquad R = .71\ (p<.001) \qquad (2)$$
$$\sigma = (.96)\ (.01) \qquad\qquad (.21)$$

where dB.A = noise and ω_R = roll rate. Comparison of the roll coefficients in the bus and train equations revealed a statistically non-significant difference between these values, suggesting that an individual's response to roll was the same regardless of the vehicle in which the motion was experienced.

A number of difficulties were experienced in conducting the train validation study on revenue Amtrak passengers. Thus, reliable data from only a small number of test segments were available, and the noise range in these samples was severely restricted. The authors reported that the correlation between the actual ratings of passengers in the validation study and the "predicted responses" (computed from the above comfort model using the roll and noise measurements made in the validation study) is .44 ($p<.06$). Thus, it could be argued that the original model predicts only about 20% of the variance in the validation passenger ratings. However, this conclusion is questionable on the basis of so few data.

Equations were also generated for various subgroups of subjects, according to age, sex, and trip experience. Comparison of the roll coefficients on the train and bus comfort equations revealed that infrequent riders were more sensitive to roll motion than frequent riders. Similarly, the equations for older riders and female subjects had larger roll coefficients than the equations for younger subjects and male subjects. On the trains where noise was an important determinant of subjects' comfort ratings, males seemed to be more sensitive than females and subjects aged 25-48 seemed to be less sensitive than younger or older subjects to the effects of roll rate amplitude. The noise coefficients for frequent and infrequent riders were approximately equal.

The approach and methodology used by these researchers resulted in the development of a potentially useful metric for the assessment of ride quality in actual transportation situations. Instead of developing an abstract curve of comfort or sensation based upon a limited number of stimuli at only a few frequencies and intensities of vibration, the modeling method allows for the subjective assessment of the entire range of motions produced by operational vehicles. A second advantage of this approach is that it allows for the inclusion of a number of environmental variables into the equation which predicts comfort.

Thus, the concept of ride quality is not restricted to mere descriptions of the motion environments of various vehicles, but could theoretically include any variables which could be quantified or categorized for the purposes of multiple regression. Third, the models generated allow for the specification and evaluation of ride variables in a relative rather than an absolute sense, since this type of compensatory modeling approach allows different ride quality factors to be traded off within certain limits to produce a similar level of subjective comfort. Finally, the end-product of this process is a linear equation which is relatively simple to comprehend and apply in a variety of situations.

Methodologically speaking, the field experiments conducted in this research effort were carefully designed, controlled, and reported. The stimuli used were valid representations of those commonly encountered in transportation situations, in terms of their intensity and frequency ranges. Exposure time of the subjects to vibration, sequence effects, individual differences, and a number of other aspects of experimental design were controlled in the present research. Furthermore, the efforts to validate the comfort models add credibility to the results for their application to solving real-world design problems, especially in light of the extreme inconsistencies which have been found in the results of previous laboratory studies in this field.

Of course, these studies are not completely free of conceptual and methodological problems. First, unlike some of the earlier studies of ride quality which asked subjects to describe vibration in terms of semantic labels such as "perceptible" or "intolerable", the use of the term "comfort" is more elusive. "Comfort" undoubtedly means different things to different people, and may even mean something different to the same person depending upon the situation. In field studies, it is difficult to give subjects physical stimuli which may serve as anchor points for their scaling judgments, as might be done in a laboratory situation. It might be argued that since the comfort ratings measured in this series of experiments were highly correlated with passenger satisfaction in terms of willingness to ride again, whatever feelings about the ride the subjects were expressing in terms of their comfort ratings is really a moot point. However, this relationship between the subjective ratings of comfort and satisfaction was formally demonstrated only in airline passengers (Jacobson and Richards, 1976); it was merely <u>assumed</u> to be valid for passengers on other modes of transportation as well by Pepler, et al. (1978, Vol. II, p.67). Also, subjective assessments of comfort were correlated with subjective assessments of willingness to ride again (Richards and Jacobson, 1975), not actual frequency of repeated airline flights.

Because of the controlled experimental design used in these studies, it was difficult to arrange for naive revenue passengers to act as subjects. Thus, in general, either experienced paid subjects were recruited in advance, or groups of passengers traveling together from some organization (e.g., football club) were solicited and allowed to ride for free as an incentive for participation. These subjects and passengers either rode specifically for the purpose of testing or were isolated from other, non-participating passengers in special vehicles set aside for the tests. This arrangement was necessary in order to administer the experimental procedures, which often took 1 hr or more.

The fact that the subjects were previously experienced in ride quality testing and the passengers usually had knowledge of the purpose of the experiment well in advance leads to speculation about the motivations and expectations of the people rating the ride comfort. Jacobson and Richards (1976) admit that their aircraft subjects were not as fearful or anxious as many revenue airline passengers. Also, the test subjects undoubtedly had a broader range of ride experiences than revenue passengers, which they could use as a baseline to assess the ride quality of the test segments. Revenue passengers receiving a free ride for their efforts may be more positively disposed to the ride environment, especially if they do not travel (and pay) regularly on a mode. Further, it is difficult to break through the social atmosphere of a large group of people on a pleasure trip, in order to get unbiased individual comfort ratings rather than a group consensus of ride quality.

The above criticisms of this body of research are relatively minor compared to those which have been made of the vast majority of studies in this field, and are not meant to detract from the originality of approach or the usefulness of the results. Rather, they simply point out the difficulty of conducting controlled field experiments using subjective measures as the dependent variable.

1.1.3 Standards for Comfort in Vibration Environments. At the present time, the most widely used and only internationally recognized standard for human exposure to whole-body vibration is the ISO Document 2631, "Guide for the Evaluation of Human Exposure to Whole Body Vibration" (International Organization for Standardization, 1974). This guideline, which required 10 years of work in preparation by the members of the ISO Subcommittee on Human Exposure to Mechanical Vibration and Shock, incorporates the findings of nearly 20 different research groups around the world. It has been accepted by 20 member nations of the International Organization for Standardization.[1] The objective of ISO 2631 is to provide the system designer or system evaluator

[1] Much of the following material describing the ISO guideline has been excerpted directly from Sussman, E.D. and Jankovich, J. "ISO Vibration Guidelines and the Transit Environment", presented at the American Society of Mechanical Engineers (ASME) Session on Mechanical Shock and Vibration, Chicago, Ill., Sept., 1977, with the permission of the senior author.

with provisional guidelines on acceptable levels of vibrations to which humans may be exposed. Acceptability is defined in terms of safety, work efficiency, and comfort. Applicability of the standard is limited to linear vibration transmitted to the body as a whole through a supporting surface when in the standing or seated positions.

The recommended limits on vibration vary according to four physical parameters of human vibration exposures:

1) Direction: The document uses a coordinate system which is fixed with respect to the human body rather than based on external references. Therefore, vibration along the X, Y, and Z axes must be evaluated relative to the passenger's position rather than the vehicle's axes.

2) Frequency: The range of application is limited to those frequencies which have primarily mechanical effects on the human body. Therefore, the basic frequency range covered in the document extends from 1.0 through 80.0 Hz.

Human response to vibration is assumed to vary with frequency of stimulation. In turn, the most sensitive frequencies are assumed to vary depending upon the axis, or direction, of vibration. Thus, two shapes of sensitivity curves are presented in the guideline. The curve for response to transverse (X- and Y-axis) vibration is lowest (most stringent) in the 1-2 Hz frequency range. The curve for response to Z-axis vibration (usually labeled "vertical" but here called "longitudinal") is lowest in the 4-8 Hz range.

3) Intensity: The document describes three conditions under which differing intensities of vibration are acceptable:

a. The exposure limit. This is the highest intensity of vibration to which humans may be safely exposed.

b. The fatigue-decreased proficiency boundary. This indicates the range of vibration amplitude which can be expected to result in a decrease in work performance, depending upon duration of exposure.

c. The reduced comfort boundary. This boundary was "derived from various studies conducted for the transport industries" (ISO 2631, 1974, p.4) with the intention of defining minimum specifications for human comfort. Activities such as reading, writing, and eating are considered to be possible at the vibration levels encompassed by this boundary.

It is assumed that human sensitivity to vibration of different frequencies varies in the same manner over a wide range of vibration intensities. Frequency dependent curves of the same shape as described previously are drawn for the three intensity boundaries, simply by transposing the same curves up or down a vertical axis of vibration amplitude. Thus, the values of the three boundaries can be computed from one another. The reduced comfort boundary is derived by reducing the fatigue-decreased proficiency boundary by 10 dB or dividing by a factor of 3.15, while the exposure limit is computed by increasing the fatigue-decreased proficiency boundary by 6 dB or multiplying by a factor of 2.

4) Duration: Duration is defined as the length of time the human body is exposed to vibration. Tolerance for the vibration environment, whether defined in terms of safety, task efficiency, or comfort, is assumed to decrease as a function of time. Thus, human response curves are drawn for various time durations of exposure. Exposure time, however, is considered in terms of a daily "dose"; therefore, for a commuter who makes two daily 30-min trips, the curves corresponding to a 1-hr duration of exposure would be appropriate.

Document 2631 also provides recommendations for measuring vibration and for applying the guidelines to real world situations involving human exposure to whole-body vibration.

The ISO guideline has been criticized on a number of counts (Allen, 1971; 1975):

1) Inadequate population cover - The studies used as the basis for formulating the ISO guideline were generally laboratory experiments conducted with young men as subjects. It is unclear whether the ISO curves can be generalized to other segments of the population, such as children, the elderly, or pregnant women. Tolerances in the laboratory may also be greater than in real life situations.

2) No guidelines for rotational vibration - The ISO guideline is applicable only to situations involving linear vibration. At the present time, however, there is very little data on human response to rotational motions, except for some work on thresholds of perceptions by Clark (1967), which might be applied in safety, work efficiency, or comfort guidelines.

3) Crest factors greater than 3 not covered - The term "crest factor" may be defined as the ratio of the power of peak vibration to the rms (mean) level of vibration, and is used to describe situations with particularly outstanding bumps or jolts which are salient above an average "baseline" level of vibration. A current proposal to extend the crest factor level to 6 is being evaluated for inclusion as an amendment to the present guideline.

4) Shapes of curves assume single-order biomechanical response to vibration - The shapes of the ISO curves imply that human response to whole-body vibration largely depends upon only one major resonance frequency range in each axis of vibration (4-8 Hz in the Z-axis, 1-2 Hz in the X- and Y- axes). Allen (1975) contends that the resonance frequencies of several important body subsystems (e.g., the eyes) are above these limits and may modify the ISO curves in the higher frequency ranges.

5) Evaluation methods inadequate for multi-axis vibration - If vibrations occur in several axes simultaneously the current standard recommends evaluation of the motion in each axis separately. The fact that interactions could occur between the motions in different axes, however, has prompted the development of an ISO summation formula (Griffin, 1977) which has been proposed in an amendment to ISO 2631 as the preferred method of evaluation for broadband vibrations such as those encountered in transportation vehicles. The amendment provides the following multi-axis formula which sums the ISO-weighted linear accelerations to achieve an effective level of acceleration as follows:

$$a_{effective} = \sqrt{(1.4a_x)^2 + (1.4a_y)^2 + a_z^2} \quad (3)$$

The effective level may then be compared with the recommended values for _Z-axis vibration_ given in Table 1 and Figure 2 of the Document 2631. Using this formula requires the weighting of the vibration by means of the electronic weighting network described in the guide, or measurement of the vibration in each of the 1/3 octave bands for all three degrees of freedom and the subsequent weighting of each 1/3 frequency octave band as per the guide.

6) _Assumption of time dependence_ - Although the assumption that vibration tolerance decreases as a function of time makes intuitive sense, and in fact the compilation of data in 1964 showed this to be the case for physiological and subjective tolerance, work efficiency, and subjective fatigue (von Gierke, 1975), there is an increasing body of evidence to contradict this assumption. Closer analysis of the original studies used in the development of the ISO standard indicate a number of methodological problems and test conditions inappropriate for application to vibration situations normally encountered in every day life (Clarke, 1976; Allen, 1975).

Current research in the field of ride quality in actual transportation situations which has addressed the issue of time dependence shows no significant difference in the subjective comfort responses of passengers exposed to vibration environments for durations of up to 4 hr (Clarke, 1976; Pepler, et al., 1978). Passenger activities, self-initiated movements, individual differences, and intensity of motion levels may influence the time dependence of comfort reactions in actual transportation situations (Pepler, et al., 1978).

Other criticisms of the ISO guideline may also be made in terms of its application to ride quality assessment and design problems. First, the guideline is quite difficult to understand and use. Second, most vehicle rides contain important vibration components at a number of frequencies. The separate evaluation of these components, as recommended in the ISO guideline, assumes no interactions between vibration effects at different frequencies. However, recent studies by Leatherwood, Dempey, and Clevenson (1978) show that significant masking of one frequency of lateral roll vibration by power at other frequencies can result in a diminution of the subjective discomfort response in a multifrequency vibration environment. Non-additive effects of multifrequency vertical motion have also been observed. Thus, separate application of the ISO criteria to various frequencies may result in an overestimation or underestimation of the acceptability of a complex vibration environment.

Finally, although the guideline mentions activities such as "eating, reading, and writing" in its characterization of the reduced comfort boundary, the vibration limits which are outlined in Document 2631 are not based upon any systematic studies of passenger behavior or activity performance in transportation situations. Rather, most of the studies referenced in this standard relate to operator performance in laboratory vibration environments or in vehicles such as forklift trucks or diesel pile drivers (as in the Miwa studies described by Clarke, 1976), which provide much higher intensities of vibration than those normally experienced in passenger vehicles. This criticism, however, also applies in general to the majority of studies of human performance in vibration environments, which are reviewed in the following section of this report.

1.2 Assessment of Human Performance in Vibration Environments

There is also a significant amount of research on the effects of vibration on human performance. The majority of these studies were laboratory experiments conducted under highly controlled conditions with single axis sinusoidal vibration stimuli at particular frequencies and amplitudes. Small numbers of subjects, usually young male military personnel or students screened for health problems, were used in these experiments. In general, the tasks which subjects performed were those commonly used in experimental psychology laboratory studies involving psychophysical judgments and simple psychomotor skills. These tasks relate more to operator efficiency in a vibration environment than to passenger activity in transportation vehicles. The intensities of vibration used in most of these studies were generally greater than those which would be commonly experienced by revenue passengers, although military pilots and other vehicle operators might be exposed to motions of this type.

Because there has been so much research in this area, and because vibration studies are generally quite expensive to conduct, there are also a number of literature reviews documenting the performance effects of vibration (e.g., Grether, 1971; Shoenberger, 1972; Collins, 1973). These reviews are quite thorough and readily available in the psychological and human factors literature. The goal of the present discussion is therefore to summarize their major conclusions regarding human performance and vibration, and to interpret the major experimental results included in these reviews and other, more recently published material in terms of their implications for the performance of passenger activities in actual transportation situations.

The performance abilities which have been studied under vibration conditions include visual acuity, tracking, perceptual motor functions, vigilance and pattern recognition, and higher cognitive abilities. In general, vibration has consistently been shown to interfere with performance of the first three types of tasks, due to peripheral mechanical effects on vision and motor skills. The latter tasks, which depend more upon higher levels of central nervous system function, seem relatively impervious to the effects of vibration.

1.2.1 <u>Visual</u> <u>Acuity</u>. Most studies of visual acuity and vibration have been conducted in the context of performance. Significant decrements in number-reading and dial-reading performance have been shown over a wide range of vibration conditions, whether the target or the subject is vibrated (Grether, 1971; Shoenberger, 1972). Although it had previously been supposed that acuity decrements depended largely upon the relative displacement between the target and the eyeball resulting from the amplitude of vibration, acuity has also been shown to be affected by an interaction between the frequency of vibration and the distance between the subject and the target (Ohlbaum, O'Briant, and Van Patten, 1971). Thus, there is poor agreement as to the frequency of vertical vibration which produces the worst visual acuity, although there may be significant decrements above 2 Hz (where reflex compensatory tracking movements break down at near reading distances), at 14 Hz (a major resonance frequency of the head), and between 20-30 Hz (the resonance range for the eyeballs and supporting structures) (Shoenberger, 1972).

Visual acuity in the vibration environment may play an important role in passenger activities such as reading, writing, and looking out the window. However, much of the visual acuity work has been done using intensities of vibration which are well above the average vibration intensities recorded in passenger vehicles. For example, Pepler, et al. (1978) computed the means of vertical vibration to be .082 $\pm$ .027 rms g for buses, .03 $\pm$

.007 for trains, and .044 ± .031 for commercial airplanes. Ohlbaum, et al., (1971) used a vibration stimulus equivalent to .53 rms g, which is several times as large as that normally experienced in passenger vehicles.

In contrast, Griffin (1975, 1976) used a psychophysical approach to determine the minimum levels of Z-axis vibration which would produce blurring of visual images consisting of point sources of light. Subjects were told to adjust their postures to maximize or minimize vibration levels causing blurring. Mean vibration intensities of approximately .076 rms g measured at the seat were found to cause blurring at 7 Hz, the most sensitive frequency. Individual differences between subjects were extremely large, however (Griffin, 1975). No significant differences were found in vibration amplitudes producing blur for targets at 4 or 20 ft for vibration at 7, 15, 30, and 60 Hz (Griffin, 1976).

Thus, it may be concluded from these results that significant decrements in visual acuity may occur at vibration levels comparable to those experienced by passengers on transportation systems, especially if there is a power peak in the 7 Hz range. However, there are great individual differences in the susceptibility of visual acuity to the effects of vibration. Subjects' posture, the use of restraints, and the size of the visual image may all serve to counteract the detrimental effects of vibration (Grether, 1971). Little work has been done on the effects of X- or Y- axis vibration or multiaxis vibration on visual acuity (Collins, 1973), which may also influence passengers' abilities to perform activities in moving vehicles.

In experimental situations involving vibration (.2 rms g) presented singly and in combination with high levels of noise (105 dB) and heat (120° F), significant decrements in visual acuity have also been found compared to control conditions. However, the combined stress conditions did not degrade performance more than when subjects were exposed to vibration alone, which shows the dominant effects of vibration on performance even in multiple stress environments (Grether, Harris, Mohr, Nixon, Ohlbaum, Sommer, Thaler, and Veghte, 1971; Grether, Harris, Ohlbaum, Sampson, and Guignard, 1972).

1.2.2 Tracking. A large number of studies of tracking performance have been conducted in vibration environments, since tracking skills are necessary for the operation of many aircraft and ground system vehicles. Tracking tasks require a combination of visual and motor skills; with sufficient practice, overlearning of the task results in a high level of performance requiring minimal cognitive effort.

In general, vibration has been shown to have a significant detrimental effect upon tracking performance, which is proportional to the intensity of the stimulus. The greatest decrements in performance have been found at 5 Hz for vertical vibration and from 1-3 Hz for X- and Y-axis vibration, which correspond to the major body resonance frequencies in these axes (Shoenberger, 1972). These relationships appear to hold regardless of whether vibration is sinusoidal or random. Tracking decrements are the greatest when tracking must be performed in the same direction as the axis of vibration (Grether, 1971); thus, horizontal tracking is worst under Y-axis vibration, and vertical tracking is worst under Z-axis vibration.

Vertical and horizontal tracking performance on a two-dimensional compensatory task was degraded more under vibration conditions alone than under any other single environmental stress or control condition (Grether, et al., 1971). It was also found that tracking performance under vibration conditions alone was not significantly different from performance under a triple stress condition including high levels of noise and heat in addition to vibration. Grether, et al. (1972) discovered an antagonistic interaction between the three stressors, such that tracking errors decreased with every additional environmental stress added to vibration. These results were attributed to increased effort on the part of the subjects as additional stress variables were added.

In other studies, high levels of noise were found to interact subtractively with low levels of vibration to improve tracking performance over low noise-low vibration conditions. Sommer and Harris (1973) found that 60 dB noise combined with .07 rms g vibration resulted in poorer tracking performance than 100 dB noise with the same level of vibration. The authors suggest that the high level of noise may distract subjects from the degrading effects of vibration by inhibiting perception of inputs from sensory modalities other than audition. Noise at 110 dB, however, was found to interact additively with vibration, to degrade tracking performance more than the 60 dB noise-vibration condition (Harris and Sommer, 1973).

As in the studies of visual acuity, the intensities of vibration used in these tracking experiments were generally above the levels to which passengers would be exposed in transportation vehicles. The lowest intensities of vertical vibration presented in these studies were: (1) .12 rms g (Holland, 1967; Gray, Wilkinson, Maslen, and Rowland, 1976), which was found to produce tracking performance decrements compared to control conditions, and (2) .07 rms g in the Sommer and Harris (1973) and Harris and Sommer (1973) studies, which provided no zero level of vibration control condition, and therefore cannot be assessed for performance decrements due to vibration alone. Although the levels of vibration used in many of these studies may be applicable to various operator tasks, it is difficult to generalize the results of such laboratory experiments to passenger activities which may involve tracking-type abilities, such as reading or looking out the window.

There is significant evidence that tracking performance is not degraded as a function of time spent in the vibration environment. Tracking errors did not increase significantly over a 6 hr experimental period when subjects were exposed to 5 Hz, .12 rms g vibration (Holland, 1967), which is equivalent to the ISO 1 hr fatigue-decreased proficiency limit. Gray, et al. (1976) found similar results over a 3 hr vibration period using the same motion stimulus; performance was actually found to improve over time due to learning effects, and this improvement was greater in the vibration than in the control condition. In their determination of optimal work-rest schedules for periods of prolonged vibration, Dudek, Ayoub, and El-Nawawi (1973) found that boredom was actually reduced by the vibration stimulus, and that a 60 min work/60 min rest schedule was associated with better tracking performance than a 30 min work/30 min rest schedule under vibration conditions.

1.2.3 Perceptual Motor Skills. Several experiments involving human performance under vibration conditions have used tasks involving simple and choice reaction times, fine manual control, and precise muscular coordination. While most of these studies were conducted in the context of operator performance, many of the skills tested may relate to passenger activities such as handcrafts, writing, drawing, and playing games.

Most studies of hand and foot simple reaction times and choice reaction times show no decrement under vibration conditions regardless of the axis of motion (Shoenberger, 1972; Grether, 1971). Studies of choice reaction times under conditions of combined vibration, noise, and temperature stress showed increases in response times in the vibration alone vs. combined stress conditions or control condition (Grether, et al., 1971, 1972); however, these studies used levels of vibration exceeding that usually experienced in passenger vehicles.

Skills requiring fine manual dexterity, steadiness, or precision of muscular control are usually degraded under vibration conditions. When subjects are vibrated, hand steadiness and foot pressure have been found to decrease, and body sway has been found to increase, compared to control conditions (Grether, 1971). Performance times for the operation of various types of switches have been found to increase with vibration amplitude for motion stimuli at certain frequencies (Dudek and Clemens, 1965). Handwriting is significantly impaired at 5 Hz, .12 rms g vibration (Gray, et al., 1976).

Because most of these studies have been conducted in an operator context, often utilizing very high levels of vibration compared to those found in passenger vehicles and highly specific tasks, the results are difficult to generalize to the performance of passenger activities. Furthermore, they neglect a number of motor behaviors commonly performed by both operators and passengers, such as eating, drinking, and walking in a vibrating vehicle. These activities involve balance, gross muscular coordination, and what might roughly be called "hand-mouth coordination." As in most of the performance studies, single-axis vibration at discrete frequencies was often used as the motion stimulus, which precludes extensive generalization to the multi-axis, broadband motion generated in transportation vehicles.

1.2.4 Vigilance and Pattern Recognition. A number of tasks studied under vibration conditions involve perceptual discrimination and monitoring of stimulus pattern changes which are related to basic problems of vigilance and pattern recognition. These tasks are roughly related to operator performance using instrument panel displays and controls. These tasks do not generally resemble the types of activities which passengers might engage in on transportation systems. However, they may involve similar perceptual, motor, and cognitive abilities, and are therefore included in this review for the sake of completeness.

Performance decrements due to vibration have generally not been observed in laboratory studies using these tasks. Patterns of light in the form of checkered matrices (Buckhout, 1964) and bar graphs (Shoenberger, 1967) can be successfully discriminated and matched to standards under vibration conditions ranging from .14 to .54 rms g at discrete frequencies of 5, 7, and 11 Hz, corresponding to major body resonances. Auditory vigilance tasks involving detection of tones from background noise are similarly resistant to the effects of lower levels (.12 rms g) of vibration. Performance of a visual search task for targets on printed sheets of random letters actually improved over time in the vibration environment, so that after 3 hr there were no significant differences in scores between the vibration and control conditions (Gray, et al., 1976).

In an experiment using a matching-to-standard technique with varying combinations of random letters serving as patterns, a performance decrement in pattern recognition response time was found under vibration conditions of .14-.42 rms g (Shoenberger, 1974). However, the increase in response time was shown to be related to the peripheral effects of vibration causing mechanical interference in the visual system and a subsequent increase in simple reaction time, rather than to a central, non-specific stress effect, which might have caused an increase in information processing time.

1.2.5 Higher Cognitive Abilities. Relatively few experiments have been conducted on the effects of vibration on intellectual tasks. This is unfortunate, since studies using appropriate levels of vibration and other environmental inputs could be applied to the assessment of ride environments for the performance of passenger activities such as studying or conducting business. These activities involve significant cognitive processes such as memory, attention, decision-making, information processing, language, and problem-solving.

The few studies which have addressed the effects of vibration and other environmental variables on performance of intellectual tasks have found no consistent effects of these factors on a number of behavioral measures. No significant differences in performance were found between control and high stress (120°F heat, 105 dB noise, .21 or .25 rms g vibration at 5 Hz, or all three) conditions for a mental arithmetic task (Grether, et al., 1971, 1972). No significant performance decrement was found under the same conditions for a voice communication task involving repetition of a vocal message (Grether, et al., 1971) or vocal response to questions during tracking (Grether, et al., 1972). On a more complex mental arithmetic task, stress in the form of 5 Hz, .18 rms g vibration and 110 dB noise was found to interact with time of day and exposure time (approximately 20 min) to produce a decrement in performance in the afternoon as opposed to the morning and in later trials as opposed to earlier trials (Sommer and Harris, 1972). The latter experiment, however, used an extremely high noise level, and the effects of noise and vibration were confounded in the experimental design.

1.3 Passenger Activities in Transportation Environments

From the preceding review of the literature in the field of ride quality and vibration research, it is apparent that the majority of studies 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; or 2) the objective effects of vibration on human performance, as measured using task-specific dependent variables such as reaction or response times and error rates in highly controlled laboratory experiments. Research in the first category is 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 may be considered multiple stress environments since they include combinations of vibration, noise, temperature, humidity, light, space, and other variables often labeled as environmental stressors. 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.

Although a few researchers in the field of ride quality have acknowledged passenger activity as a possible determinant of passenger comfort and satisfaction (see Section 1.0), there has been little systematic research on how these behaviors vary with environmental conditions on passenger vehicles. The few studies which have considered passenger activity as a variable related to ride quality have obtained subjective estimates of the importance of these behaviors to passenger satisfaction, rather than making actual observations of activities directly. The subjective importance of activities and difficulty in performing them are reported in several early studies of Short Take-off and Landing (STOL) airline passengers which laid the groundwork for later development of ride quality/comfort models.

From the questionnaire responses of air travelers, Jacobson and Martinez (1974) identified "work" or "in-flight activity" as one of four dimensions of passenger satisfaction and comfort. These authors concluded that "...the ability to work while in flight is ...closely related to comfort...[and]...essential to a person spending many of his working hours 'en route'" (p. 52). Activities were ranked according to their relative importance as follows (from most to least): reading, thinking, viewing, eating, talking, writing, daydreaming, sleeping, drinking, smoking, and walking in the aisles. Passengers traveling for personal reasons valued talking more and writing less than the business travelers (Jacobson, 1971). The subjective importance of activity was also reflected in passengers' ratings of factors considered to be important in determining aircraft comfort. Approximately 80% of those polled considered lighting to be at least somewhat important, and approximately 55% considered workspace to be at least somewhat important. These interior design features probably influence the passengers' ease of performing such activities as reading and writing.

Richards and Jacobson (1975) gave similar questionnaires to ground-based and in-flight passengers. When asked to rank the activities according to the relative amount of time spent on them during a flight, the ground-based sample responded similarly to business travelers in the Jacobson and Martinez (1974) study, except that conversation became more important and daydreaming less important than in the earlier study. Both the ground-based and in-flight subjects agreed that it was relatively easy to read in flight. They disagreed as to the ease of sleeping and writing, with the in-flight subjects rating these as difficult relative to other activities. Only concentration, reading, writing, and sleeping were included for consideration in the in-flight survey, and these were ranked for difficulty (from least to most) in just that order.

Since the items given to in-flight subjects differed in form and content from those administered to the ground-based sample, it is difficult to compare the responses on these questions regarding the ease of activity performance. Also, it is questionable from this set of results whether "people do what it is easy for them to do" and "time spent performing an activity is directly related to the judged ease of doing it" (Richards and Jacobson, 1975, p. 139) for passengers actually in-flight, since the questionnaire item regarding relative time spent on activities was administered only to the ground-based subjects. The activity categories used in the two survey forms differed, which further complicates direct comparison of the activity ratings between questions.

Richards and Jacobson (1975) also found a positive relationship between the difficulty ranks for four activities and the ride comfort ratings made by in-flight passengers, with correlation coefficients ranging from .5-.6 depending upon the activity. Except for concentration, activity difficulty was not significantly related to previous flight experience. Thus, the authors concluded that "comfort level...determines how difficult it is to perform various activities in flight..." (p. 150).

The most comprehensive analysis of passenger activity in this series of STOL airline passenger comfort studies was conducted by Rudrapatna (1977), in the course of developing noise-motion models of passenger satisfaction. Passengers on commercial flights and test subjects on special flights were asked to assess the difficulty of performance and amount of time spent on various activities, using a three-point scale in each case. Respondents rated activities from most to least difficult as follows: conversation, dozing, writing, reading, concentration/thinking, and looking out the window. The order of activities according to amount of time spent was almost the reverse, as follows from most to least: looking out the window and concentration/thinking (tied for first place), reading, conversation, writing, and dozing. Thus, the relationship between relative time spent engaged in a particular activity and the ease of performance of that behavior postulated by Richards and Jacobson (1975) was generally supported by these results. The exceptional activity in this case was conversation, which was considered most difficult and yet ranked third in terms of time spent.

Closer analysis of the subjective passenger data revealed that higher ratings of conversation difficulty resulted in lower ratings of time spent talking ($|\gamma| =.69$); further, the more important conversation was rated, the higher the rating of time spent talking. Ratings of noise annoyance were also positively associated with conversation difficulty ($|\gamma|=.62$ for passengers, .65 for special subjects).

Rudrapatna also correlated passenger activity difficulty ratings with different aspects of the ride environment. Difficulty of conversation was significantly correlated with noise levels ($r =.42-.57$, depending upon the unit of noise measurement used), while motion variables appeared to have no effect on conversational difficulty. Noise was negatively correlated with the difficulty ratings for reading ($r =-.61$) and looking out the window ($r =-.36$); noise was uncorrelated with difficulty of writing and dozing. Significant positive correlations were found, however, between transverse and vertical motions and difficulty ratings for reading ($r = .37, .52$, respectively), writing ($r = .69, .62$), dozing ($r = .77, .8$), and looking out the window ($r = .34, .34$). Ratings of conversational difficulty on a scale of 1 to 3 could be predicted from the measured noise level according to the following equation, which was generated using multiple regression techniques:

$$d'_c = 1 + .09\,[\text{db.A} - 81] \quad R = .44 \quad (p<.01) \qquad (4)$$
$$(\sigma) = \quad (.38)$$

where d'_c = difficulty rating, dB.A = noise level, R = multiple regression coefficient, and σ= standard error of the coefficient.

Activity difficulty was also positively correlated with subjective ratings of discomfort and dissatisfaction. Discomfort levels were positively correlated with difficulty ratings for reading ($r = .6$), writing ($r = .78$), conversation ($r = .31$), and dozing ($r = .73$). Significant correlations between passenger ratings of dissatisfaction and activity difficulty were also obtained for reading ($r = .54$), writing ($r = .46$), conversation ($r = .37$), dozing ($r = .68$), and looking out the window ($r = .55$).

Although the Rudrapatna (1977) study clearly reveals strong relationships between ease of activity performance and physical ride quality, subjective comfort, and passenger satisfaction, there are clearly some methodological constraints which limit the applicability of the results. First, the use of discrete three-point scales throughout the questionnaire (except for the items about comfort and satisfaction) significantly restricts the variation in subjects' responses, especially in light of the results of previous studies which show that passengers resist using the most extreme scale end-points (Richards and Jacobson, 1975). Furthermore, the use of three-point scales does not justify the application of parametric statistical techniques such as correlation and multiple regression. Second, the inclusion of data from both revenue passengers and non-passenger test subjects in the ranking of activities for difficulty and time spent complicates the evaluation of these results, since the test subjects were generally experienced in previous ride quality experiments and did not pay a fare for going on these flights. Thus, background and motivational differences may exist which influence the rank orders reported.

In any case, considering the fact that the primary purpose of this study was not directly related to the assessment of passenger activities, the results provide a substantial amount of preliminary data, which indicates that activities: 1) vary in difficulty and importance in an in-flight situation, and 2) are related to noise and motion, subjective comfort, and passenger satisfaction. Nevertheless, Rudrapatna (1977, p. 109) concludes that inferences about passenger satisfaction should be based upon subjective ratings of comfort rather than activity difficulty, "since no procedure for cumulative assessment ¢of activity° is available and since comfort is judged to be more important than the activities."

1.4 A Field Study of Passenger Activities: Purpose and Design

To date, there has been no systematic attempt to use a measure of passenger activity as a behavioral index or correlate of comfort and satisfaction in a ride environment. Assuming that passenger activities are highly correlated with subjective comfort and passenger satisfaction, and vary with different levels of the ride environment, as the limited evidence from the studies of aircraft passengers and subjects would indicate, an objective dependent variable based upon activity levels could be developed as a major correlative to physical ride quality.

An objective measure of human response to a complex motion environment based upon performance of passenger activities would have several advantages over the subjective rating scales presently in use. First, it would not require the use of semantic descriptors (e.g., "somewhat comfortable"), which may vary in meaning from one subject or situation to another. Second, activities may be more easily defined in operational terms than subjective responses and might therefore be more easily quantified. Third, a dependent variable incorporating passenger activities would be based upon what passengers actually do in transportation situations, rather than what they say they do. Thus, an activity measure might have greater predictive validity for the level of continuing passenger ridership (actual number of passengers repeating the ride) than subjective ratings of ride comfort (which were shown to be correlated with "willingness to ride again", also a subjective measure). Finally, an activity measure could be computed using the actual frequencies of revenue passengers engaged in various activities. This would obviate the need to recruit passengers or special subjects whose motivations and expectations may differ from those of actual passengers.

The application and usefulness of a dependent variable correlated with physical ride quality and based upon activities would be similar to that of the subjective comfort ratings used in previous ride quality studies. The relationships between a given activity variable and the physical parameters of ride quality could be described in quantitative terms in the form of correlation coefficients and linear equations generated using multiple regression techniques. The latter equations would be similar to those generated by Pepler, et al. (1978), except that the predicted variable would be objective Activity (A) rather than subjective Comfort (C). These Activity equations might then be used in the design future transportation systems where a certain level of passenger activity must be accommodated, or in the evaluation of systems as to level of activity which existing ride quality conditions might allow.

The following chapters of this report describe a three part field study of passenger activities on intercity trains, which was conducted for the following purposes:

1) to develop a behavioral taxonomy of passenger activities, which would identify and describe the general categories and relative frequencies of common passenger activities on intercity trains;

2) to obtain subjective opinions from passengers regarding the importance of such activities for their satisfaction on the trains, and the role of ride quality factors in the performance of passenger activities; and

3) to determine and describe the relationships between the frequency levels of passenger activities and the physical and operational parameters of the ride.

The behavioral taxonomy was developed using strictly observational methods on a number of Amtrak trains in the northeastern United States, and is described in Section 2. of this report. Subjective opinion data was gathered by Amtrak on selected trains operating in the Northeast Corridor, which encompasses the route between Boston and Washington, DC., using a questionnaire

(Section 3.). The physical parameters of ride quality, including vibration, noise, temperature, humidity, and light, plus a number of other trip and operational variables, were measured and recorded on the same section of the Northeast Corridor in conjunction with simultaneous observations of passenger activities, in order to develop quantitative relationships between the physical and behavioral variables (Section 4.).

Because of the descriptive nature of this field study and the use of actual passengers rather than laboratory subjects, the proper control conditions necessary for precise hypothesis testing were not available. However, it was generally expected that:

1) A number of categories of passenger activities could be observed, and that while these activities might vary on a short-term basis with changes in trip and operational variables, a stable long-term frequency distribution could be established.

2) Some level of correspondence could be established between the observed frequencies of passenger activities and subjective opinions of the importance of these behaviors for trip satisfaction.

3) Of all the environmental factors, vibration would be considered by passengers as the main variable interfering with activity performance, especially for activities with significant motor and visual components.

4) Quantitative relationships could be established between the levels of activity and the physical parameters of ride quality, which would be useful in the design and evaluation of future advanced transportation systems for the prediction of activity levels from knowledge of the ride quality and trip factors.

2. BEHAVIORAL TAXONOMY OF PASSENGER ACTIVITY

2.1 Method

2.1.1 Subjects. The subject sample consisted of 850 passengers observed on seven Amtrak train rides. Subjects were observed on trains traveling in both directions on three routes (New York-Boston, Boston-Albany, and Albany-New York), at various times of the day, on various days of the week, under heavy and light crowding conditions, and in a number of vehicles of three different types, in order to obtain a representative sample of Amtrak system users.

2.1.2 Apparatus. The behavioral coding form used to record passenger activity is shown in Appendix A.

2.1.3 Procedure. Observations were made on a number of Amtrak trains for the purpose of recording passenger activities. On each trip, several observational sweeps were made through the main aisle of each vehicle of the train at one hour intervals, starting with the rear end of the last car and working toward the head end. Most passenger seats faced in the direction of travel; thus, the observer approached passengers from behind and was usually able to determine and record each person's behavior without disrupting ongoing passenger activity.

In the majority of cases, activities could be coded into one of the following 12 categories: Doing Nothing, Sleeping, Smoking, Viewing, Talking-Listening, Handcrafts, Games, Eating, Drinking, Reading, Writing, and Other. Descriptions of these activities are provided 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. Similarly, a person with a cup of coffee on his tray who was engaged in conversation as the observer passed by was coded in the Talking-Listening rather than Drinking category.

Multiple activities were coded into the category of the more effortful behavior component, according to the ranking of activity difficulty shown in Table 2. The activities were ranked according to six *a priori* behavioral criteria which the ride quality and vibration research literature and previous passenger observations 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. For

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

Table 1 (Cont.)

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.)

Table 1 (Cont.)

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

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

example, Drinking was judged to require a high degree of balance, for which it received 3 points, some amount of eye focussing and sustained visual attention, for which it received 1 point each, a moderate degree of hand-eye coordination, a high level of hand-mouth coordination, and some degree of extraordinary vibration and noise compensation. The sum of effort points for Drinking resulted in an effort rank of 10 compared to the other activities. Doing Nothing, Sleeping, Smoking, and Viewing, which were ranked between 1 and 4 for effort, have been 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.

The observations recorded for the purposes of this taxonomy were made in November and December of 1976 on seven Amtrak trains over the following three routes: 1) New York - Boston (one trip on Amtrak Train Number 171 - The Southern Crescent, and two trips on Train Number 174 - The Statesman); 2) Boston - Albany (two trips on Trains Number 448 and 449 - The Lakeshore Limited); and 3) Albany - New York (two trips on Trains Number 72 and 79 - The Washington Irving). Activities were recorded in a total of 26 different vehicles; passengers in 21 vehicles were observed on single trips, while five other vehicles were used on each of two trains. Observations were made in three types of vehicles: 1) Amcoaches (regular railroad coaches with a seating capacity of 84 passengers); 2) Amcafe snackbars (two coach sections with a total seating capacity of 55, separated by a snackbar and adjacent standing area); and 3) Amclub parlor cars (similar to Amcafe cars in terms of general layout, but with wider, larger seats, more legroom, first class service, and a seating capacity of 18 in the parlor section). The number of passengers observed in each vehicle on each trip route is shown in Figure 1.

2.2 Results

2.2.1 Trip Characteristics of Observed Amtrak Ridership

The numbers of Amtrak passengers observed in the course of these seven trips were analyzed according to time of day, trip route, vehicle type, and level of vehicle occupancy, to determine some general characteristics of the ridership in this area. The observational data used in this and subsequent analyses of the behavioral taxonomy results have been restricted to those data recorded during the one observational sweep made on each trip in which the greatest number of passengers were observed. In this way, inferences may be made on the basis of independent observations, rather than on repeated (and therefore correlated) observations of the same individuals.

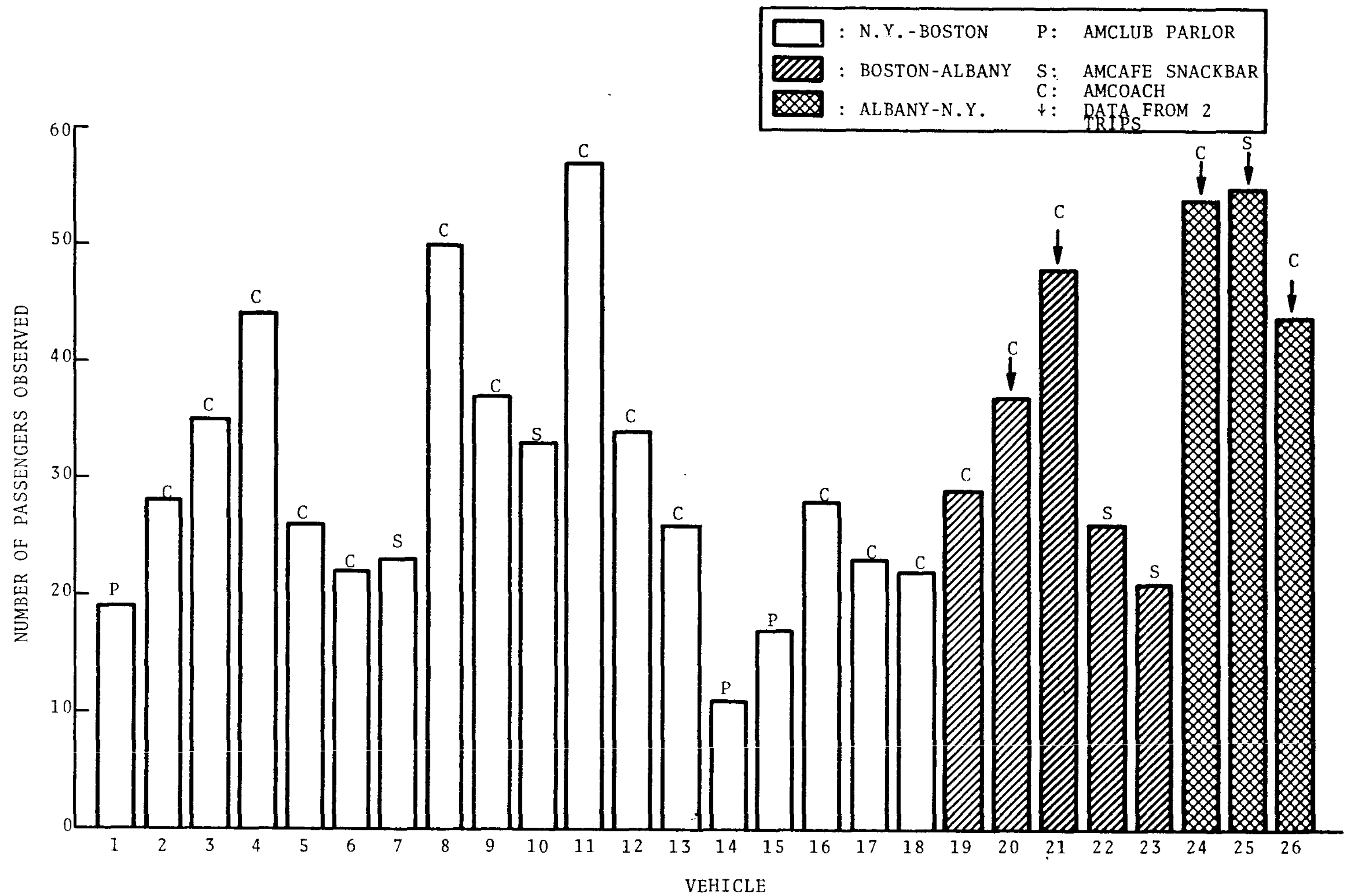

Figure 1. Breakdown Of Observations According To Trip Route And Vehicle

Figure 2 illustrates that most passengers included in the analysis were observed in the afternoon (12 noon - 5 p.m.), rather than in the morning (before 12 noon) or evening (after 5 p.m.). A statistical comparison of the actual number of passengers observed in each time category to the frequencies expected according to the proportion of trips (or observational sweeps) made at that time of day was done using the X^2 test. The results of this test confirmed the finding that there were fewer passengers riding in the morning and evening, and more riding in the afternoon, than would be statistically expected on the basis of the proportion of trips (or observational sweeps) made at that time of day ($X^2 = 41.98$; d.f. = 2, $p<.001$).

Figure 3 indicates that the largest number of passengers were observed on Amcoach rather than Amcafe (snackbar) or Amclub (parlor) vehicles. There were significant differences between the proportions of seating capacity used by passengers in the different types of vehicles. A X^2 test comparing the numbers of passengers observed in the different vehicle types to the number expected for each type based on the over-all average vehicle occupancy of 42.4% confirmed that Amclub and Amcafe cars were more densely occupied than Amcoach vehicles ($X^2 = 47.42$, d.f. = 2, $p<.001$).

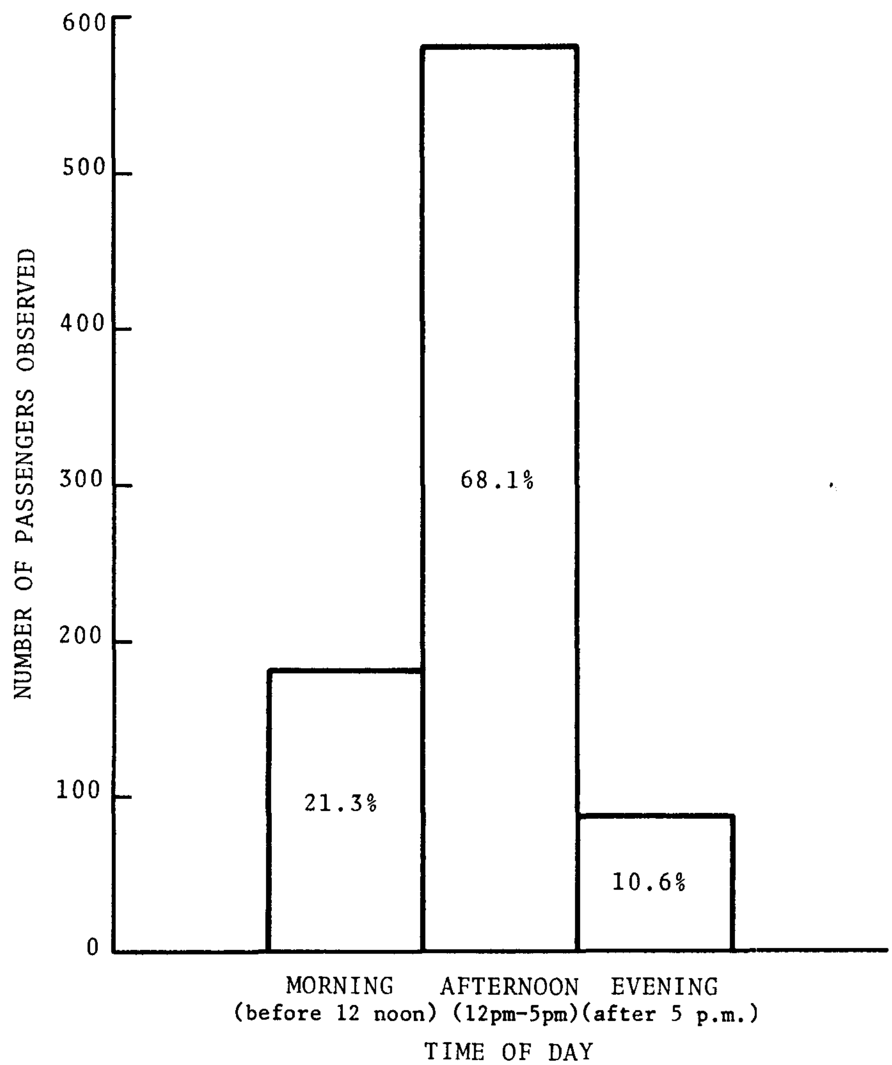

Figure 2. Breakdown Of Observations According To Time Of Day

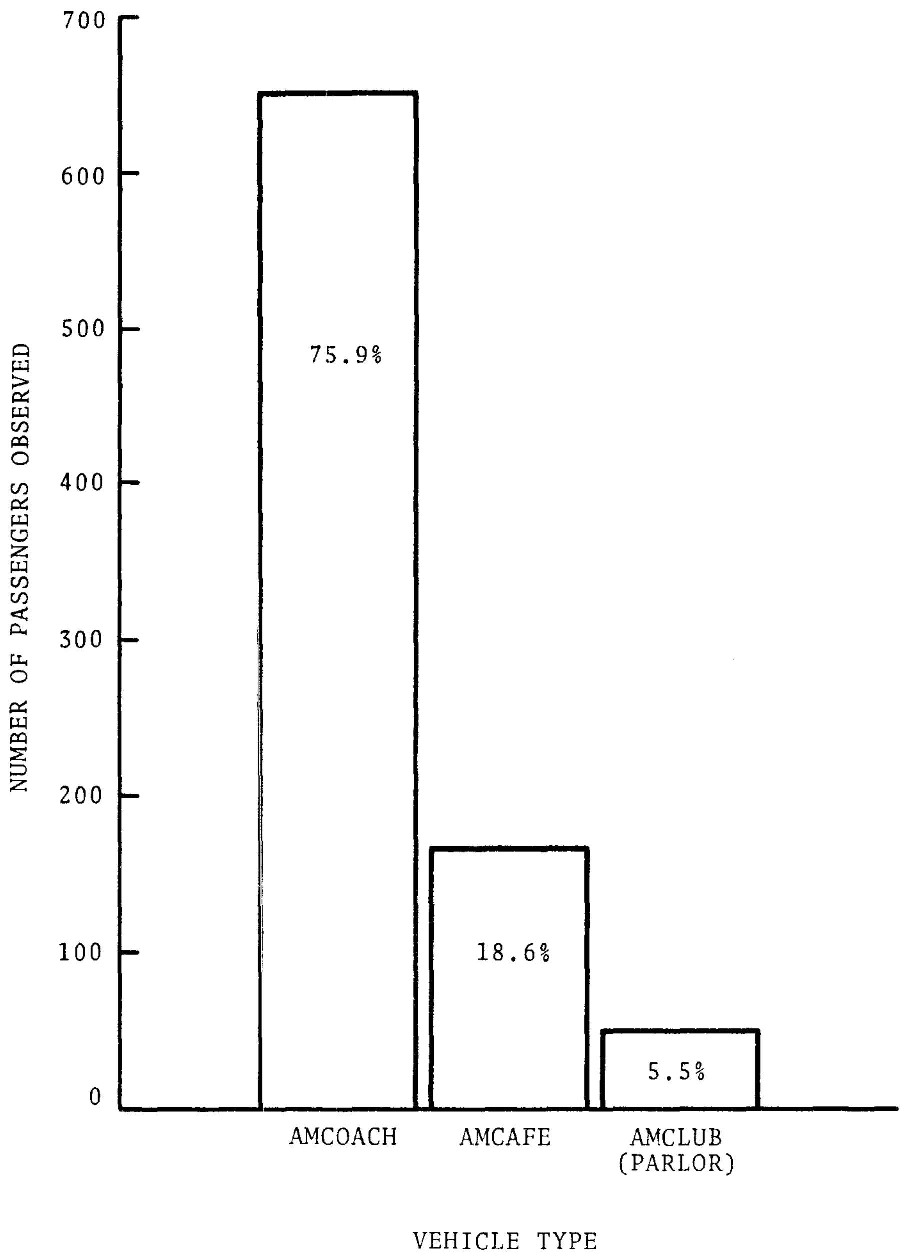

Figure 3. Breakdown Of Observations According To Vehicle Type

Figure 4 also shows significant variations in percent occupancy for different vehicles of the same type, in the case of Amcoaches and Amcafes. X^2 tests were performed to compare observed frequencies of passengers within each vehicle type, with expected frequencies calculated for each vehicle in each type as the product of the total seating capacity and average percent occupancy for vehicles of that type (e.g. for Amclub vehicles, fe = 18 (total seating capacity) x 87.0% (average Amclub occupancy) = 16). Only the Amclub vehicles had similar levels of occupancy (X^2 = 2.18, d.f. = 2, N.S.); significant differences were found between cars in the Amcoach (X^2 = 51.48, d.f. = 17, $p<.001$) and Amcafe (X^2 = 17.89, d.f. = 4, $p<.001$) vehicle types.

Trip route also influenced level of ridership. Figure 5 shows that the greatest number of passengers were observed on the Boston - New York route; however, three trips were made on this route and only two trips on each of the other two routes. In order to perform a valid X^2 test to detect differences in ridership between the three routes, the expected frequency of passengers on each route was calculated and compared with the actual number of passengers observed over all trains on that route. A X^2 test showed statistically significant differences between levels of ridership on the three routes (X^2 = 41.4, d.f. = 2, $p<.001$). While all trains carried relatively small numbers of passengers, the New York - Albany trains carried the smallest proportion compared to trains on the other routes.

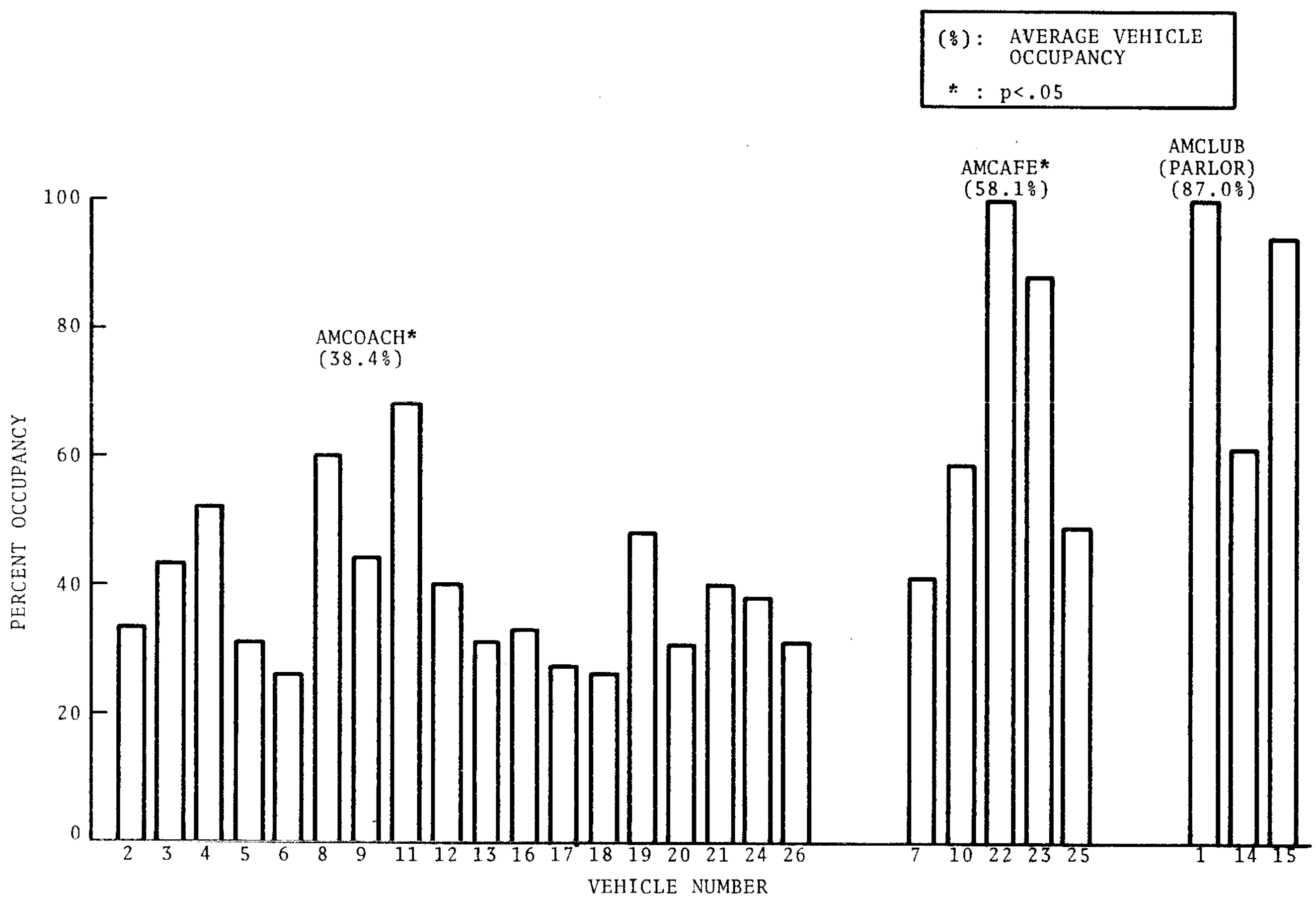

Figure 4. Percent Occupancy As A Function Of Vehicle and Vehicle Type

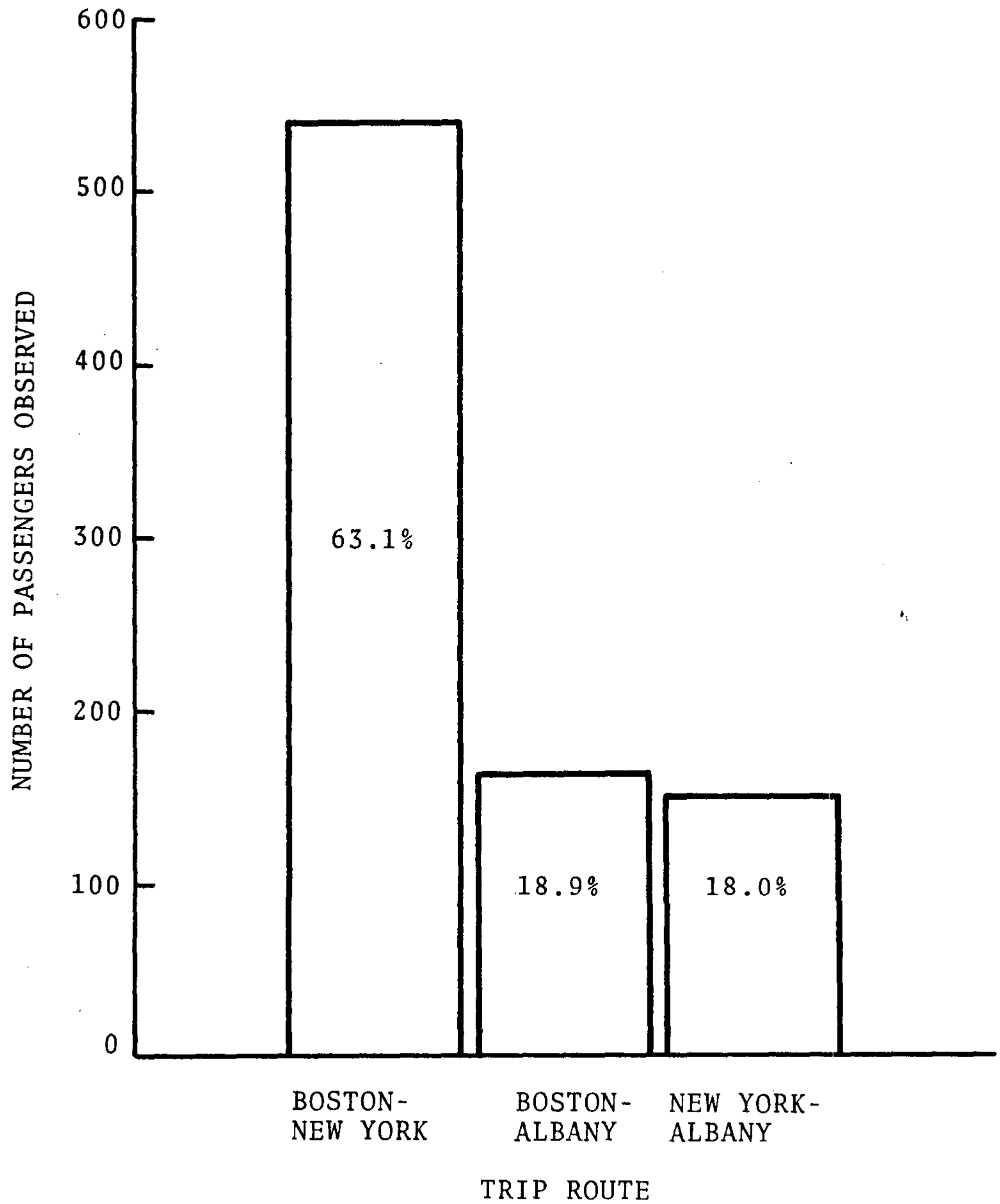

Figure 5. Breakdown Of Observations According To Trip Route

2.2.2 Activities of Observed Amtrak Ridership

Figures 6 through 10 illustrate the frequencies of the various activities observed on the trains according to various trip parameters. The activities listed along the horizontal axes of these figures have been ordered from Low to High according to the Effort ranks discussed in Section 2.1.3. Percentages for the activities shown in Figures 7 through 9 have been calculated to represent the proportion of each behavior observed relative to all other activity at a given time of day (Figure 7), on a given vehicle type (Figure 8) or on a certain trip route (Figure 9). Percentages of all activities add up to 100 if summed over any particular level of the trip variable in question. For instance, adding the percentages of all 12 activities represented by an open bar for "morning" in Figure 7 will result in the sum of 100%.

Figure 6 indicates that the distribution of activities observed is clearly not uniform ($X^2 = 806.4$, d.f. = 11, $p<.001$). The most popular behaviors observed included Viewing (24.4%), Reading (24.2%), Sleeping (14.4%), and Talking - Listening (10.9%), which account for almost 75% of all observations. Among the least popular activities were Handcrafts (0.7%), Games (1.3%), Doing Nothing (2.6%), and Writing (3.3%), which accounted for less than 10% of all observations. The low frequency of Smoking observed is deceptively small, since most Smokers also engaged in more effortful behaviors such as Drinking and Reading,

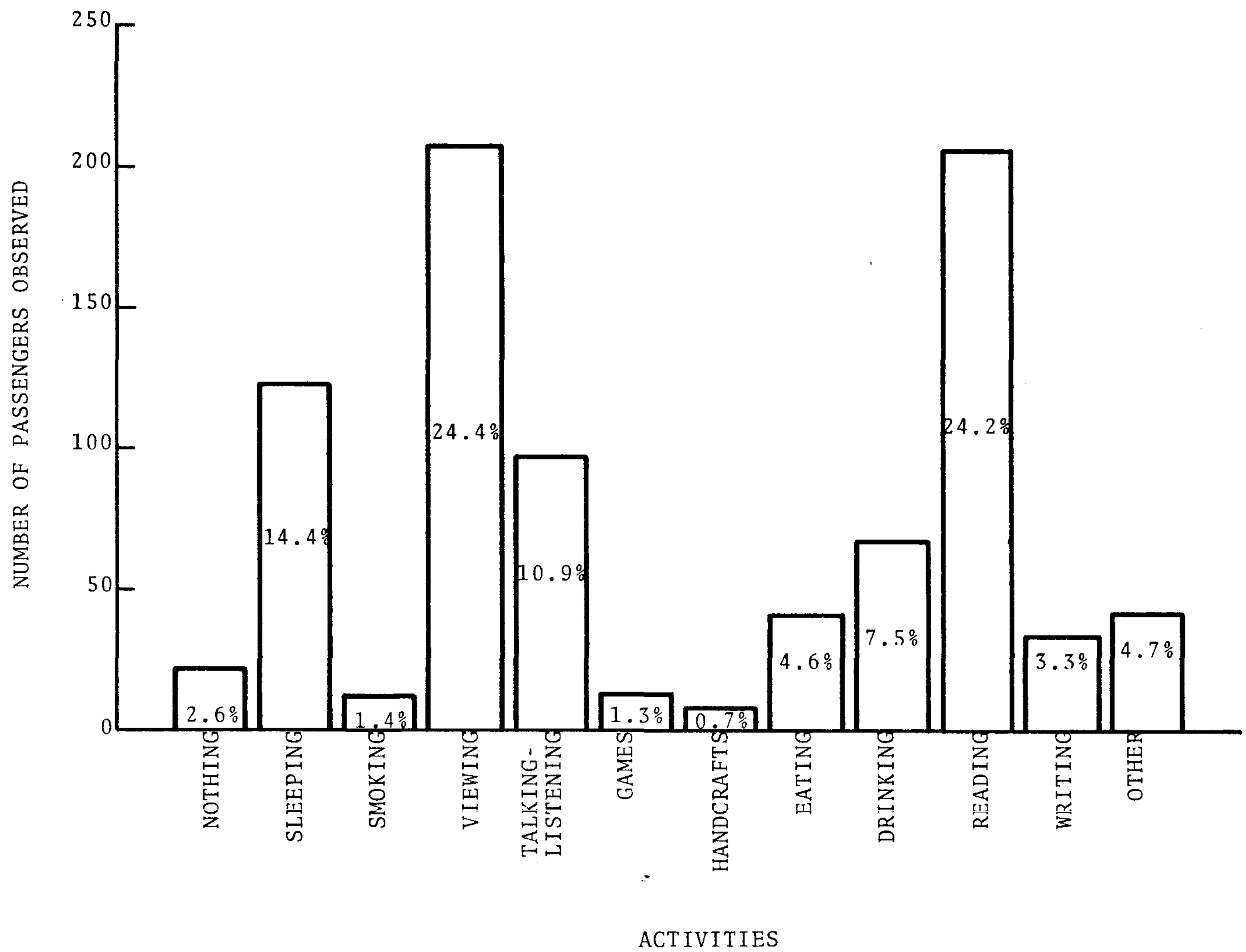

Figure 6. Breakdown Of Observations According To Activity

and were therefore coded into these other activity categories. A X^2 test comparing the observed frequencies of High, Medium, and Low Effort activities to frequencies expected on the basis of a uniform distribution showed significant differences between these activity categories (X^2 = 78.23, d.f. = 2, $p<.001$). While there were greater frequencies of High and Low Effort activities than might be expected by chance, fewer Medium Effort behaviors were observed.

Frequencies of activity clearly varied with time of day (X^2=70.90, d.f.=22, $p<.0001$), as shown in Figure 7. Controlling for different numbers of passengers at different times of day, the relative number of passengers observed Reading and Writing increased (X^2 = 5.17, d.f. = 2, $p<.06$ and X^2 = 10.04, d.f. = 2, $p<.01$, respectively) from morning to evening. Frequencies of Sleeping and Smoking also increased with time, although not significantly. Viewing peaked in frequency in the afternoon and decreased in the evening, while Doing Nothing decreased with time. Eating was significantly more frequent in the morning than later in the day (X^2 = 45.86, d.f. = 2, $p<.001$). Social activities such as Talking - Listening and Drinking were also observed most frequently in the afternoon.

Activities also varied according to vehicle type (X^2=74.49, d.f.=22, $p<.0001$), as shown in Figure 8. Amcoach passengers slept significantly more than Amcafe or Amclub passengers (X^2 = 6.46, d.f. = 2, $p<.05$), while Amclub cars had the greatest

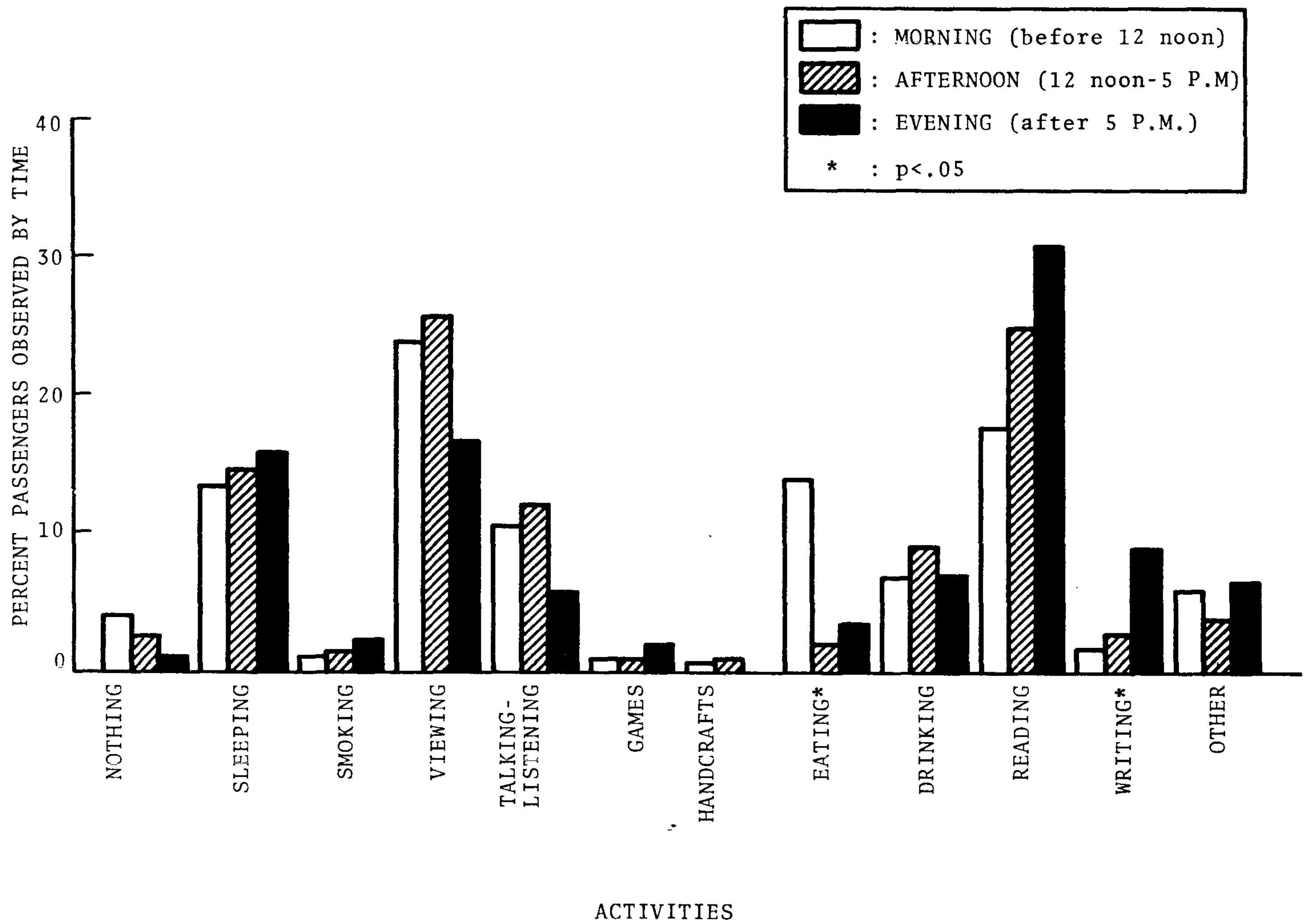

Figure 7. Breakdown Of Activities By Time Of Observation

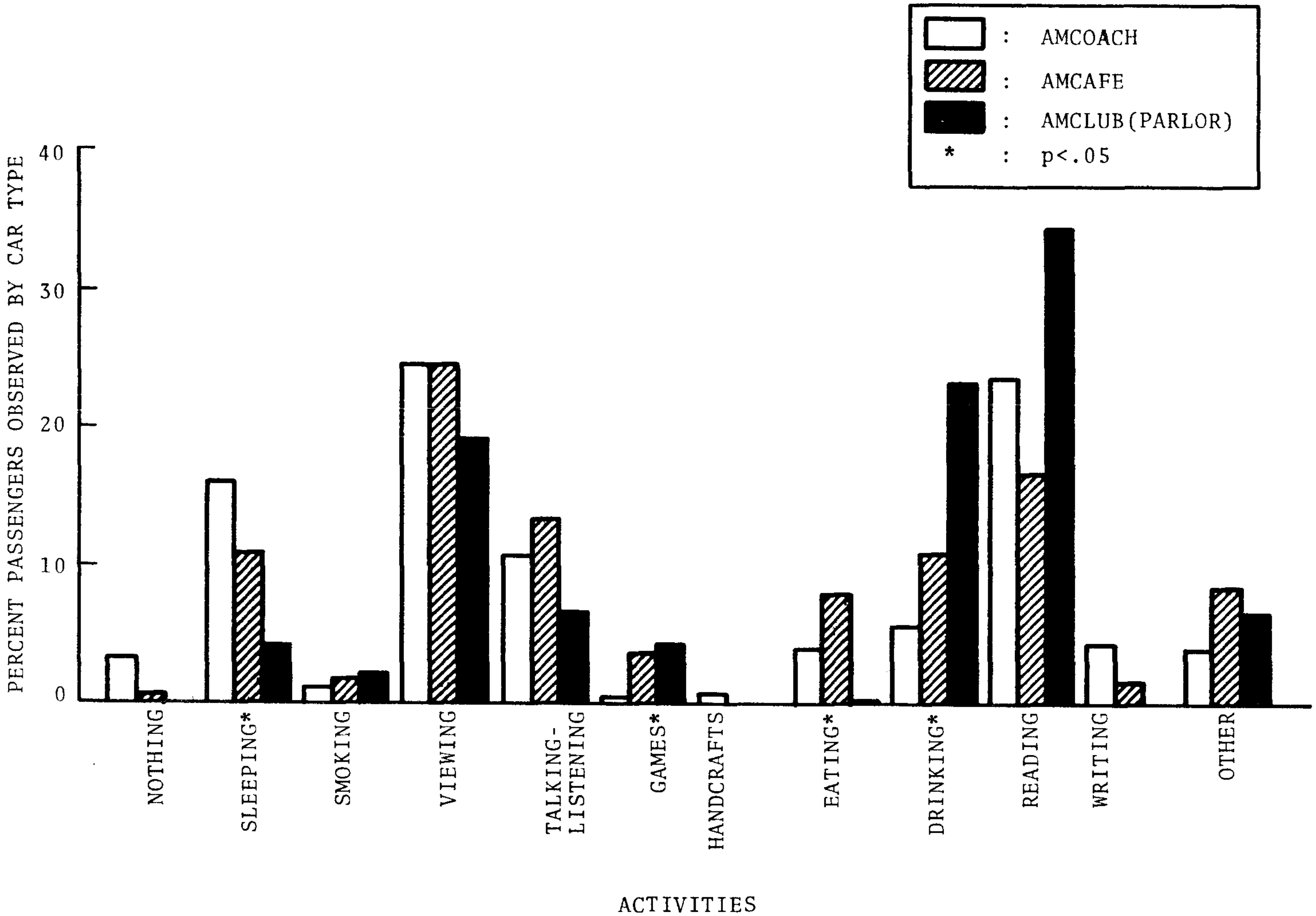

Figure 8. Breakdown Of Activities By Car Type

relative numbers of people Reading ($X^2 = 5.53$, d.f. = 2, $p<.06$) and Drinking ($X^2 = 26.86$, d.f. = 2, $p<.01$). A greater proportion of Amcafe passengers ate compared to those in Amcoach and Amclub vehicles ($X^2 = 7.67$, d.f. = 2, $p<.05$). Table 3 shows that the greatest number of passengers observed in Amcoach vehicles were engaged in Low Effort behaviors ($X^2 = 124.26$, d.f. = 2., $p<.001$), while the greatest number of Amclub passengers performed High Effort activities ($X^2 = 17.22$, d.f. = 2, $p<.001$). Although the majority of Amcafe passengers were split between Low and High Effort activities ($X^2 = 23.04$ d.f. = 2, $p<.001$), the greatest proportion of Medium Effort behaviors (17.1%) occurred in these cars. A X^2 test of independence also showed activity effort to be significantly related to vehicle type ($X^2=11.7$, d.f.=4, $p<.05$).

It appears that trip route may also influence activity ($X^2=75.74$, d.f.=22, $p<.0001$). Figure 9 shows that the highest proportion of readers was observed on the Boston - New York route ($X^2 = 26.91$, d.f. = 2, $p<.001$), while the highest proportions of talker - listeners and game players were found on the Boston - Albany trips ($X^2 = 19.43$, d.f. = 2, $p<.001$ for Talking-Listening; $X^2 = 10.57$, d.f. = 2, $p<.01$ for Games). Drinking occurred with relatively higher frequency on this route also, although the differences with other routes were not statistically significant. A greater proportion of passengers slept, looked around, and ate on the New York - Albany route, although only the differences in

Table 3

Distribution of Passengers Engaged in High, Medium, and Low Effort Activities According to Vehicle Type

VEHICLE TYPE

	Amcoach (% (N))	Amcafe (% (N))	Amclub (% (N))
Low	45.2 (291)	38.0 (60)	25.5 (12)
Medium	12.1 (78)	17.1 (27)	10.7 (5)
High	39.0 (252)	36.8 (58)	57.4 (27)
Other	3.7 (24)	8.2 (13)	6.4 (3)
	(X^2=124.26 d.f. = 2 $p < .001$)	(X^2=23.04; d.f. = 2 $p < .001$)	(X^2=17.22; d.f. = 2 $p < .001$)

X^2 (independence) = 11.7; d.f. = 4, $p<.05$)

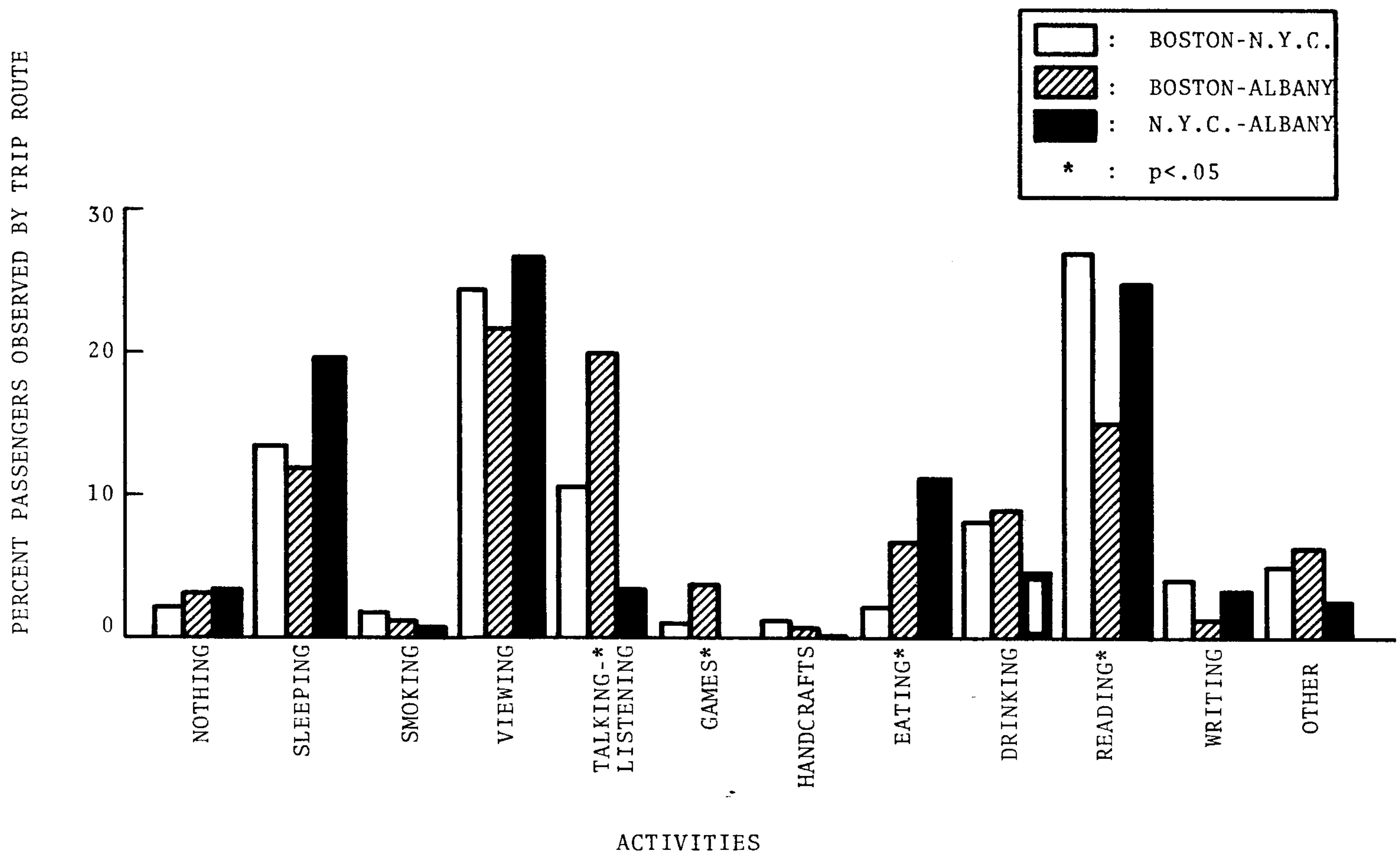

Figure 9. Breakdown Of Activities By Trip Route

frequencies of those Eating proved to be significant ($X^2 = 24.41$, d.f. = 2, $p<.001$).

There is some evidence that vehicle occupancy may influence activity distributions in Amcoach cars. Vehicle occupancy may be defined as the proportion of available seating capacity occupied by passengers in any given vehicle, and is computed as the ratio of the number of passengers observed in a vehicle to the total available seating capacity. Figure 10 shows a comparison of the activity distributions of the two most sparsely occupied Amcoach cars observed (Numbers 6 and 18, both having a vehicle occupancy of 26%) to the two most densely occupied Amcoaches observed (Numbers 8 and 11, with respective vehicle occupancies of 60 and 68%). These cars were chosen from the New York-Boston trips, so as not to confound the comparison of activities by level of crowding with possible differences between trip routes. It may be seen that a higher proportion of passengers in the sparsely occupied vehicles slept and read, while a higher proportion of passengers in the more crowded cars ate, drank, and engaged in conversation. These results did not prove to be statistically significant, however, on the basis of the small number of vehicles used in these tests.

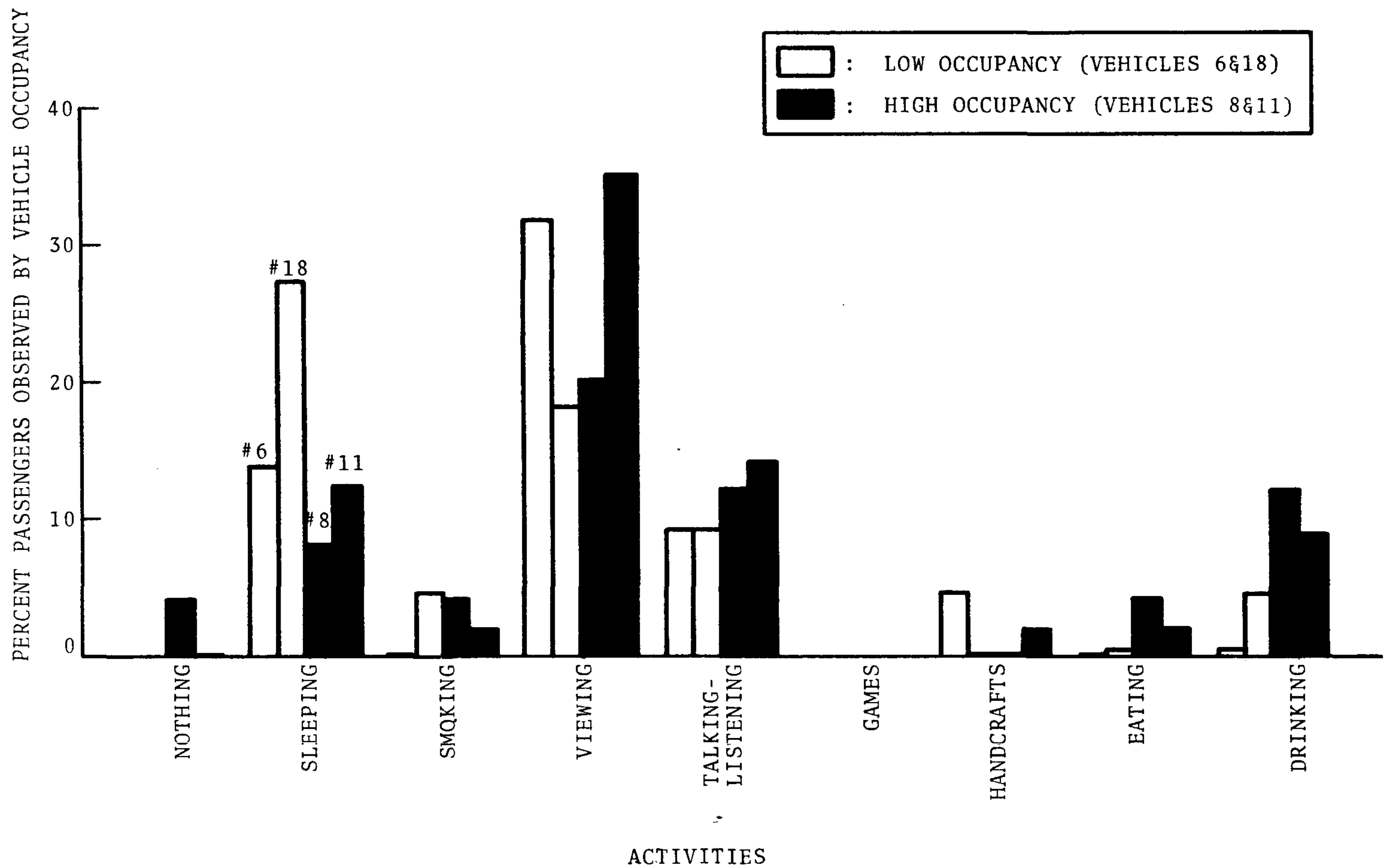

Figure 10. Comparison Of Activity Distributions According To Vehicle Occupancy

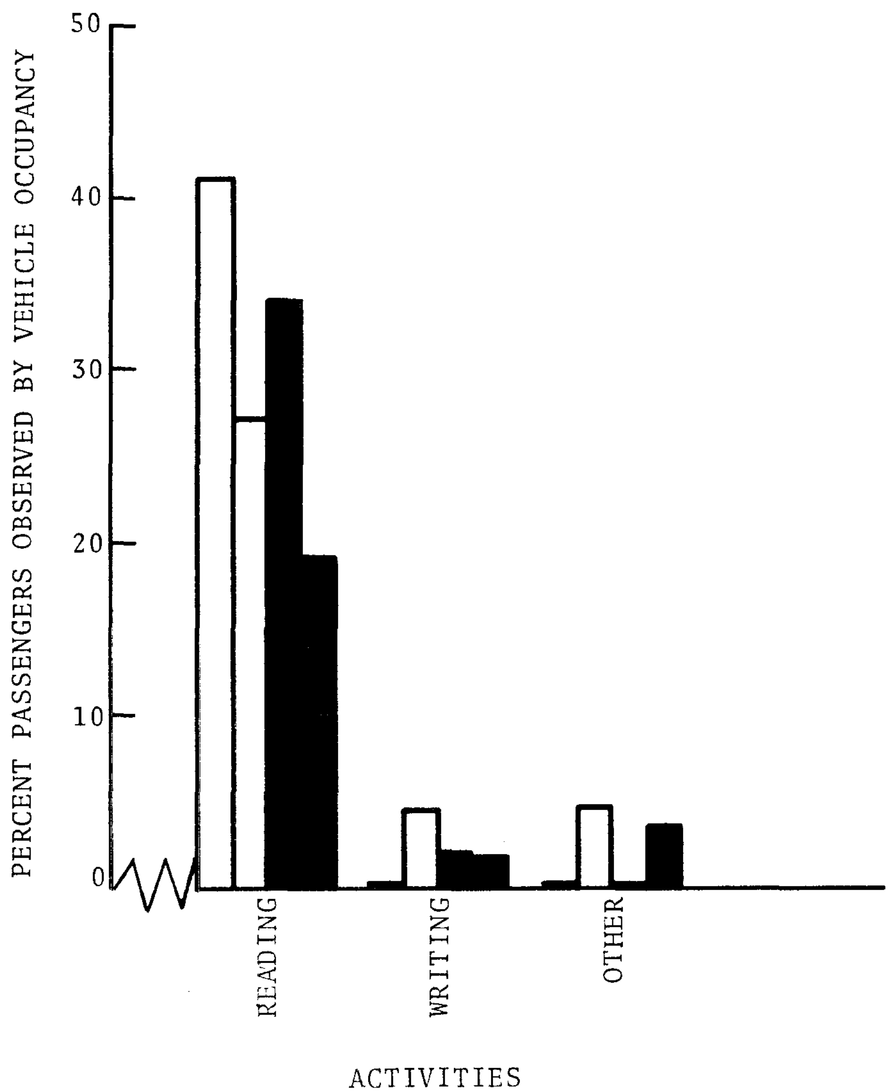

Figure 10. (Cont)

2.3 Discussion

A behavioral taxonomy was developed in the first part of this study of passenger activities to determine the range and distribution of these behaviors on interurban trains, and to find out whether variations in behavioral patterns might be explained by trip, comfort, or ride quality variables. The results showed that certain activities occurred more frequently than others, and that activity varied with time of day, vehicle type, trip route, and level of vehicle occupancy. The observed frequencies of various activities and the ways in which behavioral distributions change may be discussed in light of particular characteristics of the Amtrak system, as well as in terms of the possible role of ride quality and comfort variables.

The fact that different activities do not occur with equal frequency may be explained in terms of several factors. Viewing and Reading clearly stand out as the most frequently performed behaviors on these trains. Viewing, which most often consisted of looking out the window of a moving vehicle, occurred with high relative frequency in all vehicle types, over all trip routes, and under varying conditions of vehicle crowding. Only during the evening hours, when darkness decreased outdoor visibility, did Viewing behaviors drop off. Viewing activity was particularly high during periods of acceleration and deceleration of the train, or when there was any change in motion. Bodies of water seemed to prompt particularly high frequencies of Viewing, and may explain the especially large proportion of passengers engaged in this activity on the New York - Albany route, which parallels the Hudson River.

Reading was also an exceptionally popular activity, which tended to increase in frequency as time progressed from morning to evening. Reading seemed to drop off, however, whenever social opportunities arose for passengers. This is shown by the lower-than-average frequencies of Reading: a) in Amcafe snackbars, where Talking-Listening played a larger role; 2) on the Boston - Albany route, where passengers on the long trip to or from Chicago spent more time socializing (Talking-Listening, Drinking) than on other routes; and 3) in densely occupied vehicles, where social activities such as Talking-Listening, Drinking, and Eating prevailed.

The popularity of Reading and Viewing as passenger activities is also reported in three separate studies using questionnaires to assess the subjective importance of a number of comfort variables among air travelers. Jacobson and Martinez's (1974) STOL (Short Take-off and Landing) passenger subjects ranked Reading and Viewing first and third, respectively, in terms of importance compared to nine other activities. Richards and Jacobson's (1975) ground-based study of airline passengers showed that subjects ranked Reading first and Looking out the Window fourth in terms of relative time spent on a total of 11 activities. Finally, Rudrapatna (1977) found Looking out the window and Reading to be ranked first and second in terms of time spent on six activities. Looking out the window also tied with Concentration/Thinking as the "easiest" activity to perform.

Among the least frequently observed activities were Handcrafts, Games, Doing Nothing, and Writing. One possible explanation for these activities' relative infrequency of occurence might simply be personal preference; Handcrafts, for instance, may only appeal to a very small proportion of the passenger population. Another might be a lack of "props" necessary to perform certain activities. Clearly, Handcrafts requires the passenger to bring certain materials on the trip which cannot be bought or otherwise obtained on board the train; similarly, toys are usually necessary for participation in Games.

Finally, the ride quality and physical environment of the train may discourage the performance of certain activities. Writing, for example, appeared to be difficult in the motion environment experienced on these trains. The cramped seating and small fold-out tables in Amcoach vehicles also may have prohibited passengers from spreading out their work materials for Writing. The importance of adequate space for Writing is shown by the higher frequencies of this activity observed in the evening when the trains were less crowded, and in the cars with lower vehicle occupancy.

Writing was also rated to be the most difficult of seven activities by passengers polled in Richards and Jacobson's (1975) ground-based questionnaire study of airline passengers' comfort, while Rudrapatna's (1977) airline passenger subjects ranked it only moderate in difficulty compared to five other activities. Subjects in both of these studies reported spending little time writing compared to the other activities, which supports the results of this taxonomy.

The a priori ranking of activities according to effort in Table 1 provides a useful means of: 1) classifying multiple behaviors into a single category for the purpose of recording activities; and 2) grouping activities together into larger categories for the purpose of comparing different levels of behavior in terms of relevant trip variables. The six behavioral criteria used for assessing the effortfulness of each activity, and the ratings for each criterion pertaining to each activity, were suggested by the ride quality and vibration research literature on performance reviewed in Section 1.2 and confirmed by observations on previous train rides not included in the data analysis of this taxonomy. Some evidence for the validity of these ranks may also be obtained by comparing them with the empirical ranking of activities by airline passengers in two questionnaire studies performed by Richards and Jacobson (1975) and Rudrapatna (1977) in Table 4.

Table 4

Comparative Effort Ranking of Passenger Activities According to Questionnaire Results of Airline Passenger Studies vs. the Present Study

	Richards & Jacobson (1975)		Rudrapatna (1977)	The Present Study (1978)
Data Source	Ground-based Respondents	In-flight Respondents	In-flight Respondents	*A Priori*[1] Ranking
Least	Reading	Concentration	Looking out the window	Doing Nothing[2]
Difficult	Relaxing	Reading	Concentration/ Thinking	Sleeping
	Concentrating	Writing	Reading	Smoking
	Conversing	Sleeping	Writing	Viewing
	Eating		Dozing	Talking-Listening
	Sleeping		Conversation	Games
	Writing			Handcrafts
				Eating
				Drinking
Most				Reading
Difficult				Writing

1. See Table 1 for effort ratings of activities on the basis of six behavioral criteria.
2. Corresponds to "Relaxing", "Concentrating", "Thinking"

Considering the fact that the activity effort ranks were derived on the basis of two modes of transportation with quite different motion environments, the similarities in ordering are considerable. The only real differences between the assessments of effort arise for Sleeping, which is rated as a difficult activity by the air travelers and as a relatively easy activity on the a priori scale, and for Reading, which air travelers find to be easy, but which is rated as a High Effort behavior in this study. It is believed that the vertical motion of airplanes and the short flight times experienced by the air travelers in the Richards and Jacobson and Rudrapatna studies may have interfered with sleep more than the predominantly rolling lateral motions and long trip times experienced by train passengers. Conversely, the same rolling motions, which are relatively lower in amplitude on airplanes than on trains, are believed to interfere with the eye focussing and visual attention necessary for Reading.

The predominance of High Effort activities among Amclub passengers, Low Effort activities among Amcoach passengers and the even split between High and Low Effort behaviors among Amcafe passengers, clearly has implications for the effect of ride quality/comfort variables on passenger satisfaction. The three types of vehicles may be regarded as representing three levels of passenger service in terms of the acceptability of the Amtrak system.

Of all three vehicle types, there is the least amount of space between seats in Amcoach vehicles, and little individual passenger space to perform more difficult activities such as Reading and Writing. Passengers must walk through the vehicle to another car to obtain food at a snackbar. These conditions are probably the least favorable for performing active behaviors; hence the high percentage of Low Effort activities observed. The Amcoach vehicle layout is illustrated in Appendix B.

Amcafe vehicles, on the other hand, accommodate fewer people, and there are at least four groups of double seats facing each other, allowing more legroom and greater opportunities for social behavior. Food service right in the vehicle and the greater average amount of space per person may also have encouraged a higher frequency of High Effort activities. The Amcafe vehicle layout is also shown in Appendix B.

Finally, Amclub vehicles offer the highest level of service, comfort, personal space, and passenger amenities. Waiter service at the passenger's seat may have encouraged Eating and Drinking, while the larger seats, more legroom, and large lapboards available provided a good workspace for Reading and Writing.

Of course, differences in the individual characteristics of passengers traveling in Amclub vs. Amcoach/Amcafe cars may have also influenced the activity distributions in these cars. It has been found on Amtrak Metroliners that more Metroclub passengers travel for business purposes than Metrocoach passengers;[2] the same might be expected on Amfleet vehicles. Passengers traveling for business purposes might wish to engage in more work-related activities (Reading and Writing) and might also be more inclined to eat and drink on the trains in order to maintain a business schedule.

Many activities observed on the train seem to vary with time of day, in accordance with the normal human activity cycle which peaks in the middle of the day (Kleitman, 1939). This was particularly true with social activities, such as Talking-Listening and Drinking, and also Viewing, which was largely dependent upon natural levels of light. The High Effort activities of Reading and Writing increased in frequency as the day progressed; the evening frequency peaks in these behaviors may have been due to the onset of darkness which caused a significant number of Viewers to engage in alternative activities.

The results of this taxonomy provide baseline information regarding the categories and frequencies of passenger activities on intercity trains. In the second part of this study, the importance of passengers' subjective preferences for different

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[2]Personal communication based on results of Amtrak Quantitative Market Analysis survey of Metroliner passengers performed from July 30-August 6, 1976.

behaviors, and their perceptions of environmental factors' interference with activity performance, are explored and related to actual patterns of behavior determined through observation.

3. PASSENGER ACTIVITY/RIDE QUALITY SURVEY

3.1 Method

3.1.1 Subjects.

A total of 804 subjects were sampled from the passengers on 13 Amtrak trains in the Northeast Corridor, running on the same routes each day in both directions between Washington, DC and Newark, NJ. Amtrak passengers participated in this survey every day from Monday through Friday during the week of July 18-22, 1977. Subjects were sampled throughout each test day (morning, afternoon, and evening), in order to obtain a representative sample of Northeast Corridor Amtrak system users.

3.1.2 Apparatus.

The survey form which was distributed is reproduced in Appendix C. Pens and pencils were also available for the subjects' use.

3.1.3 Procedure.

A questionnaire developed to assess passengers' activity preferences and perceptions of vehicle ride quality was distributed at random to approximately 25% of the passengers in each car of 13 trains traveling between Washington, DC and Newark, NJ. This survey was conducted by Amtrak in coordination with a secondary data collection effort involving the simultaneous observation of passenger activities by the experimenter. The experimental procedure is described below.

The experimenter and an Amtrak Quantitative Market Analysis representative experienced in survey data collection techniques boarded each train in the rear vehicle. While the train was in motion, the experimenter walked through the vehicle, observing and recording passenger activities using the same methods described in Section 2.1.3. When the experimenter finished taking data in a given vehicle, she proceeded to the next car. The Amtrak representative then began the survey distribution procedure in the vehicle just observed by the experimenter.

Proceeding from the rear to the front of each vehicle, the Amtrak representative approached every fourth passenger as a potential survey respondent. He introduced himself to each passenger as a representative of the Amtrak Marketing Department, and explained that a survey was being conducted "to find out what you think of the ride and what you like to do on the train." The passenger was then handed a questionnaire, requested to fill it out, and given a pen or pencil to write with. Respondents were told to hold onto the completed survey form until it was collected from them, or to leave it on their seats if they had to get off the train before the Amtrak representative returned. No further instructions were given about filling out the questionnaire, except to answer specific questions and point out the instructions written in the survey form.

When the Amtrak representative had finished distributing the questionnaires in each vehicle, he proceeded to the next vehicle, always staying one car behind the experimenter until he had covered the whole train. Completed survey forms were then collected from the passengers or from their seats.

This survey was conducted between July 18-22, 1977 on Amtrak Trains #172 (The Patriot, Washington, DC-Newark), #169 (The Colonial, Newark-Philadelphia), and #171 (The Patriot, Philadelphia-Washington,DC).

3.2 Results

Of the 900 questionnaires distributed, 804 were returned containing any data whatsoever which could be included in the analysis of results. Only six passengers of all those approached by the Amtrak representative refused to participate in the survey at all. However, 30 questionnaires were collected in which not even one item had been answered, resulting in a total refusal rate of 4%. Twelve questionnaires were disgarded, all from the same vehicle, because operational problems precluded the recording of activity data which would have been correlated with the subjective responses. The other 48 questionnaire forms were never returned to the Amtrak representative.

The experimenter and two assistants coded the 804 completed questionnaires for computer processing. Criteria for coding ambiguous and anomalous responses and categories for the coding of spontaneous passenger comments were worked out in advance using 76 questionnaires from a pilot study of the present survey conducted in April, 1977, resulting in a high level of agreement between the three coders.

Appendix D summarizes in tabular form the distribution of results in each response category for each item on the passenger activity/ride quality survey. Figures 11 through 15, which represent the results of this survey in the following discussion, are based upon the numerical values in these tables.

3.2.1 Subjective Importance of Activity

The distribution of responses to Question 1, plotted in Figure 11 and summarized in Appendix D, shows that passengers felt certain activities play an important role in their general satisfaction while riding the train. Over 50% of the respondents considered eight of the 12 activities listed to be important to their satisfaction with Amtrak train travel. Reading and Thinking were considered to be important activities by the greatest numbers of respondents (87.6% and 85.9%, respectively), followed by Sleeping (76.1%), Beverage consumption and Looking around (72.9% and 72.6%, respectively), Eating (70.4%), and Conversation (61.9%). Games and Handcrafts were considered to be

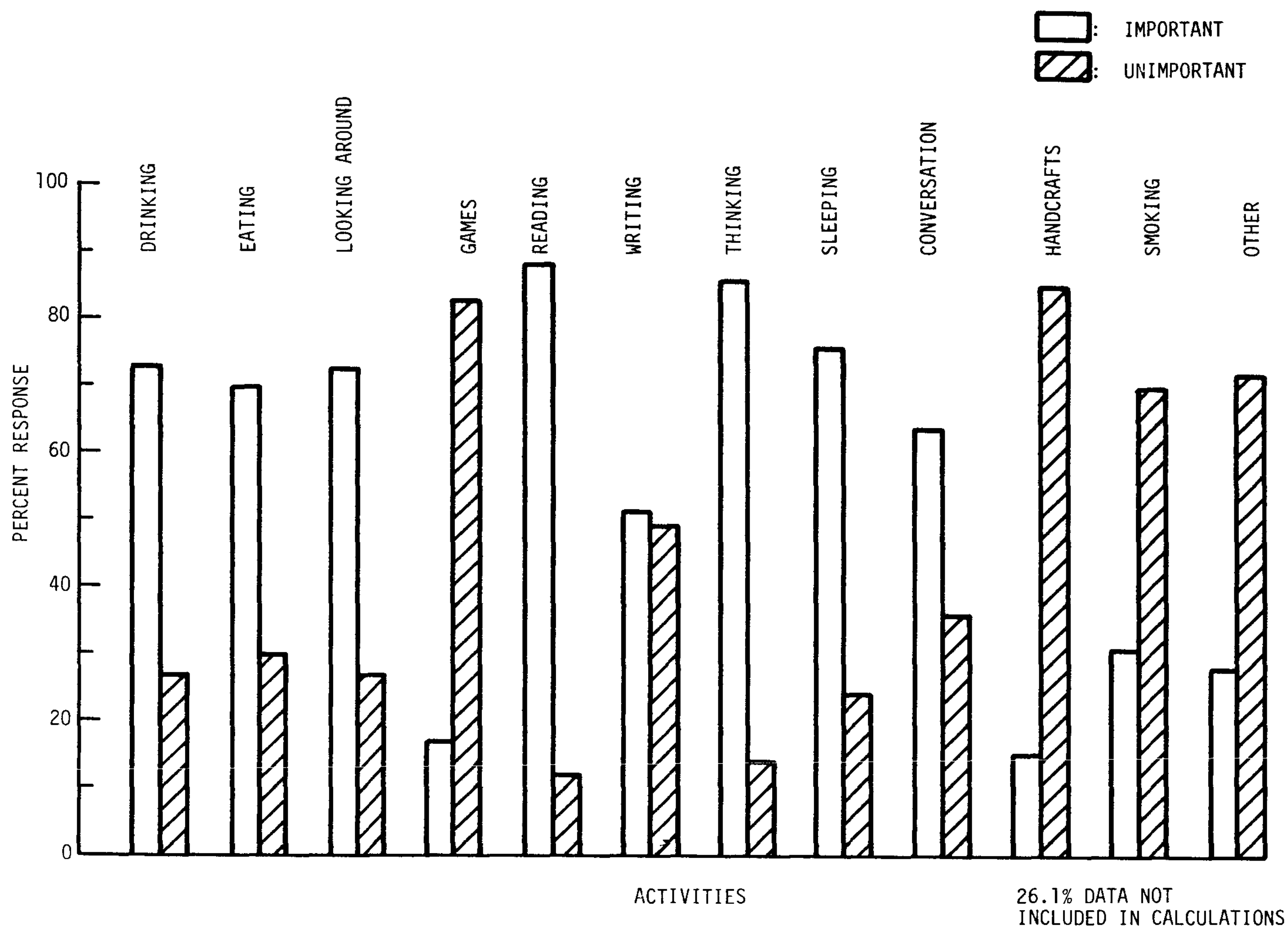


Figure 11. Percent Respondents Rating The Importance Of Activities (Question 1)

unimportant by the greatest numbers of respondents (82.7% and 82.5%, respectively), followed by Smoking (69.5%). Writing was felt to be important by about half the respondents (50.7%), while the other half judged it to be unimportant (49.3%). Few respondents (only 20.8%) bothered to make any response regarding the importance of Other activities, and of those who did respond, the majority (72.0%) felt these were unimportant.

Figure 12 and Appendix D show the distribution of responses to Question 2, regarding passengers' preferences for the amount of time spent doing various activities. It appears that the vast majority of respondents were content with the amount of time they presently spent engaged in these travel behaviors. However, approximately 20-30% of the sample would prefer to spend more time Reading, Writing, Sleeping, Thinking, having Conversation, and Looking Around on future train trips. Activities which a similar proportion of passengers would like to spend less time on included Smoking, Handcrafts, and Games.

Comparison of the results of Questions 1 and 2 shown in Figures 11 and 12 suggest that the activities considered important by the majority of passengers are also the behaviors which the greatest numbers wish to spend more time on. These behaviors include such activities as Reading and Sleeping. Conversely, the activities which are considered to be unimportant are the same as those which passengers prefer to spend less time doing on future trips (e.g., Handcrafts, Smoking). A Pearson

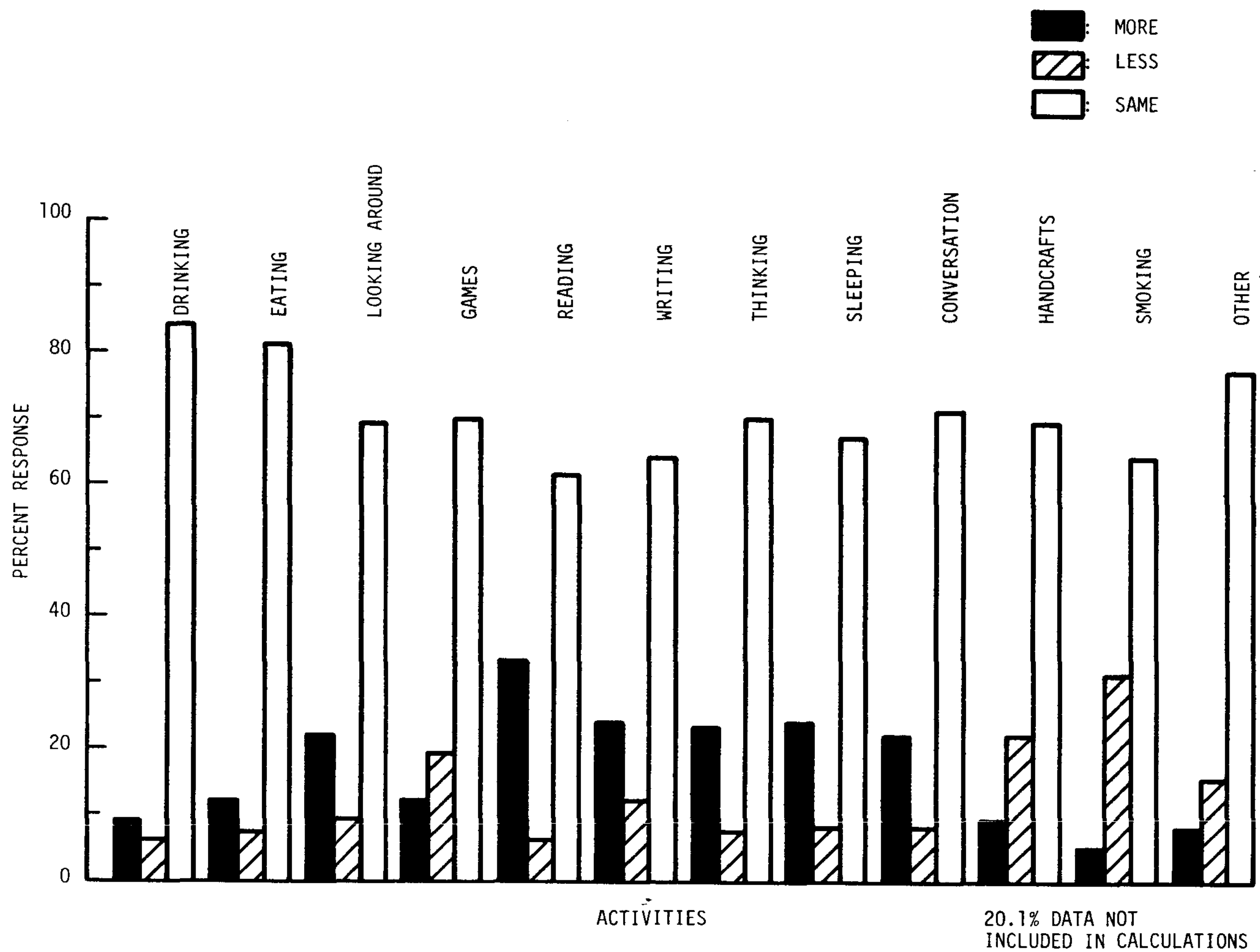


Figure 12. Percent Respondents Rating Time Preference For Activities On Future Trips (Question 2)

correlation of 0.93 ($p<.01$, d.f. = 10) was computed between the proportions of passengers responding in the "Important" category for Question 1 and the "More" category for Question 2, using the percent values for each activity shown in Appendix D. Similarly, a Spearman rank correlation of 0.66 ($p<.02$, d.f = 10) was found by ranking the activities according to importance and time preference, based on the percentage response in the "Important" and "More" categories in these two questions. These high parameteric and non-parametric correlation values suggest a strong relationship between subjective attitudes towards individual activities' importance and the amount of time passengers wish to spend doing them.

In addition, several non-parametric tests of association were performed on passenger's responses to corresponding activities in Questions 1 and 2, to determine the level of consistency of individual passengers' attitudes toward the various activities. The results are shown in Table 5. (Passengers responding in the "Same" category in Question 2 have been excluded from the analysis). For each activity, there is a statistically significant relationship between responses of "Important" on Question 1 and "More" on Question 2, and "Unimportant" on Question 1 and "Less" on Question 2. Phi coefficients range from 0.43 for Sleeping to 0.77 for Other; contingency coefficients were consistently lower, ranging from 0.40 to 0.61 for the same activities.

Table 5

Results of Non-Parametric Tests of Association between Passengers' Judgments of Activity Importance and Time Preference

Activity	# of Pairs	Phi* Coefficient	X^2**	Contingency Coefficient
Beverage Consumption	98	.54	26.13	.47
Eating	129	.69	57.57	.57
Looking around	189	.57	58.17	.49
Games	156	.63	58.98	.53
Reading	245	.61	84.39	.52
Writing	202	.54	55.86	.47
Thinking	184	.52	45.36	.46
Sleeping	192	.43	33.16	.40
Conversation	166	.57	51.56	.50
Handcrafts	164	.73	83.82	.59
Smoking	198	.56	57.62	.49
Other	37	.77	18.62	.61

* All Phi coefficients are significant at the .001 level.
** All X^2 values are significant at the .00001 level.

Since questionnaires were distributed to a 25% sample of the same passengers whose activities were actually observed, it is possible to determine the relationships between the distributions of observed activities and the distributions of subjective responses about activities in Questions 1 and 2. In other words, it was possible to test the relationships between the activities people are <u>actually</u> doing, the activities which they say are <u>important</u> to their satisfaction, and the behaviors they would <u>like</u> to be doing on the trains.

Table 6 compares the relative proportions of activities observed from a total of 3310 passengers, with the percentages of responses made in selected categories for the same activities on Questions 1 and 2. Rank order values from low (1) to high (12) are also included for the various activities. Table 7 shows the parametric and non-parametric correlations between these values. There is clearly a strong positive relationship between the activities which passengers perform and the activities they feel to be subjectively important. An even stronger relationship exists between the observed performance levels of activity and passengers' desire to spend more time on these behaviors on future trips. The low negative correlations between observed levels of activity and the percentages of passengers responding in the "Same" category on Question 2 shows that passengers are really not quite satisfied with the amount of time they presently spend on different activities.

Table 6

Relative Proportions of Passenger Activities Observed and Responses to Questions of Activity Importance and Time Preference

Activity Observed (Survey Descriptor)	Observed Relative Frequency (% (Rank))	% Responding "Important" on Question 1 (% (Rank))	% Responding "More" on Question 2 (% (Rank))	% Responding "Same" on Question 2 (% (Rank))
Doing Nothing (Thinking)	6.3 (8)	85.9 (11)	23.1 (9)	70.2 (8)
Sleeping	15.9 (10)	76.1 (10)	23.9 (10)	66.8 (4)
Smoking	0.5 (1.5)	30.5 (4)	5.0 (1)	64.2 (3)
Viewing (Looking around)	25.5 (12)	62.7 (7)	21.7 (7)	69.3 (6)
Talking-Listening (Conversation)	15.0 (9)	61.9 (6)	21.8 (8)	70.7 (9)
Games	1.6 (3)	17.3 (1)	11.6 (5)	69.7 (7)
Handcrafts	0.5 (1.5)	17.5 (2)	8.9 (3)	69.2 (5)
Eating	2.9 (6)	70.4 (8)	12.1 (6)	80.6 (11)
Drinking (Beverage Consumption)	2.4 (4)	72.9 (9)	9.4 (4)	84.4 (12)
Reading	22.2 (11)	87.6 (12)	33.4 (12)	60.6 (1)
Writing	2.7 (5)	50.7 (5)	24.4 (11)	63.6 (2)
Other	4.4 (7)	28.0 (3)	8.3 (2)	77.1 (10)

Table 7

Parametric and Non-Parametric[1] Correlations Between Observed Activities and Subjective Ratings of Importance and Time Preference

	Observed Relative Frequency of Activity (Activity Ranks)
Proportion Responding "Important" - Question 1 (Importance Ranks)	r = .56 (.65) ($p<.1$) ($p<.02$)
Proportion Responding "More" - Question 2 (Time Preference Ranks)	r = .74 (.67) ($p<.01$) ($p<.02$)
Proportion Responding "Same" - Question 2 (Time Preference Ranks)	r = -.35 (-.08) (NS) (NS)

1. Spearman rank order correlations corrected for ties (Hays, 1973, p. 791) are shown in parentheses.

3.2.2 Perceptions of Ride Quality and Its Subjective Effects on Passenger Activities

Figure 13 and Appendix D show the distribution of ride comfort responses to Question 3. The results suggest that the ride quality of the Amtrak trip was judged quite positively by the majority of respondents. The most frequent response to this question was "Comfortable" (43.9%), and over 75% of the passengers polled responded in the comfortable range (either "Somewhat Comfortable", "Comfortable", or "Very Comfortable").

The results of Questions 4 and 5, regarding passengers' perceptions of how environmental and other variables interfere with their ability to do specific activities, are shown in Figures 14 (a through e) and 15 (a through f). The numerical values of these distributions are shown in Appendix D. For Low Effort activities such as Smoking, Looking Around (Viewing), and Thinking (Doing Nothing), the most frequent response to Question 4 was "None of the above interfere with my [activity]." These three activities generally had low response rates, which may also indicate a lack of perceived interference by ride quality or comfort factors. Sleeping, which was also designated as a Low Effort activity, was perceived to be disrupted by the rough ride by over one-fourth of those responding to this item. One-fifth of those responding also felt that noise interfered with this activity, while 11% cited temperature and space factors as restrictive.

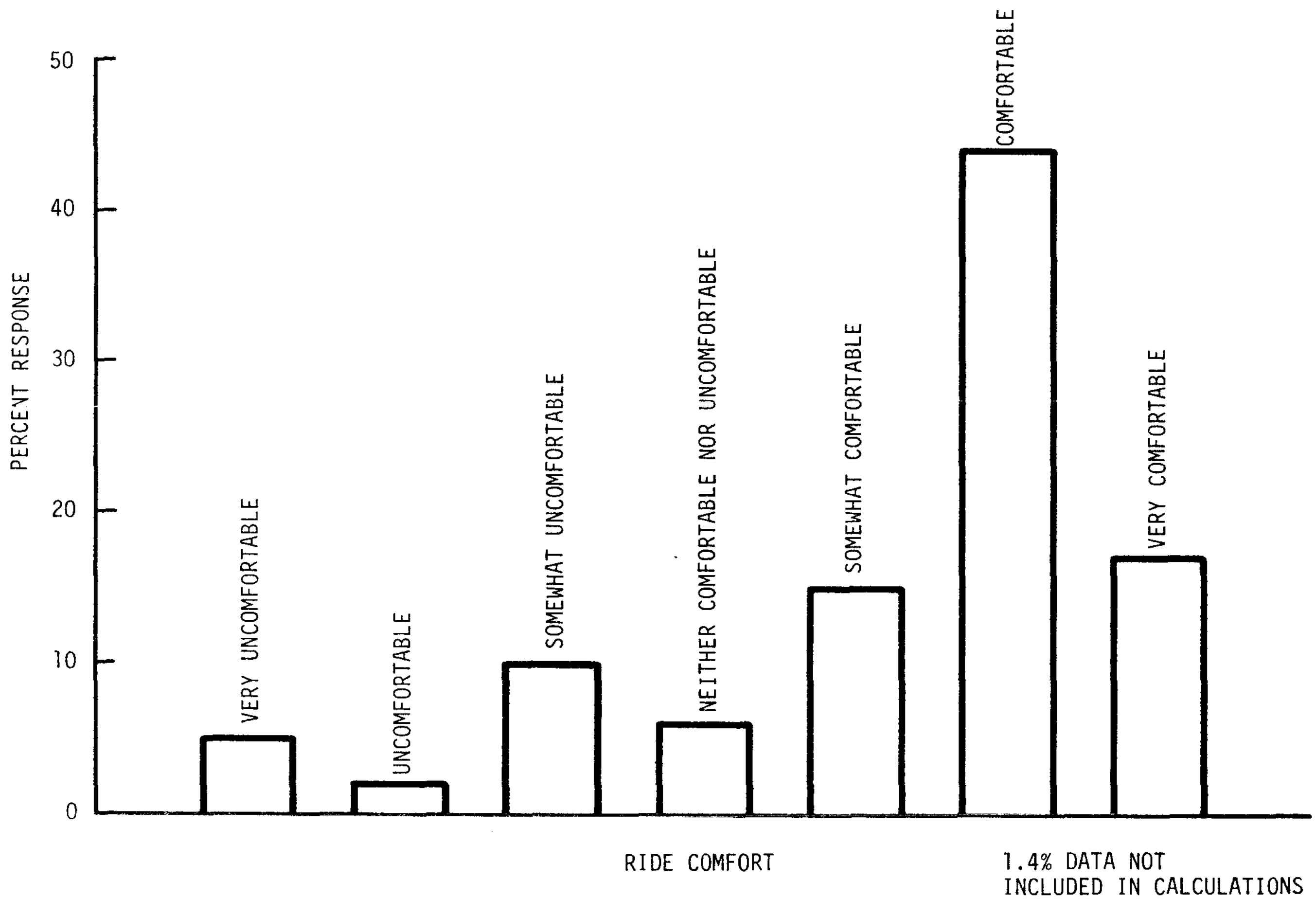


Figure 13. Distribution Of Ride Comfort Responses (Question 3)

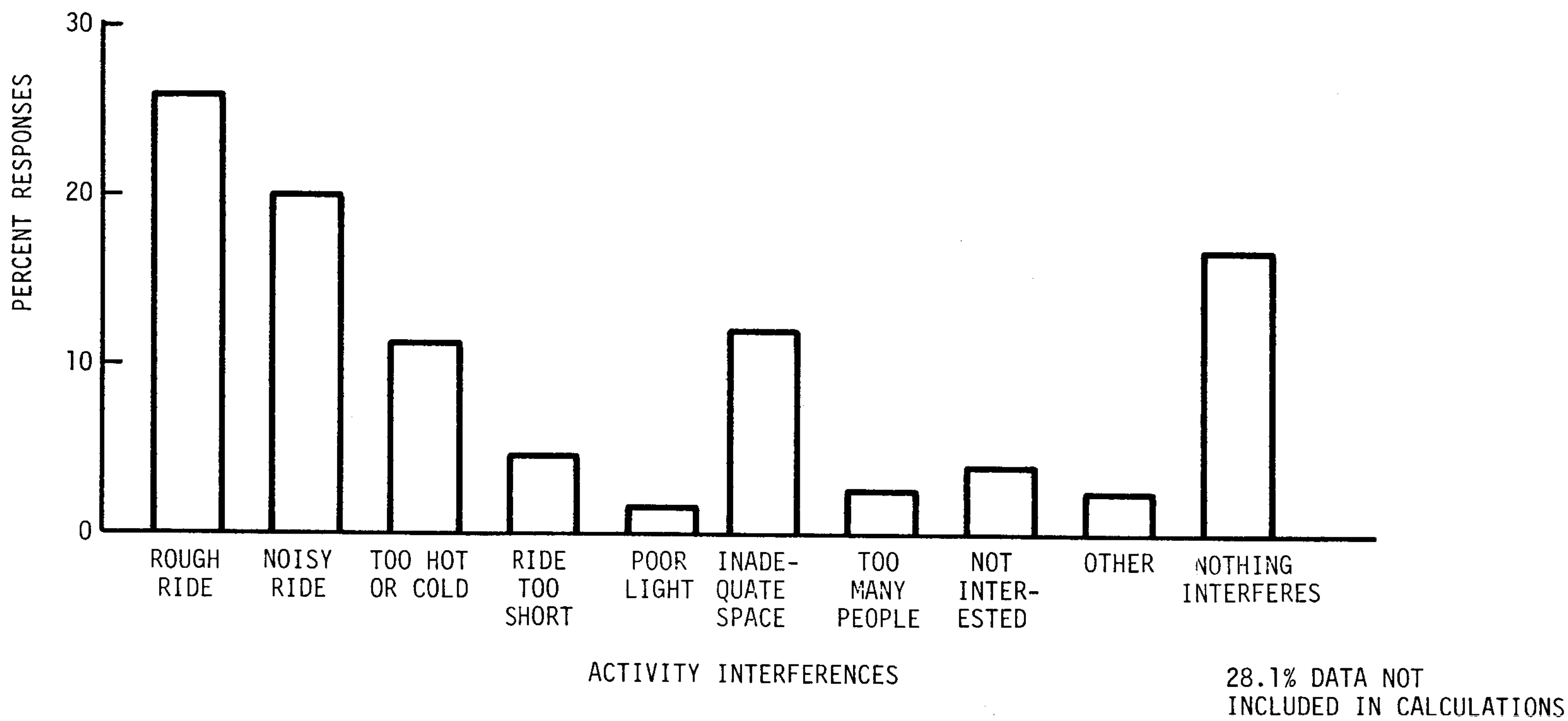


Figure 14a. Distribution Of Activity Interferences For Sleeping

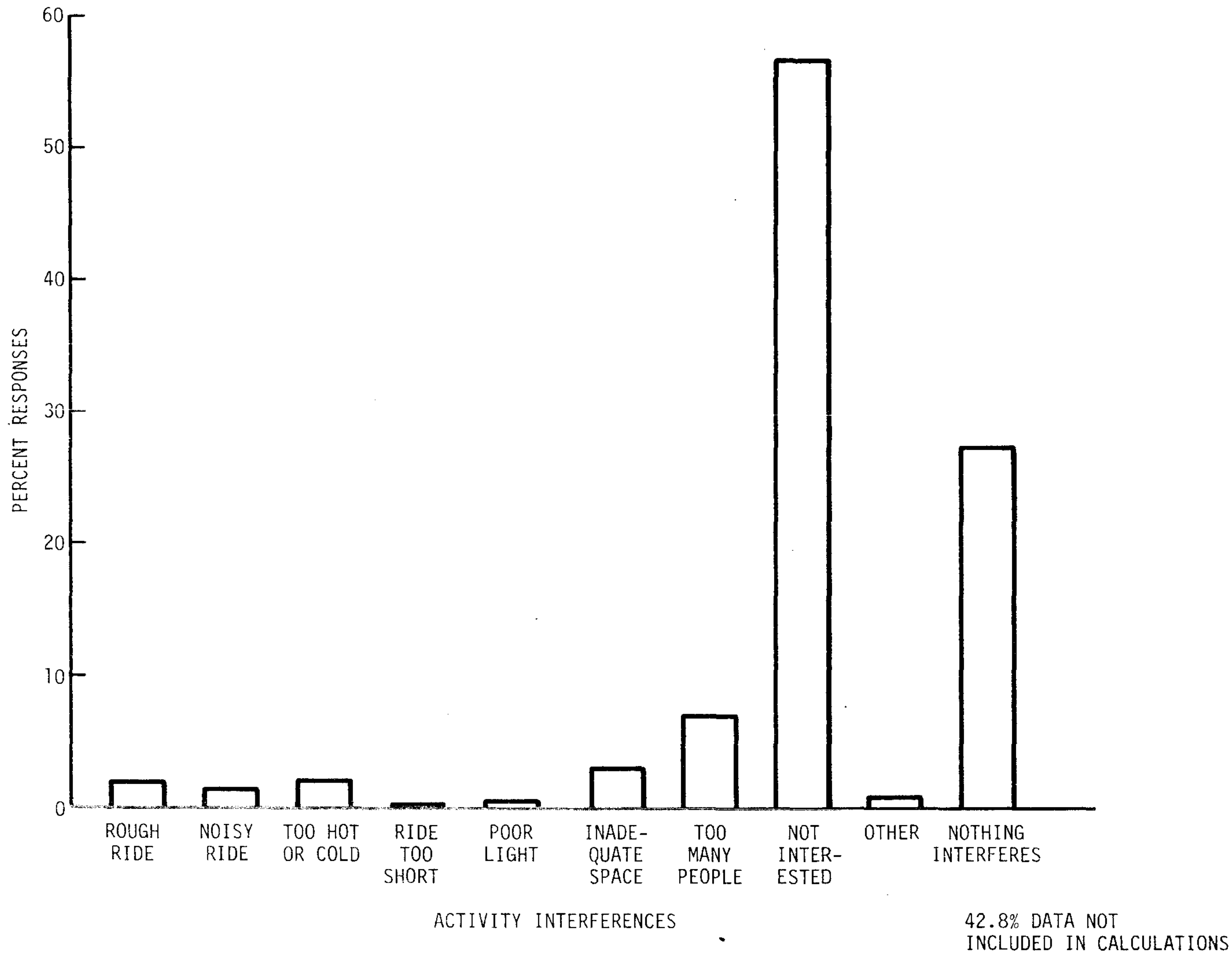


Figure 14b. Distribution Of Activity Interferences For Smoking

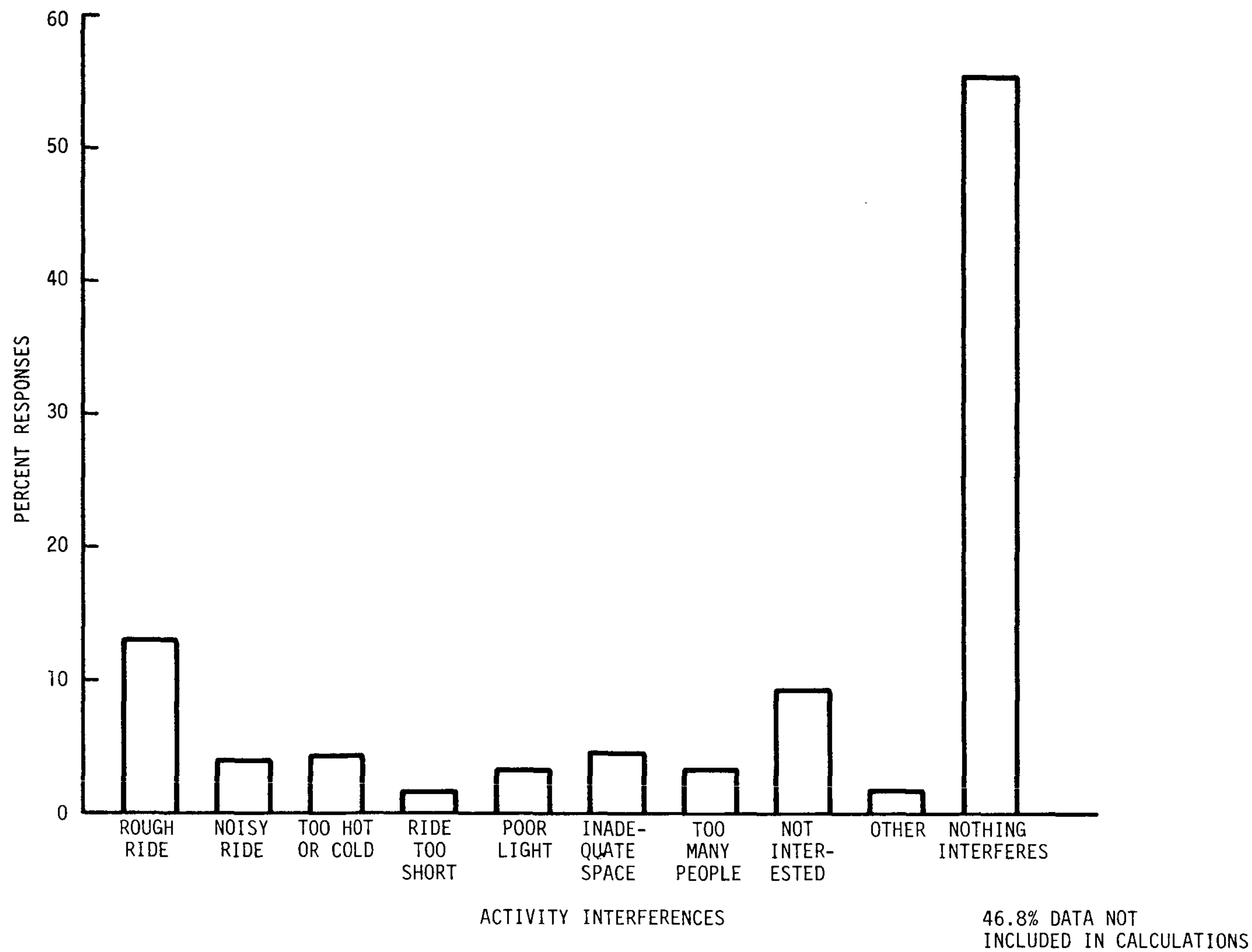


Figure 14c. Distribution Of Activity Interferences For Looking Around

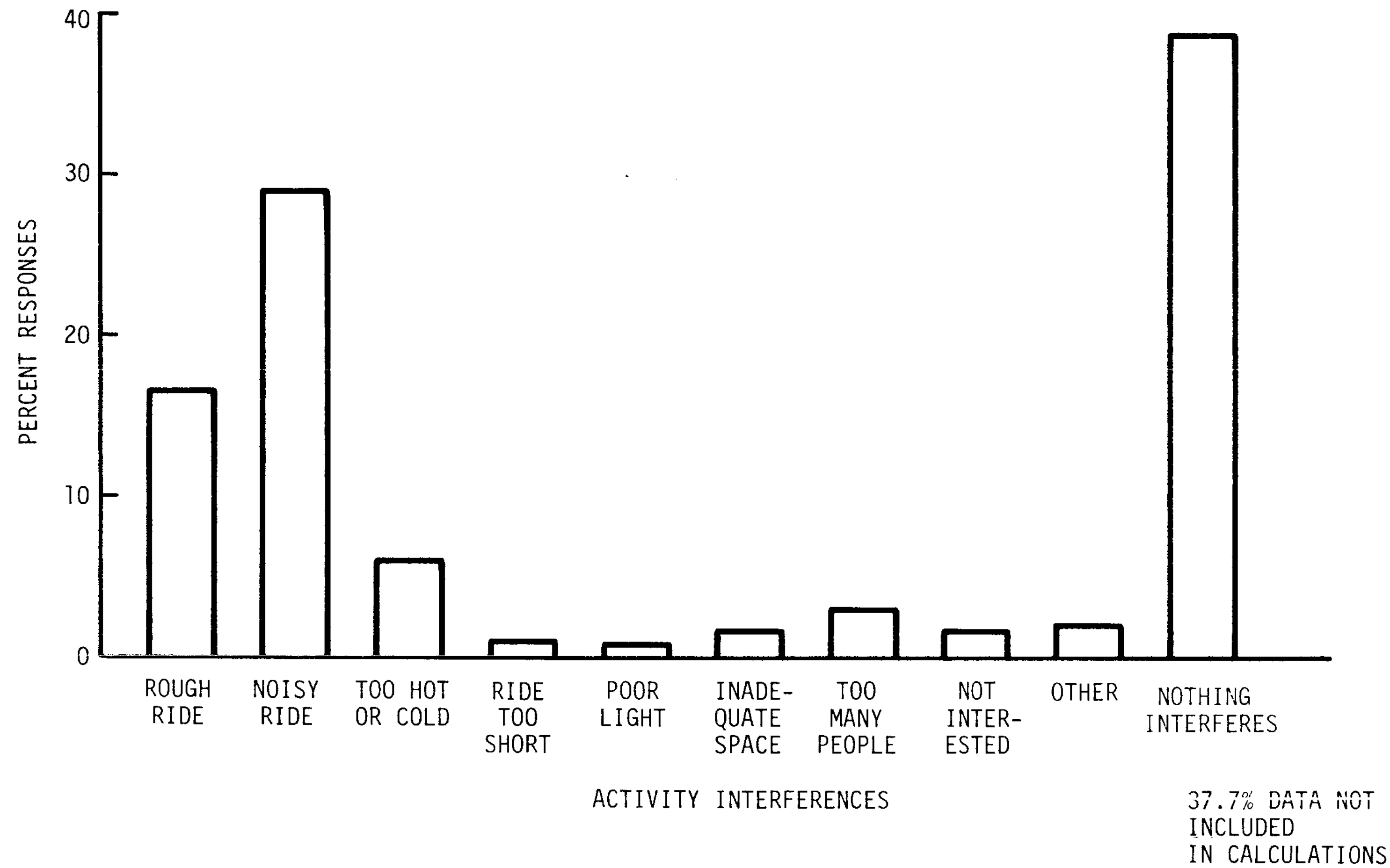


Figure 14d. Distribution Of Activity Interferences For Thinking

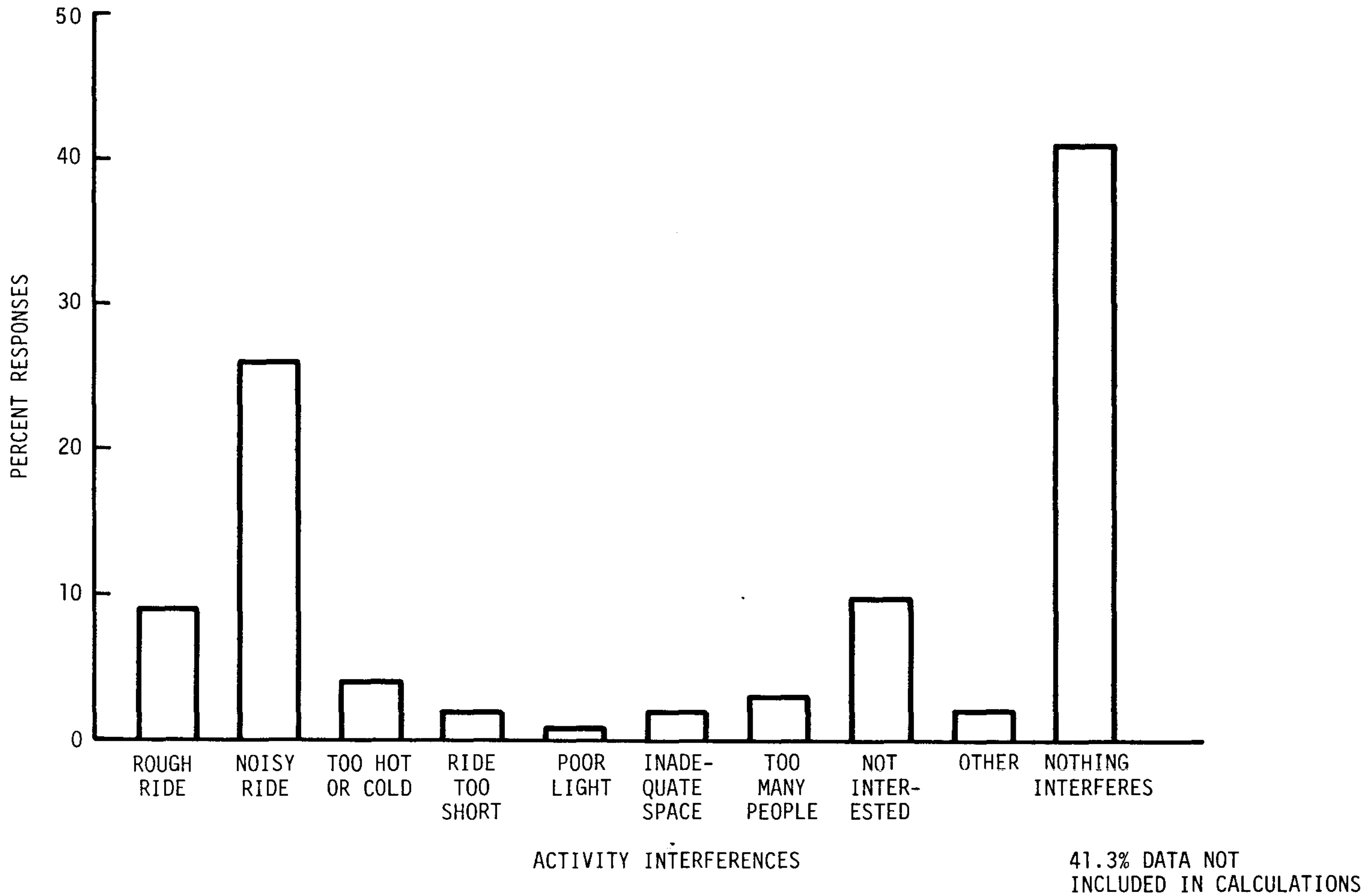


Figure 14e. Distribution Of Activity Interferences For Conversation

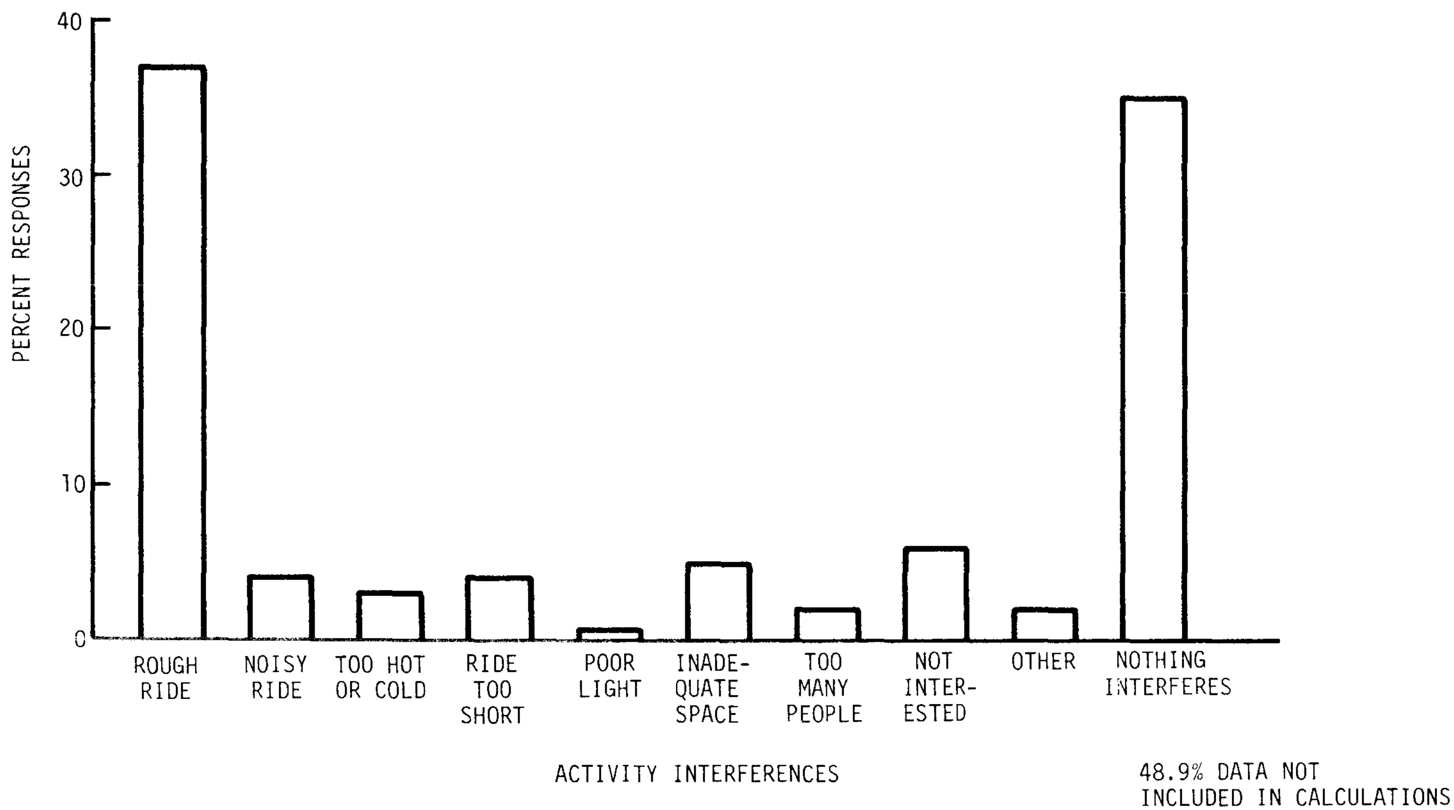


Figure 15a. Distribution Of Activity Interferences For Eating

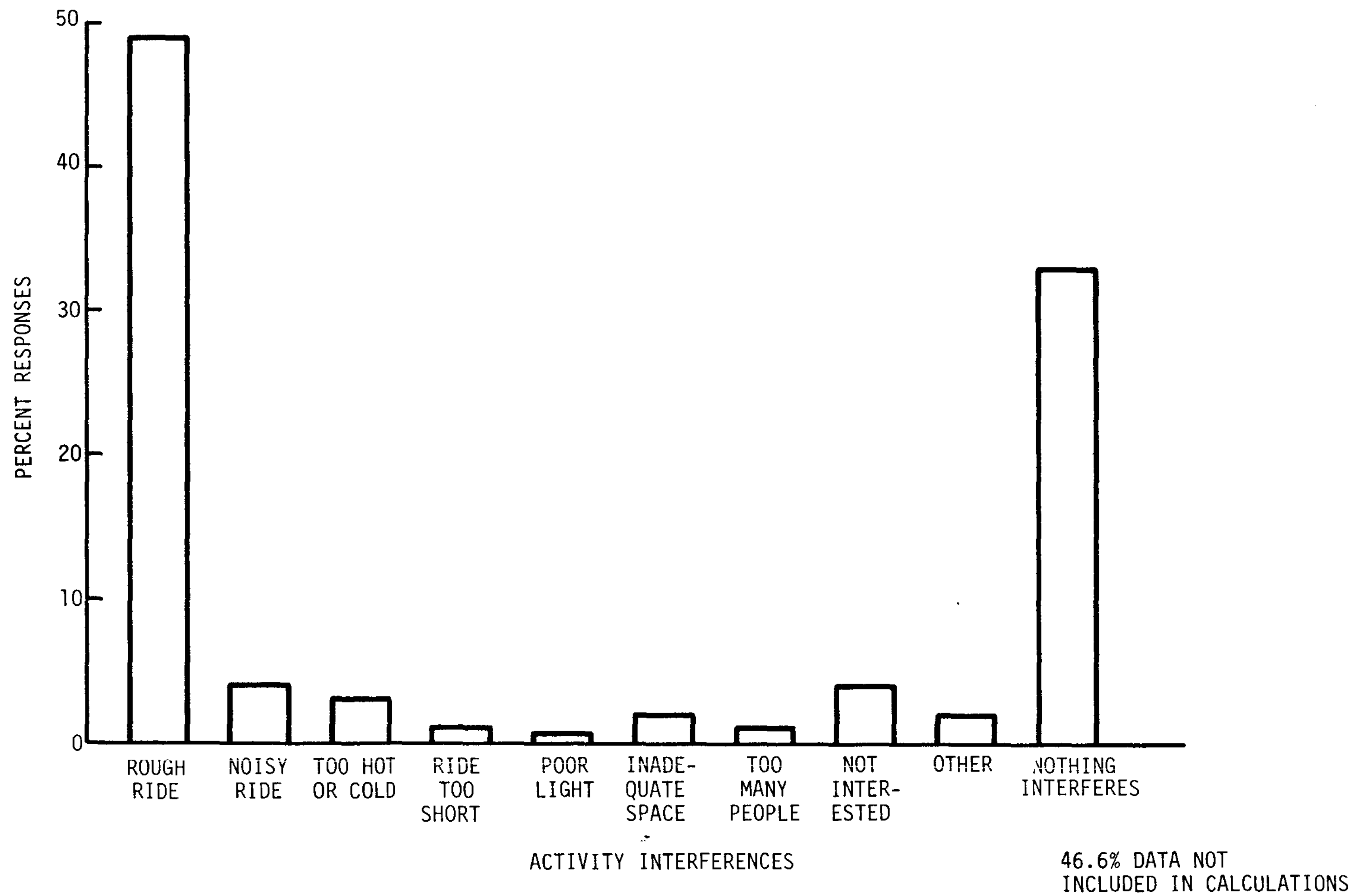


Figure 15b. Distribution Of Activity Interferences For Beverage Consumption

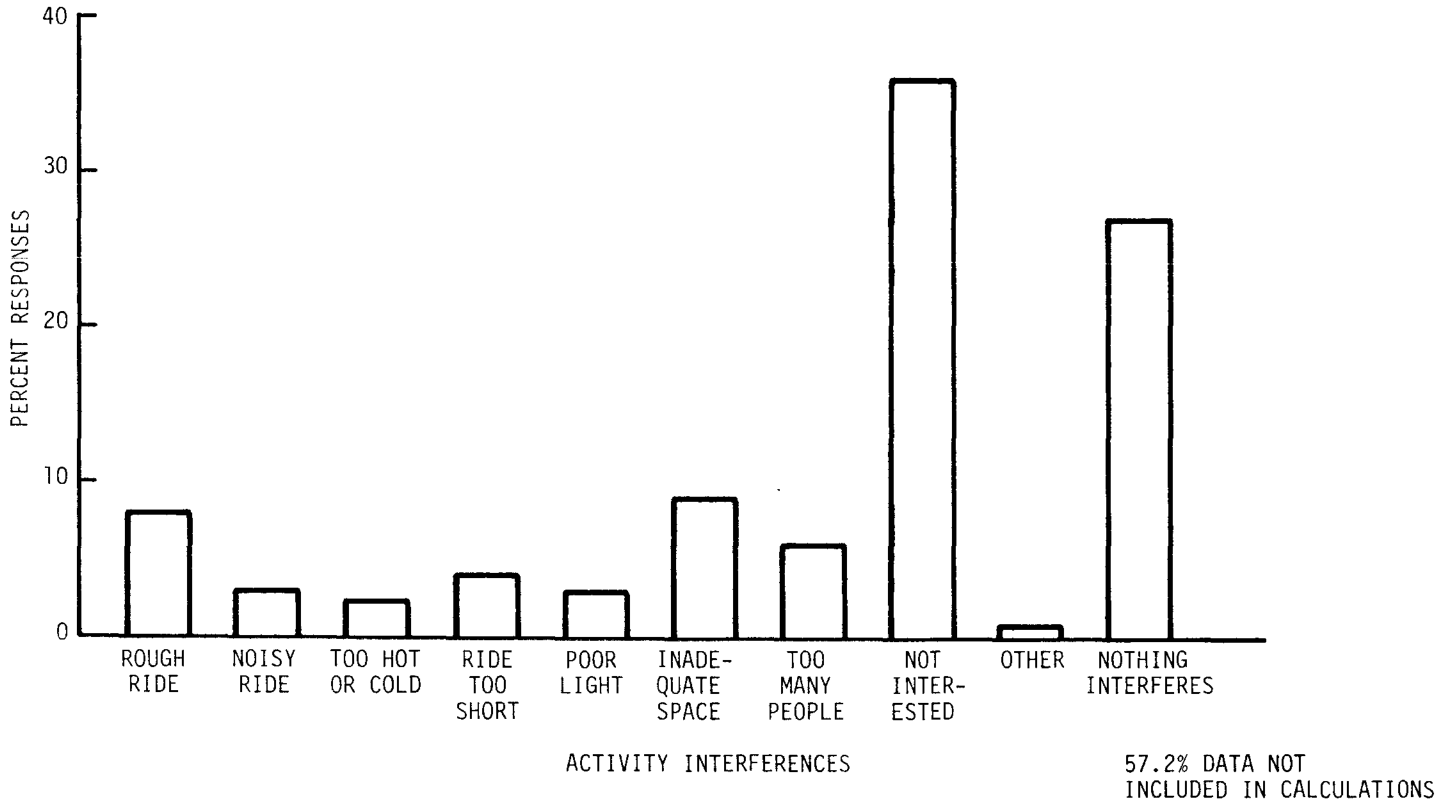


Figure 15c. Distribution Of Activity Interferences For Games

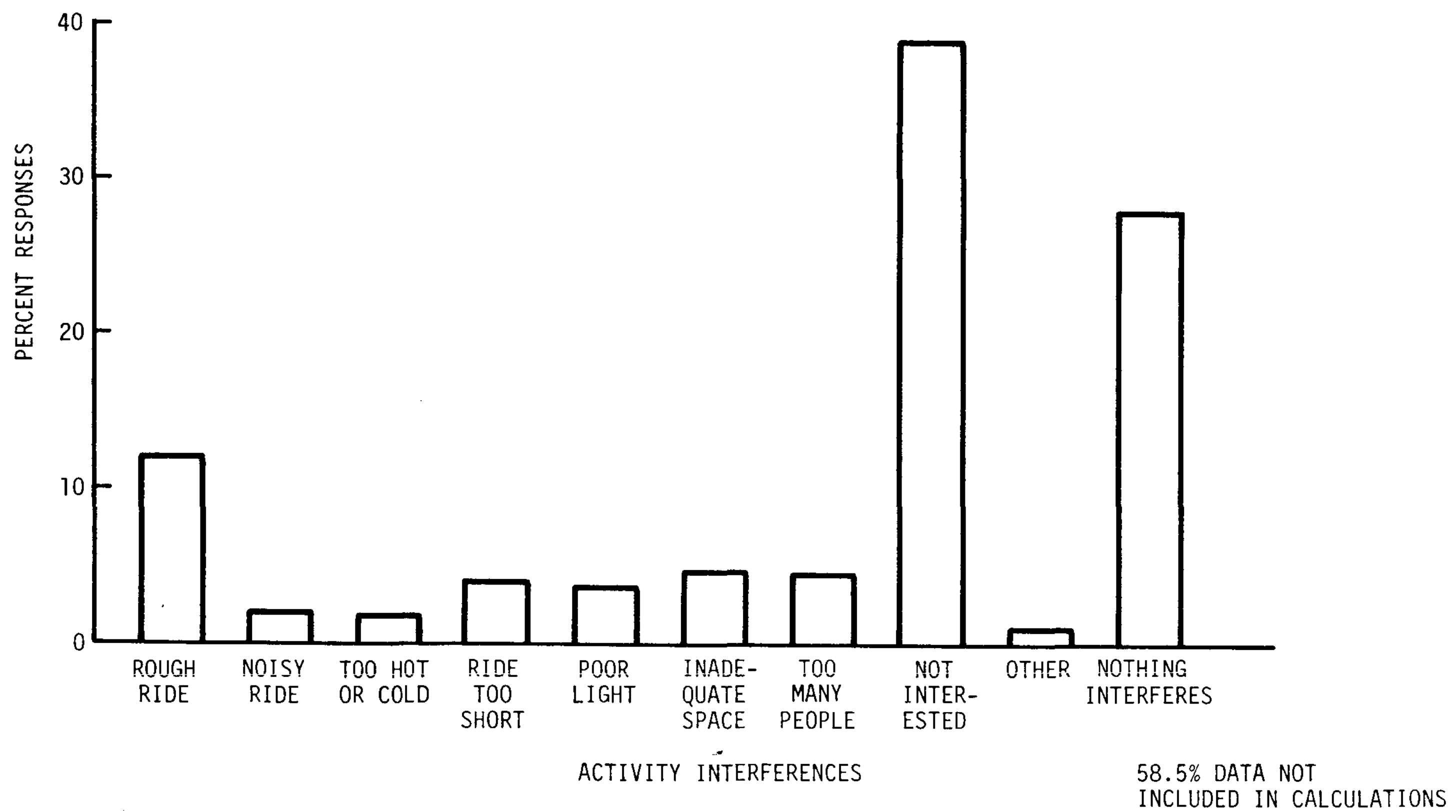


Figure 15d. Distribution Of Activity Interferences For Handcrafts

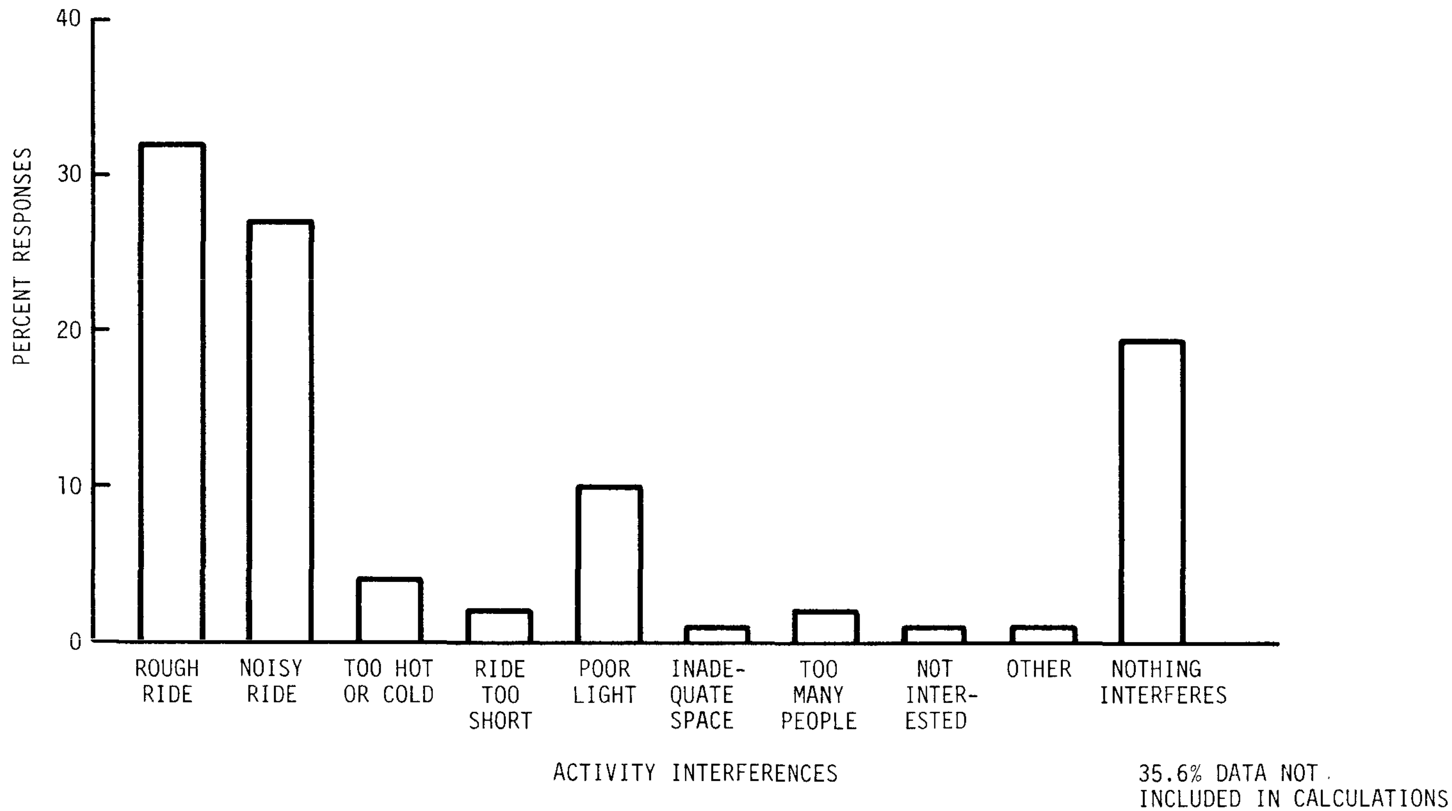


Figure 15e. Distribution Of Activity Interferences For Reading

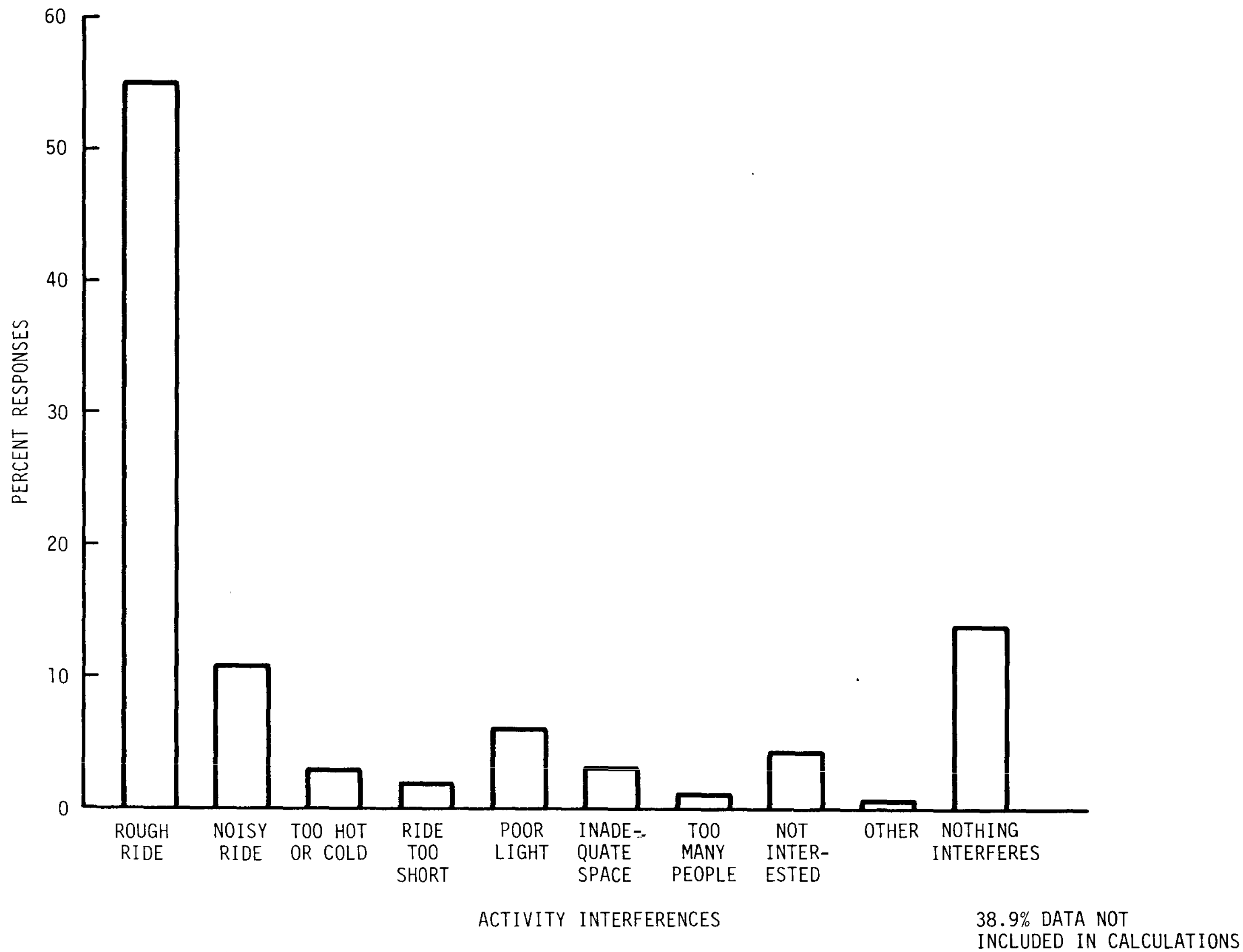


Figure 15f. Distribution of Activity Interferences For Writing

For Medium Effort activities such as Games and Handcrafts, the largest percentages of response were in the "not interested" and "none of the above interfere" categories. The response rates were also quite low for these activities. Forty-one percent of those responding did not perceive Talking-Listening (Conversation) to be disrupted by any of the factors listed in Question 4, although roughly one-fourth said that noise interfered with their conversation.

Passengers perceived ride quality and comfort factors to interfere more with High Effort activities than with Low or Medium Effort behaviors. Ride roughness was perceived to interfere with the High Effort activities of Eating, Drinking, Reading, and Writing more than any other comfort, trip, or personal preference variable, and more than for any of the Low and Medium Effort activities. Noise was also cited as a disruptive factor by 27.1% of the respondents for Reading and 10.7% of the respondents for Writing. Poor lighting was perceived to interfere with Reading and Writing more often than with the other activities. Passengers also expressed the lowest level of disinterest for the High Effort activities, compared to responses for Low and Medium Effort behaviors. Sums of the percentage responses in the ride quality and comfort related categories for Questions 4 and 5 (i.e., "Rough ride...", "Noisy ride...", "...too hot or cold...", "...light poor...", "...not enough space...", and "...too many people...") are shown in Table

8. There is clearly a trend toward a higher level of perceived interference with the High Effort activities.

The total percent interference response for each activity may also be used to rank order the activities for performance difficulty on the train. These ranks may then be compared to the *a priori* ordering of activities by effort discussed in Section 2.0. Table 9 shows the two sets of activity ranks. The major discrepancy between the two orders is caused by the high ranks of Doing Nothing (Thinking) and Sleeping and the low ranks of Games and Handcrafts obtained from the total perceived interference responses to Question 4, in comparison to the *a priori* ordering. The sums of interference responses for High Effort activities were generally high enough and the sums for Looking Around and Smoking low enough to yield ranks for these activities which are comparable to the *a priori* ranks. The Spearman correlation coefficient (corrected for ties) between the two orders is 0.48 which is not significant ($t=1.64$, d.f.=9).

Table 9 also shows a set of activity ranks derived from percent response in the "Rough ride interferes with my [activity]" category on Questions 4 and 5. This rank order is more similar to the *a priori* effort ranks than is the order based on total percent interference response (Spearman $r = 0.59$; $t=2.19$, d.f.=9, $p<.1$) between *a priori* and "rough ride" ranks). Also, the rank order correlation between the "rough ride" ranks and the order based on total percent interference response is so

Table 8

Total Percent Ride Quality Interference Response (Questions 4 and 5) as a Function of Activity Effort

Activity	Total % Interference Response	Effort
Doing Nothing (Thinking)	56.7	
Sleeping	52.8	Low
Smoking	15.5	($\bar{X}$ = 39.3)
Viewing (Looking Around)	32.1	
Talking-Listening (Conversation)	44.8	
Games	32.1	Medium
Handcrafts	28.4	($\bar{X}$ = 35.1)
Eating	51.6	
Drinking (Beverage Consumption)	58.4	High
Reading	76.1	($\bar{X}$ = 66.4)
Writing	79.5	

Table 9

A Priori Effort vs. Perceived Interference Ranks[1]
Derived from Questions 4 and 5

Activity	*A Priori* Effort Rank	Rank Based on Total % Interference Response	Rank Based on % "Rough Ride" Response
Doing Nothing (Thinking)	1	8	6
Sleeping	2	7	7
Smoking	3	1	1
Viewing (Looking Around)	4	3.5	5
Talking-Listening (Conversation)	5	5	3
Games	6	3.5	2
Handcrafts	7	2	4
Eating	8	6	9
Drinking (Beverage Consumption)	9	9	10
Reading	10	10	8
Writing	11	11	11

A Priori Effort Rank vs. Total % Interference Response: r = .48 (NS)

Total % Interference Response vs. % "Rough Ride" Response: r = .86 ($p<.01$)

A Priori Effort Rank vs. % "Rough Ride" Response: r = .59 ($p<.1$)

1. 1 - low; 11 = high

high ($r = 0.86$; $t=5.05$, $d.f.=9$, $p<.01$) as to suggest that rough ride is the dominant comfort factor in passengers' perceptions of variables which interfere with their activities.

The total percent interference response for each respondent from Questions 4 and 5 was also correlated with the response to Question 3 regarding ride comfort. A Spearman rank order correlation of -0.32 ($p<.0001$) was found, using data from 792 respondents who answered Question 3 and at least some part of Questions 4 and/or 5. Since the higher scores on Question 3 signify a more comfortable ride, the correlation coefficient indicates that the more comfortable a respondent rated the ride, the fewer complaints were made about ride quality variables interfering with activities, and vice versa.

3.2.3 The Effects of Trip Characteristics on Passengers' Perceptions of Activity and Ride Quality

Questions 6 through 11 were used in the survey to obtain information about certain trip variables which might influence passengers' attitudes toward the importance of activities and the effects of ride quality on activities. These variables include trip distance, previous trip experience, trip purpose, and number of traveling companions. The percentage distributions of responses to these questions are shown in Appendix D.

Questions 6 and 7 were used to determine the actual distances which passengers in the survey sample traveled on their trips on the Northeast Corridor. Almost 40% of the passengers polled were traveling a distance of 200-300 miles on Amtrak. A total of more than 60% of the respondents made 100-300 mile trips, considered to be in the intermediate distance range. Approximately 20% traveled less than 100 mi or more than 300 mi.

The effects of trip distance on perceived importance of activity were assessed using an Activity Importance Index, which was computed for each respondent as the total number of activities checked as "Important" on Question 1. Table 10 shows the results of a one-way analysis of variance on this index by trip distance. Activity Importance was shown to increase the longer the trip ($p<.01$). Similarly, an Activity Time Preference Index was computed by counting the total number of activities which each respondent wished to spend "More" time doing on future trips (Question 2). The results of a one-way analysis of variance on this index for trip distance (Table 11) suggest a direct relationship ($p<.1$) between length of the trip and the number of activities respondents wished to spend more time on. There was no significant difference in mean ride comfort ratings on Question 3 between the four groups of passengers traveling known trip distances ($F=1.77$, d.f = 3,768).

Table 10

Results of One-Way Analysis of Variance of Activity Importance Index by Trip Distance

Source	SS	d.f.	MS	F
Between (Trip Distance)	118.03	4*	29.51	5.81 ($p<.01$)
Within	4055.53	799	5.08	
Total	4173.56	803		

Table 11

Results of One-Way Analysis of Variance of Activity Time Preference Index by Trip Distance

Source	SS	d.f.	MS	F
Between (Trip Distance)	31.33	4	7.83	2.03 ($p<.1$)
Within	3078.55	799	3.85	
Total	3109.87	803		

* In this and all subsequent analyses of variance in Sections 3.2.3 and 3.2.4, the number of treatment groups = the number of trip or demographic variable categories in the survey item being analyzed + 1. This additional group includes passengers who did not respond to or gave anomalous responses to the trip variable or demographic item in question.

In order to assess the effects of trip distance on passengers' perceptions of ride quality variables' interference with activities, an Activity Interference Index was computed for each respondent by counting the total number of comfort-related response categories checked across all activities in Questions 4 and 5 (i.e., "Rough ride...", "Noisy ride...", "...too hot or cold...", "...light poor...", "...not enough space..." and "...too many people..."). No significant differences between the average values of this index were found as a function of trip distance (F=1.13, d.f.=4,799).

Question 8 was originally included in the survey to determine differences between passengers riding in first class (Amclub) vs. coach vehicles. However, it was later decided to limit data collection to only tourist class Amcoach vehicles, as these provided greater numbers of people for observation. Therefore, all passengers responding to Question 8 answered in the same category ("Coach").

It was possible, however, to separate respondents into two vehicle groups, depending upon whether they sat in Amcoach or Amcafe cars. It was found that 83.1% of the passenger sample was polled in Amcoach vehicles, and 16.9% in Amcafe cars. No significant differences were found between these two groups on the Activity Importance Index (t=0.66, d.f.=802), Activity Time Preference Index (t=0.33, d.f.=802), or Activity Interference Index (t=.08, d.f. =802). However, passengers in the Amcoach vehicles rated the ride as significantly more comfortable than passengers in the Amcafe cars ($t=2.93$, d.f.=790, $p<.01$).

Question 9 was used to assess the level of previous trip experience of respondents on Amtrak trains on the Northeast Corridor. The distribution of responses is shown in Appendix D. The most frequent response to this item ("More than 10 times") was given by 36.3% of the passengers polled. However, over 50% of the respondents had little or no previous trip experience. Only a very few passengers reported having an intermediate level of trip experience ("6-9 times").

Since it was expected that differences in previous trip experience might cause systematic variations in passengers' attitudes toward activities and ride quality, one-way analyses of variance were conducted on the three activity indexes and ride quality ratings as a function of trip experience. No significant differences were found as trip experience varied for Activity Importance ($F=1.79$, d.f.=4, 799), Activity Time Preference ($F=1.24$, d.f. =4, 799), ride comfort ratings ($F=1.56$, d.f.=4,787), or Activity Interference ($F=1.51$, d.f.=4, 799).

Question 10 was included to determine the reasons for passengers' Amtrak trips. The percentage distribution of results is shown in Appendix D. The most frequent trip purpose reported by respondents in this July survey was "vacation or recreation" (48.2%). Another 24% were traveling to conduct "personal affairs", while 20% reported that the purpose of their trip was for "business or work".

The results of a one-way analysis of variance on the Activity Importance Index by trip purpose (Table 12) showed that significantly fewer activities were rated as important by respondents traveling for business or school purposes than by those on vacation/recreation-related trips ($p<.05$). However, the greatest number of Activity Interference responses (Table 13) were made by passengers traveling for business and school purposes, as opposed to those making trips for personal, vacation/recreation, or other reasons ($p<.01$). No significant differences were found between groups traveling for different reasons on the Activity Time Preference Index ($F=64$, d.f. =5,798) or on the ride comfort ratings ($F=1.05$, d.f. =5,786).

The distribution of responses to Question 11 regarding traveling companions is shown in Appendix C. Over half the respondents reported traveling alone; an additional 24.3% traveled with only one other person. Very few passengers polled traveled in groups of three or more.

Number of traveling companions did not affect respondents' attitudes toward the importance of activities to any great extent, as shown by the non-significant results of one-way analyses of variance on Activity Importance ($F=0.86$,d.f.=5,798) and Activity Time Preference ($F=0.21$,d.f.=5,798). Ratings of

Table 12

Results of One-Way Analysis of Variance of Activity Importance by Trip Purpose

Source	SS	d.f.	MS	F
Between (Trip Purpose)	74.03	5	14.81	2.88 (p<.05)
Within	4099.54	798	5.14	
Total	4173.56	803		

Table 13

Results of One Way-Analysis of Variance of Activity Interference by Trip Purpose

Source	SS	d.f.	MS	F
Between (Trip Purpose)	411.45	5	82.29	3.37 (p<.01)
Within	19481.92	798	24.41	
Total	19893.37	803		

ride quality and its effects on passenger activity were worse for respondents traveling with more companions. Table 14 shows the results of a one-way analysis of variance on ride comfort ratings; passengers traveling with "5 or more others" rated the ride as significantly less comfortable than passengers traveling with fewer companions ($p<.05$). There was also a statistical trend ($p<.1$) toward higher Activity Interference Index values for passengers in this same group (Table 15).

3.2.4 The Effects of Demographic Characteristics on Passengers' Perceptions of Activity and Ride Quality

Questions 12 through 16 were included in this survey to obtain general demographic information about the passenger sample. The Activity Indexes based on responses to Questions 1,2,4, and 5 and the ride quality ratings from Question 3 have been broken down according to the major levels of the demographic factors. This type of analysis permits the determination of the effects of individual differences on passengers' attitudes toward activities and the perceived effects of ride quality on various activities. The demographic variables of interest are sex, education, age, occupation, and income. The percentage distributions of responses to Questions 12 through 16 regarding these demographic factors are presented in Appendix D.

Table 14

Results of One-Way Analysis of Variance on Ride Comfort Ratings as a Function of Traveling Companions

Source	SS	d.f.	MS	F
Between (Companions)	35.21	5	7.04	2.73 ($p<.05$)
Within	2026.37	786	2.58	
Total	2061.58	791		

Table 15

Results of One-Way Analysis of Variance on Activity Interference as a Function of Traveling Companions

Source	SS	d.f.	MS	F
Between (Companions)	249.67	5	49.93	2.03 ($p<.1$)
Within	19643.71	798	24.62	
Total	19893.37	803		

The results of Question 12 show that approximately 56% of the respondents were women and 44% were men. One way analyses of variance for the male, female, and unidentified sex groups were not significant for Activity Importance (F=0.1,d.f.=2,801), Activity Time Preference (F=0.48,d.f.=2,801), or Activity Interference (F=1.06, d.f. = 2,801). No significant differences in ride comfort response between males, females, or those who did not respond to Question 12 were found (F=1.38,d.f.=2,789).

The distribution of responses to Question 13 was extremely skewed, with 75% of the sample claiming to have at least a college education. Almost one-fourth reported having at least some high school training, and only a very few respondents said they had attended only grade school. The results of the same questionnaire item on the pilot study conducted three months earlier, and the results of Amtrak's own survey conducted on similar Amfleet equipment in the Northeast Corridor in May, 1976, present virtually the same educational distribution. However, the most recent statistics available on educational background from the Bureau of the Census (U.S. Department of Commerce, 1977) indicate that 60.8% of the Northeast regional sample had attained a high school education, while only 38.0% had any college or professional training. Thus, it appears that Amtrak passengers in the Northeast Corridor may be better educated than the general public living in the same region.

Educational background appeared to influence respondents' answers to Question 1 on Activity Importance and Question 3 on ride comfort. There was a trend ($p<.1$) toward a lower mean Activity Importance Index for passengers with a grade school education or less, compared to those respondents with high school, college, or unknown educational backgrounds (Table 16). As level of education increased, the average comfort rating decreased, resulting in significant ($p<.05$) differences between the mean response on Question 3 for the different educational groups (Table 17). No significant differences were found between groups for the Activity Time Preference or Activity Interference Indices ($F=0.22$, d.f.=3,800 and $F=1.83$, d.f.=3,800, respectively).

The age distribution of respondents according to the results of Question 14 is shown in Appendix D. The median and mode of this distribution fell in the 25-34 year old response category (28.8%) with number of respondents decreasing progressively with age above and below the modal category. A large number of respondents (25.2%) also fell into the 18-24 year old category, such that over half the passengers polled were aged 18-34 years.

The importance of passenger activity and ride quality factors seems to decrease as a function of age. As age increased, the number of activities passengers rated as "Important" decreased, resulting in significant differences ($p<.01$) between age groups on the Activity Importance Index (Table 18). Similarly, the number of activities passengers wished to spend "More" time on

Table 16

Results of One-Way Analysis of Variance on Activity Importance Index as a Function of Educational Background

Source	SS	d.f.	MS	F
Between (Education)	36.93	3	12.31	2.38 ($p<.1$)
Within	4136.63	800	5.17	
Total	4173.56	803		

Table 17

Results of One-Way Analysis of Variance on Ride Comfort Responses as a Function of Educational Background

Source	SS	d.f.	MS	F
Between (Education)	26.04	3	8.68	3.36 ($p<.05$)
Within	2035.54	788	2.58	
Total	2061.58	791		

decreased as age increased, resulting in significant differences ($p<.01$) between age groups on the Activity Time Preference Index (Table 19). The total number of factors which respondents indicated as interfering with activity decreased with age, resulting in significant differences ($p<.01$) in the Activity Interference Index means between age groups (Table 20). No significant differences were found between mean ride comfort ratings for the different age groups ($F=1.12$, d.f.=7,784).

The distribution of responses to Question 15 regarding occupation is shown in Appendix D. It is clear that the sample is representative of passengers in a wide range of occupations, the greatest numbers of which lie in the Professional and Technical (29.5%) and Student (20.5%) categories. Statistically significant differences between occupational groups were found for the Activity Importance Index ($p<.01$, Table 21), Activity Time Preference Index ($p<.01$, Table 22), Activity Interference Index ($p<.01$, Table 23), and ride comfort ratings ($p<.01$, Table 24). Because of the large number of groups, it is easier to characterize occupational differences in responses by describing overall patterns in response to the various activity and ride quality questions rather than by looking at each index individually.

Table 18

Results of One-Way Analysis of Variance of Activity Importance as a Function of Age

Source	SS	d.f.	MS	F
Between (Age)	328.18	7	46.88	9.70 ($p<.01$)
Within	3845.39	796	4.83	
Total	4173.56	803		

Table 19

Results of One-Way Analysis of Variance of Activity Time Preference as a Function of Age

Source	SS	d.f.	MS	F
Between (Age)	195.66	7	27.95	7.63 ($p<.01$)
Within	2914.22	796	3.66	
Total	3109.87	803		

Table 20

Results of One-Way Analysis of Variance of Activity Interference as a Function of Age

Source	SS	d.f.	MS	F
Between (Age	1277.70	7	182.53	7.80 ($p<.01$)
Within	18615.67	796	23.39	
Total	19893.37	803		

Table 21

Results of One-Way Analysis of Variance on Activity Importance as a Function of Occupation

Source	SS	d.f.	MS	F
Between (Occupation)	235.16	12	19.60	3.94 ($p<.01$)
Within	3938.40	791	4.98	
Total	4173.56	803		

Table 22

Results of One-Way Analysis of Variance on Activity Time Preference as a Function of Occupation

Source	SS	d.f.	MS	F
Between (Occupation)	163.09	12	13.59	3.65 ($p<.01$)
Within	2946.78	791	3.73	
Total	3109.87	803		

Table 23

Results of One-Way Analysis of Variance on Activity Interference as a Function of Occupation

Source	SS	d.f.	MS	F
Between Occupation)	857.34	12	71.44	2.97 ($p<.01$)
Within	10936.04	791	24.07	
Total	19893.37	803		

Table 24

Results of One-Way Analysis of Variance on Ride Comfort as a Function of Occupation

Source	SS	d.f.	MS	F
Between (Occupation)	65.52	12	5.46	2.13 ($p<.01$)
Within	1996.06	779	2.56	
Total	2061.58	791		

Table 25 shows that military personnel and students had the highest mean index scores regarding activity importance and time spent on activities, indicating a consistently positive attitude toward the importance of passenger activities for their satisfaction in riding the trains. The students, however, seemed to find it difficult to perform desired activities on the trains as indicated by the high Activity Interference score, although they rated the ride quite favorably. The military personnel did not seem to encounter these problems.

Sales personnel considered few activities to be important, but wished to spend more time on activity and perceived a high level of interference with activities. They also rated the ride comfort as quite severe compared to other groups.

Table 25

Mean Activity and Ride Comfort Index Values for Different Occupational Groups

Occupation	Activity Importance Index (Mean (Rank*))	Activity Time Preference Index (Mean (Rank))	Activity Interference Index (Mean (Rank))	Ride Comfort Rating (Mean (Rank))
Laborers	4.9 (3)	1.6 (8)	3.6 (3.5)	5.4 (10.5)
Public Service	5.5 (5)	1.4 (5)	5.2 (9)	4.8 (4)
Craftsmen	6.1 (11.5)	1.8 (9)	5.0 (7.5)	4.3 (1)
Military	6.4 (13)	2.8 (13)	5.5 (12)	5.0 (5)
Clerical	5.6 (6.5)	1.5 (6.5)	3.6 (3.5)	5.2 (7.5)
Sales	3.7 (1)	2.1 (11)	6.2 (13)	4.6 (2)
Professional & Technical	5.8 (9.5)	1.5 (6.5)	4.7 (6)	5.1 (6)
Managerial	5.6 (6.5)	1.3 (3.5)	5.0 (7.5)	5.2 (7.5)
Students	6.1 (11.5)	2.2 (12)	5.4 (11)	5.5 (12)
Housewives	5.1 (4)	0.9 (2)	2.8 (2)	5.4 (10.5)
Retired	4.1 (2)	0.6 (1)	1.7 (1)	5.3 (9)
Other + Farmers and Farm Managers	5.7 (8)	1.3 (3.5)	3.8 (5)	5.6 (13)
Unknown	5.8 (9.5)	2.0 (10)	5.3 (10)	4.7 (3)

* 1 = lowest mean value, 13 = highest mean value

Professional and technical people, who might be expected to have a greater concern for activities and ride quality if they spend time doing business on the trains, did in fact have a high mean Activity Importance rating. However, they did not complain inordinately about factors interfering with their activities, nor did they rate the ride severely. This may have been due to the fact that a large proportion of respondents in the Professional/Technical occupations (nearly 40%) had the highest level of trip experience.

Activities seemed to matter the least to respondents who were Housewives or Retired. These passengers also perceived few ride-related interferences with activities and rated the ride quality favorably, compared to passengers in other occupations.

The distribution of responses to Question 16 regarding income is shown in Appendix D. The median and modal income category (37.2% response) for this sample was \$10,000-\$20,000. Almost as many passengers (35.5%) had incomes in the \$20,000-\$50,000 range. Nearly one-fourth of the sample came from households earning \$10,000 or less, while only 4.3% had incomes exceeding \$50,000. Over 12% of the sample did not answer Question 16 about household income.

The most recent statistics available from the Bureau of the Census (U.S. Department of Commerce, 1978) indicate that the general population in the Boston-New York-Philadelphia region has a slightly lower income distribution than Amtrak Northeast Corridor passengers. The median household income for the general population is \$13,200-\$13,500 in these areas, which is in the same median income range as the Northeast Corridor passengers. However, in the general population, there are 10% fewer households in the \$20,000-\$50,000 range, and 10% more households in the under \$10,000 range, compared to the income distribution of Amtrak passengers in this survey.

Activities were less important to respondents with incomes in the \$20,000-\$50,000 range than to those with larger or smaller incomes. A one-way analysis of variance on the Activity Importance Index (Table 26) shows that these differences between income groups were statistically significant ($p<.01$). No other significant differences were found, however, between income groups for Activity Time Preference ($F=1.73$, d.f.=4,799), Activity Interference ($F=0.78$, d.f.=4,799), or ride comfort ratings ($F=0.68$, d.f.=4,787).

Table 26

Results of One-Way Analysis of Variance of Activity Importance Index as a Function of Household Income

Source	SS	d.f.	MS	F
Between (Income)	72.57	4	18.14	3.53 ($p<.01$)
Within	4100.99	799	5.13	
Total	4173.56	803		

3.2.5 Passengers' Comments Regarding General Service

An item was also included at the end of the questionnaire to solicit passengers' spontaneous comments about general train service. Special attention was paid to respondents' remarks about ride quality factors such as vibration, noise, temperature, and space features, particularly when reference was made to the effects of these variables on passenger activities. It was found that comments could be broken down into several basic categories; the distribution of these responses is shown in Appendix D.

Approximately 20% of the comments could be characterized as positive remarks about service in general. Positive comments were usually unspecific in nature (e.g., "pleasantly surprised on my first ride"), although some referred to train personnel, the interior decor of the vehicles, and general concepts such as comfort and convenience. The rest of the comments consisted of criticisms ("trains are late too often") or suggestions for improvement of services ("Would like to see revolving seats toward windows, making viewing easier").

Approximately 13% of all comments referred specifically to the quality of the ride; 2.2% of these remarks were positive ("comfortable ride") and 10.8% were negative (e.g., "train too bumpy", "Rough ride interferes with walking and use of restroom facilities"). An additional 7.7% of the comments were complaints about noise, temperature, and lighting. Less than half the respondents (45.9%) made any spontaneous comments at the end of the questionnaire.

3.3 Discussion

From the results of the survey on passenger activity preferences and the perceived effects of ride quality factors on activities, it may be concluded that:

1) Many activities, especially Reading, are considered to be important to passengers' satisfaction with the train ride. These activities are generally the same ones which passengers are most often observed performing on the trains.

2) A significant number of passengers would like to spend more time engaged in certain activities, such as Reading and Sleeping, than they presently do. The activities which passengers wish to spend more time on are the same ones which they feel are important to their satisfaction with the trains, and which they are most often observed doing already on the trains.

3) While the ride is generally perceived as comfortable by the majority of passengers, ride roughness is considered to interfere significantly with the performance of desired activities by a large number of passengers.

4) Trip variables and demographic characteristics of the passengers influence the perceived importance of activities, subjective ratings of ride comfort, and the perceived interference of ride quality factors with activity performance.

The questionnaire results confirm many previous hypotheses about the role of activities in passengers' perceptions of ride comfort and the general acceptability of the Amtrak train ride environment. They also raise other issues regarding the relative importance of ride quality variables (which may be, at least theoretically, controlled) vs. trip and demographic variables (which cannot be controlled) in explaining passengers' attitudes toward activities and perceptions of ride quality. These hypotheses and issues will presently be discussed in detail.

3.3.1 Subjective Attitudes toward Individual Activities

The results of Questions 1 and 2 regarding activity importance and satisfaction with time spent on activities clearly indicate a consistent preference for certain activities over others, and the subjective importance of activities in passengers' judgment of the over-all acceptability of the Amtrak ride. The subjective values of activities are positively related to the frequency with which passengers are observed to perform activities, verifying the validity of the survey results. There is also a significant positive correlation between the positive or negative directions of responses given by individual passengers for each activity in Questions 1 and 2. It may therefore be concluded that individual respondents expressed fairly consistent positive or negative attitudes toward the value of various activities for their satisfaction on the train, providing evidence for the reliability of the questionnaire.

It is also interesting to study the patterns of responses to activities on the questionnaire items vs. their observed frequencies. Certain activities show clearly consistent patterns of responses on all measures. For example, Reading is a highly valued activity in terms of importance and time spent, as shown by the results of Questions 1 and 2. Although Reading generated a large number of interference factor responses in Question 5, the large proportion of passengers actually observed reading leads to the hypothesis that ride quality interferences may be overcome by sufficient effort or motivation on the part of the passenger. The results of Questions 1, 2, and 5 suggest, however, that even more Reading would take place on the trains if the ride environment were more conducive to this activity.

Similarly, Handcrafts is an unpopular activity which is rarely observed on the trains. Passengers do not perceive it to be important relative to other activities, and they do not wish to invest more time in it on future trips. Its interference response rate on Question 5 was very low, probably because so many respondents were not interested in it, or did not perceive any interferences because they had never attempted to perform Handcrafts on the trains.

On the other hand, certain inconsistencies between the results of the subjective survey items and the observational data provide important insights into the effects of ride quality factors vs. passengers' motivations to perform highly valued behaviors. Writing, for example, was considered to be an important activity by approximately half the respondents polled, and only 2.7% of the passengers were observed Writing. However, almost 25% of the sample wished to spend more time Writing on future trips. Writing also generated the greatest number of ride quality interference responses of all activities on Questions 4 and 5. These results clearly indicate a discrepancy between passengers' perceived ability to write on the trains and their desire to engage in Writing as a valued activity. Thus, it seems that passengers perceive the ride environment on the trains to prevent them from writing as much as they wish.

The situation is somewhat reversed for Viewing. Viewing was perceived as an activity of only moderate value in terms of importance and relative time investment on Questions 1 and 2. However, the greatest proportion of passengers were observed to be engaged in Viewing behaviors, and a relatively small number of interference factors were associated with Viewing relative to the other activities on Questions 4 and 5. Thus, it may be hypothesized that while Viewing is not a very highly valued activity, large numbers of passengers engage in this behavior at least partly because the ride environment is conducive to it, compared to other more difficult activities, or because the ride environment prohibits them from doing other, more rewarding activities.

It is difficult to interpret the results of survey items referring to Smoking, which is regarded as a controversial issue among passengers in terms of the relative numbers of smoking vs. non-smoking cars on the trains. Thus, some respondents may have answered Questions 1 and 2 in terms of the importance of the Smoking behaviors of other passengers for their personal satisfaction on the train. This may have inflated the numbers of responses in the "Important" and "Less" categories of Questions 1 and 2 respectively.

3.3.2 Discrepancies between Over-All Comfort and Activity Interference

The ride comfort ratings of Question 3 were remarkably high for this sample, considering the number of ride quality factors indicated as interferences with activities in Questions 4 and 5. In fact, only a low negative (but statistically significant) correlation was obtained between the ride comfort ratings and total number of interference responses over all activities for each respondent, suggesting that the effects of ride quality factors on activities played only a small part in passengers' subjective judgments of over-all ride comfort.

The results of Question 3 may be compared with those of Pepler, et al. (1978), who administered a similar seven-point scale to 60 Amtrak passengers over a series of track segments pre-determined to reflect a random sample of ride conditions on the Northeast Corridor. The mean comfort rating of these passengers was equivalent to 4.9 on the scale used in Question 3. This was slightly lower than the mean value of 5.2 obtained from the respondents on the present questionnaire, but still in the same "somewhat comfortable" range.

The ride quality factor which was most frequently perceived to interfere with activity was ride roughness. This was especially true for the previously designated High Effort activities (Eating, Drinking, Reading, and Writing) and for Sleeping, which was considered to be a Low Effort behavior. Previous studies by Grether, et al., (1971, 1972) have also shown the virtual masking by vibration of the perceived effects of other environmental factors, using much higher intensities of vibration, noise, and temperature than passengers experience on Amtrak trains.

In the Grether, et al. (1971) study, subjects were exposed to environmental stresses singly and in combination, while performing a variety of tasks, including compensatory tracking, voice communications, and mental arithmetic. It was found that subjects rated the condition in which they experienced vibration alone equally as unpleasant as the condition involving combined exposure to noise, temperature, and vibration stresses. Grether, et al. (1972) subsequently found that subjects rated conditions as less acceptable and more severe as the number of stresses increased. However, ratings of the "intrusiveness" (i.e., interference) of stresses on task performance were not worse for the combined stress conditions than for the condition in which subjects experienced vibration alone. These studies support the results of the present survey, which show: 1) that subjective ratings of over-all "comfort" in an environment containing vibration, noise, and other stresses may be inconguent with ratings of the ease of performance of desired activities or other behaviors in that environment; and 2) that subjects' perceptions of the effects of environmental stresses upon performance of activities or tasks may be explained equally well by vibration factors alone as by the effects of combined environmental stresses.

A discrepancy also arose between the activity performance difficulty ranks derived from the total percent interference response on Questions 4 and 5, vs. the a priori effort ranks discussed in Section 2. The difference in orders may be explained by the passengers' perceptions of high levels of interference for Sleeping and Doing Nothing (Thinking), which received low effort ranks on the a priori scale, and the low perceived levels of interference for Handcrafts and Games, which were previously rated as Medium Effort activities. The low interference scores for the latter activities may have been due to the general unpopularity of these behaviors, resulting in a lack of interest in them and little experience on which to base a realistic response regarding ride quality interferences. The relatively high interference response for Sleeping may be justified, since the irregular ride motions and constant stopping and starting of the train may prevent a person from falling asleep (rather than "rocking him to sleep", as might be expected in a more regular motion environment) or may continually wake him up.

The high level of interference perceived for Thinking, compared to the low level of effort attributed to its behavioral and operational counterpart (Doing Nothing) on the observational _a priori_ scale, may have been caused by the respondents' misinterpretation of the activity descriptor used on survey form. The term "Doing Nothing" was changed to "Thinking" for the purpose of the survey, because it was felt that "Doing Nothing" had negative connotations which no passenger would want to associate with his own behavior regardless of the situation. Unfortunately, survey respondents may have associated the term "Thinking" with higher level activities such as Reading and Writing. Thus, it is difficult to draw any conclusions from the passengers' interference responses to Thinking regarding its actual performance difficulty as applied to the behavioral category of Doing Nothing.

From these results, it may be concluded that subjective perceptions of ride comfort are largely independent from perceptions of ease of performance of desired activities. It was expected that the easier passengers perceived activity performance to be (i.e., the fewer interference responses to Questions 4 and 5), the more comfortable they would rate the ride on Question 3. This is clearly not the case. Rather, passengers seem to perceive over-all comfort as a static concept, to be judged without reference to active participation in activities. Thus, in a hierarchy of factors which influence over-all subjective comfort, feelings of ease or difficulty in performing various activities would probably not rank very highly compared to more direct sensations of motion, heat or cold, loudness, spaciousness, and so on, which stereotypically are known to affect comfort.

3.3.3 The Importance of Passenger Variables in Questionnaire Responses

It is not surprising that differences in trip or demographic characteristics influence passengers' values of activities, perceptions of ride comfort, and ride quality factors' interference with activities. Previous studies have rarely examined differences in perceptions of ride comfort associated with such variables, and the differential importance of activities and various aspects of the ride environment depending upon these passenger variables has not generally been reported in the literature. This information is important, considering the growing concern of transportation systems with consumer issues and the potential usefulness of such information for the purposes of market segmentation. Where other evidence is available from previous studies, comparisons with the present set of results will be made.

3.3.3.1 The Subjective Value of Activities

Differences in responses to Questions 1 and 2, in the form of the Activity Importance and Activity Time Preferences Indices, show that the role which activities play in determining the overall acceptability of the Amtrak ride varies depending upon passenger characteristics.

It was expected and found that activities might be of greater value to passengers the longer the trip distance. Since trip time varies directly with trip distance, the importance of having some means to stay occupied appears to increase the longer the trip, probably in order to prevent or decrease boredom. Similar results were obtained by West, Ramagge, West, and Jones (1973) in a study of British Rail Inter-City passengers. These authors found that the importance of entertainments, newspaper stalls, and other provisions for passenger activities increased directly with trip time, while concern for such ride quality factors as noise, vibration, temperature, and the cleanliness of the vehicles decreased over a five-hour period.

Trip purpose also affected the number of activities passengers felt to be important. The finding that respondents traveling for business or school purposes valued fewer activities as important than did those traveling for vacation or recreation purposes may seem anomalous. However, it was also found that passengers making business and school trips checked significantly greater numbers of ride quality interference factors on Questions 4 and 5, compared to those traveling for vacation/recreation purposes. Perhaps for business travelers, who were highly experienced compared to passengers traveling for other reasons, repeated attempts to perform a wide variety of behaviors satisfactorily met with little success, resulting in a devaluation of all but those activities essential for the conduct of business. Experienced business travelers may also acquire a routine consisting of a small number of highly valued behaviors which they are able to perform to some reasonable level of satisfaction, which might also explain their relatively low Activity Importance Index values.

Age is an important demographic variable in terms of the degree to which passengers value activities. As age increased, both the number of activities rated important and the amount of extra time passengers wished to invest in such behaviors decreased. One might speculate that with increasing age, other factors, such as services provided by train personnel or other convenience features, might take precedence over the need to have something to do.

Occupation also seems to affect the relative value of activities. Military personnel and students rated the largest number of activities to be important and wished to spend more time on the greatest number of activities. It was expected that passengers in professional/technical occupations would rank higher on the Activity Importance and Time Preference Indices relative to other jobs than they actually did; i.e., that activities would be more important to them than to those in other occupations. As suggested previously, it is possible that they were only interested in a limited number of activities, which would have resulted in the lower scores for Questions 1 and 2. Housewives and retired persons were the least concerned with activities. The differing interests of passengers in different age groups may explain the responses of retired passengers. Also, housewives managing small children on the train may be so preoccupied that they really have no time or interest for the activities listed in the questionnaire.

Educational level also influenced the value of activities for passenger satisfaction. More activities were judged to be important on Question 1 by respondents with high school and college educations than by those with only grade school or less. Perhaps these passengers are more aware than less educated respondents of the image they are presenting to the researcher in the form of their responses.

Thus, it may be concluded that the most important trip and demographic variables affecting passenger value of activities are trip distance (or trip duration), trip purpose, age, occupation, and possibly level of education.

3.3.3.2 Perceptions of Ride Quality and Its Effects on Activity

Previous studies which have examined the effects of various trip and demographic variables on passengers' ratings of ride quality have uncovered remarkably few differences due to these factors. The results of the present survey, however, show that while certain variables may not always affect passengers' feelings of ride comfort, they may be more important in influencing their perceptions of activity performance difficulty in the motion environment.

Variables such as age and sex have been considered by a few researchers in terms of the differential sensitivity of various groups to ride motion. As in the present study, no significant differences due to sex were found using airline passengers (Richards and Jacobson, 1975), subjects in ride motion simulators (Duncan and Conley, 1975), or paid Amtrak passenger volunteers (Pepler, et al., 1978). Richards, Jacobson, and Kuhlthau (1978), however, did find that female commuters were generally more comfortable in the flight environment, but attributed the sex difference to seat variables, such as shape, firmness, and leg room, rather than to motion variables.

No significant differences in ratings of ride quality due to age were found by Richards and Jacobson (1975), and Duncan and Conley (1975), or Richards, et al. (1978) in previous studies, supporting the results of the present survey. Pepler, et al. (1978) found that subjects in the youngest (aged 16-24) and oldest (49 or older) age groups rated the ride as less comfortable than those in the middle (25-45) age group. The results of the present survey, using finer age groupings, suggest the opposite; i.e., that the youngest (age 18 or less) and oldest (age 65 or more) passengers rated the ride as most comfortable. The latter result may be explained by the lower relative sensitivity of young people to roll (Pepler, et al., 1978), which is the dominant motion on the train, and the general reluctance of elderly passengers to be critical, which was reflected in their responses to many items on the questionnaire.

Although there are no clear-cut effects of age on feelings of general comfort, age does influence sensitivity to ride quality variables which disrupt activity. The number of ride quality factors checked as disruptive to activities in Questions 4 and 5 decreased monotonically as age increased. Older people may be less sensitive to these factors simply because they value activities less than younger people, or because they do not expect to use their time productively on the trains. At any rate, these differences clearly exist when ease of performing activities is considered, rather than just general subjective feelings of comfort in the ride environment.

Richards and Jacobson (1975) found no clear differences in ride comfort ratings on airline flights as a function of occupation, although professional/technical people tended to be less critical of the ride than managers. Using a greater number of occupational categories, the present survey results indicate that ride comfort ratings and perceptions of ride factors' interference with activities may be influenced by passengers' occupations. Managers seemed to be slightly less critical of the ride but slightly more sensitive to interference with activities than professional/technical personnel.

Richards and Jacobson(1975) found no significant differences in ride ratings as a function of income or trip purpose, supporting the results of the present survey. However, respondents traveling for business- or school-related purposes did perceive more ride quality factors as interfering with activities than those traveling for other reasons, again suggesting that ease of activity performance may be more sensitive than subjective comfort ratings to differences in certain passenger variables.

It was surprising to find that passengers in Amcoach vehicles rated the ride as significantly more comfortable than those in the Amcafe cars. It was expected that any difference would have been in the reverse direction, since the Amcafe cars have more spacious seating and provide greater opportunities to engage in activities such as Talking-Listening, Eating, Drinking, and Smoking than the Amcoach vehicles. Amcafe cars were, however, more crowded in terms of vehicle occupancy than Amcoach cars (although the difference was not statistically significant), which may have influenced perceived comfort. Also, no passengers could sit in the center of the Amcafe cars, since the snackbar was located there (see Appendix B for vehicle floor plans); thus, passengers rating the ride comfort were restricted to seats at the ends of the car, where the ride motions are more intense. This seating arrangement may have resulted in lower mean comfort ratings for Amcafe vehicles than for Amcoach vehicles, where a large number of respondents were able to sit in the more comfortable center seat positions.

The finding that perceptions of ride quality and its interference effects on activity were significantly worse for passengers traveling in large groups may have been due to the fact that large numbers of people sitting together were very cramped for seating space. In general, most individual passengers and their belongings occupied at least two seats each when vehicle occupancy permitted. Therefore, it may have been uncomfortable for large groups to sit together, and the effects of such factors as vibration, noise, and temperature on activities may have become more salient. Also, people traveling in groups undoubtedly wish to communicate with each other and do things together. However, since most seats face in one direction only, it may be difficult for groups of more than two people to perform desired activities. This seating factor may especially affect the on-board activities of families traveling with children.

Although activities appear to be of greater value to passengers the longer the trip, comfort ratings were not significantly lower for passengers traveling longer distances, nor did passengers on long trips report a greater number of ride quality factors as interferences with activity. West, et al. (1973) also found that ride quality factors were important to train passengers only for about the first hour of the trip; the importance of "things to do," however, was found to increase with time.

These results support the contention that ride comfort does not necessarily decrease merely as a function of time spent in the motion environment (Clarke, 1976; Brown, 1975; Pepler, et al., 1978). Especially in a complex motion environment where actual revenue passengers are concerned, other factors, notably passenger activities, may significantly alter the time/comfort relationship by diverting the passenger's attention away from the comfort variables such as vibration, noise, and temperature in favor of other stimuli (e.g., reading materials, food, puzzles, etc.). Thus, at least in real transportation situations where passengers are given the opportunity to engage in behaviors other than rating ride quality, comfort need not decrease and the salience or importance of ride quality factors need not increase, merely as a function of time.

It may be concluded from the results of the present study that while relatively few passenger variables affect subjective feelings of general ride comfort, they may be important in terms of the number of environmental factors perceived to interfere with performance of desired activities. These variables include age and trip purpose. Other factors, such as education and vehicle type, seem to affect subjective ratings of the ride but not the perceptions of ride quality factors' interference with activity. Passengers' occupations and number of traveling companions influence both perceptions of general ride comfort and activity interference due to ride quality variables, while sex, income, previous trip experience, and trip duration or distance affect neither of these variables.

3.3.4 Implications of Survey Results for Future Passenger Train Service

The present survey addressed problems of very limited scope in terms of the larger passenger issues which are important to the over-all viability of passenger train systems now and in years to come. In fact, passengers sometimes indicated on their survey forms that time delays and other operational problems were of higher immediate priority than the performance of activities. However, it was also clear from the responses to the first five questionnaire items and the high frequency of spontaneous comments that ride quality issues also play a role in passenger satisfaction. When the passengers' attention is focussed on these factors, they begin to realize that they are not able to do the activities they enjoy because of the ride or other environmental variables, and that this may be an important source of dissatisfaction and boredom with the train ride.

Based on the results of this survey, recommendations for general improvements in present or future passenger train service include the following:

1) High priority should be given to providing reading and writing materials on board the trains, keeping windows clean, and making sure all lights are working properly. Many passengers value reading, viewing inside and outside the train, and writing, and significant percentages wish to do more of these activities.

2) Provisions for games and other behaviors are probably unnecessary, as these activities are not highly valued by most passengers.

3) Drinking straws and covers on cold beverages, and covers which fold back only partially to allow the sipping of hot liquids, are also suggested to facilitate drinking behavior.

The above recommendations are most important on long trips, where activities are especially valuable to passenger satisfaction with the ride. In addition:

4) In order to allow for the satisfactory performance of activities, especially those requiring a large amount of effort to perform in a motion environment, it is also recommended that future service provide for a smoother ride.[3] Present levels of noise, temperature, space, and other environmental factors are perceived to be adequate for the types and levels of activities desired by most passengers. The present levels of ride motion, however, are particularly disruptive to performance of activities, although they do not seem to adversely affect the passengers' perceptions of over-all comfort.

An important goal of Amtrak's marketing policy involves identification of the needs of special passenger groups for the ultimate purpose of increasing ridership. The following results,

[3]Ride motion levels which would be acceptable for the performance of various activities cannot be determined from the results of this survey. This issue will be discussed, however, in Section 4.

which are based upon the responses of passengers with different trip and demographic characteristics, may have important implications for changes in service or system design:

1) Activities are more important to passengers on long distance trips. Thus, greater provisions and opportunities for activity performance should be made for passengers on trips of 300 mi or over. These include work materials (books, magazines, paper, pencils, etc.), workspace, and other activity-related services or amenities.

2) Passengers traveling on business trips require a smooth, quiet ride more than other passengers, to perform a small number of highly valued activities. Extra books or other materials are probably not required especially for business passengers, who generally bring work materials with them.

3) Passengers traveling in large groups (five or more) need more space to perform activities and a smoother ride than is presently available in Amcoach and Amcafe vehicles.

4) Students like to be able to do a wide variety of behaviors, and may respond well to extra provisions of books, magazines, music, etc. for desired activities. Young people are also more sensitive to ride

quality-related interferences with activities, and thus require a smoother ride for greater ease of activity performance on the train.

5) Elderly, retired people and housewives do not seem to value activity- or ride quality-related factors very highly. Thus, improvements in these areas will probably not alter ridership among these groups.

3.3.5 Implications of Survey Results for Further Research

It is clear from the results of the first two parts of this study that:

1) Amtrak passengers perform a variety of activities, with varying frequencies;
2) Many of these activities are important to their subjective satisfaction with the ride, and they would like to do even more of them; and
3) The ride quality, and in particular, the roughness of the ride, interferes significantly with passengers' perceived ability to perform desired activities, although it does not seem to adversely affect their over-all comfort.

The next logical step is to investigate the ways in which environmental variables such as vibration affect the behaviors which people perform on the train. In the next phase of this study, observations of passenger activities and measurements of the physical ride parameters are made simultaneously in order to develop predictive relationships between these sets of variables.

4. MEASUREMENT OF THE RIDE ENVIRONMENT AND ITS EFFECTS ON PASSENGER ACTIVITIES

4.1 Method

4.1.1 Subjects. The subject sample consisted of 2829 passengers observed on 14 Amtrak train rides in the Northeast Corridor. These passengers were observed in 81 cars of different types (Amcoach and Amcafe) on trains traveling in both directions between Washington, DC and Newark, NJ, on different days of the week (Monday through Friday) at different times of the day each day (from 9:00 a.m. to 5:00 p.m.), in order to obtain a representative sample of Northeast Corridor Amtrak system users.

4.1.2 Apparatus. The apparatus used to measure ride vibration is shown in Figure 16. Linear accelerations in three axes were measured using the battery-operated portable accelerometer set developed by the NASA Langley Research Center (Catherines, Clevenson, and Scholl, 1972). This unit (Figure 17) consisted of three seismic mass pieso-resistive accelerometers mounted in the three mutually perpendicular directions. Each axis was calibrated independently. The maximum bandwidth of the accelerometers was 0 to 100 Hz (cycles per second).

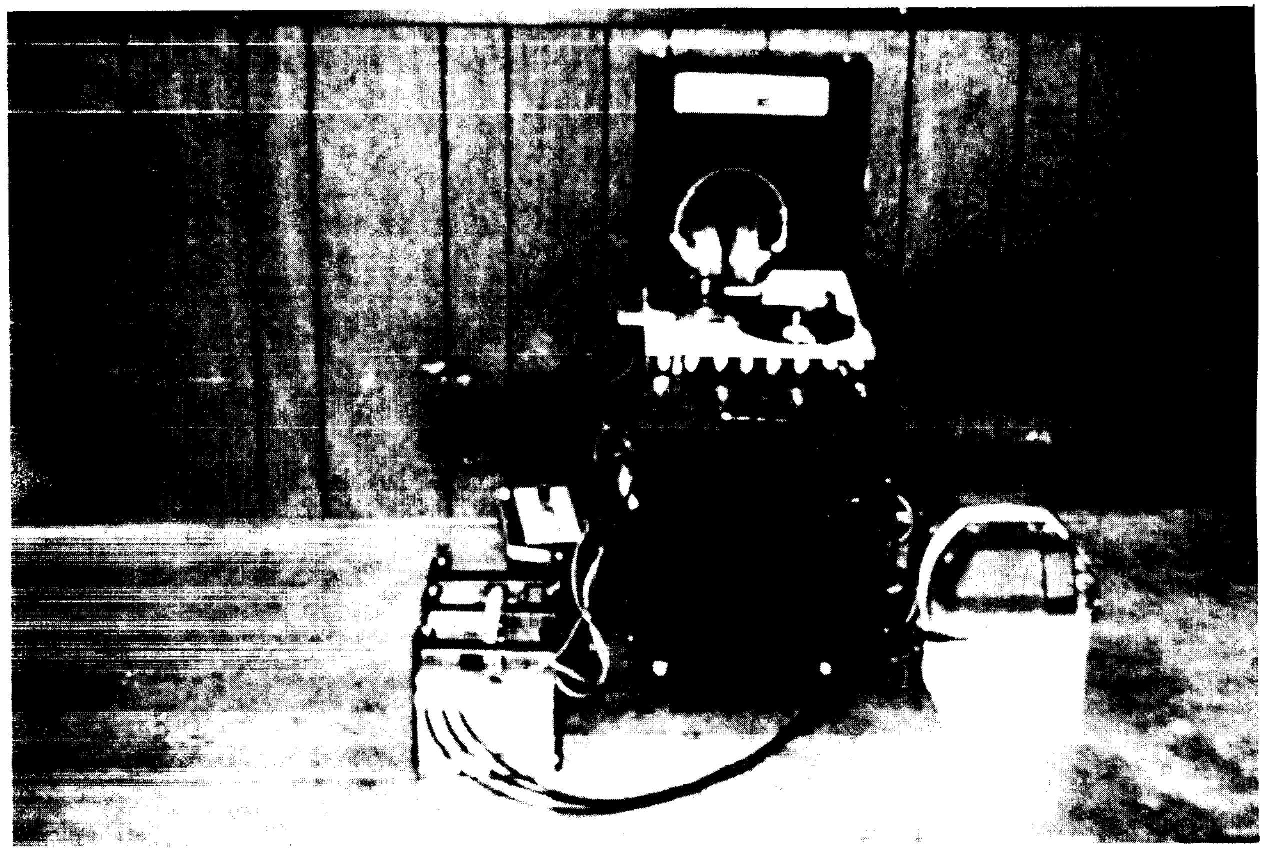


Figure 16. Equipment Used To Measure And Record Vibration On Northeast Corridor Amtrak Trains (Counterclockwise: Headphones, Tape Recorder, Power Source for Recorder, Modified NASA Accelerometer Package, Inverter Battery)

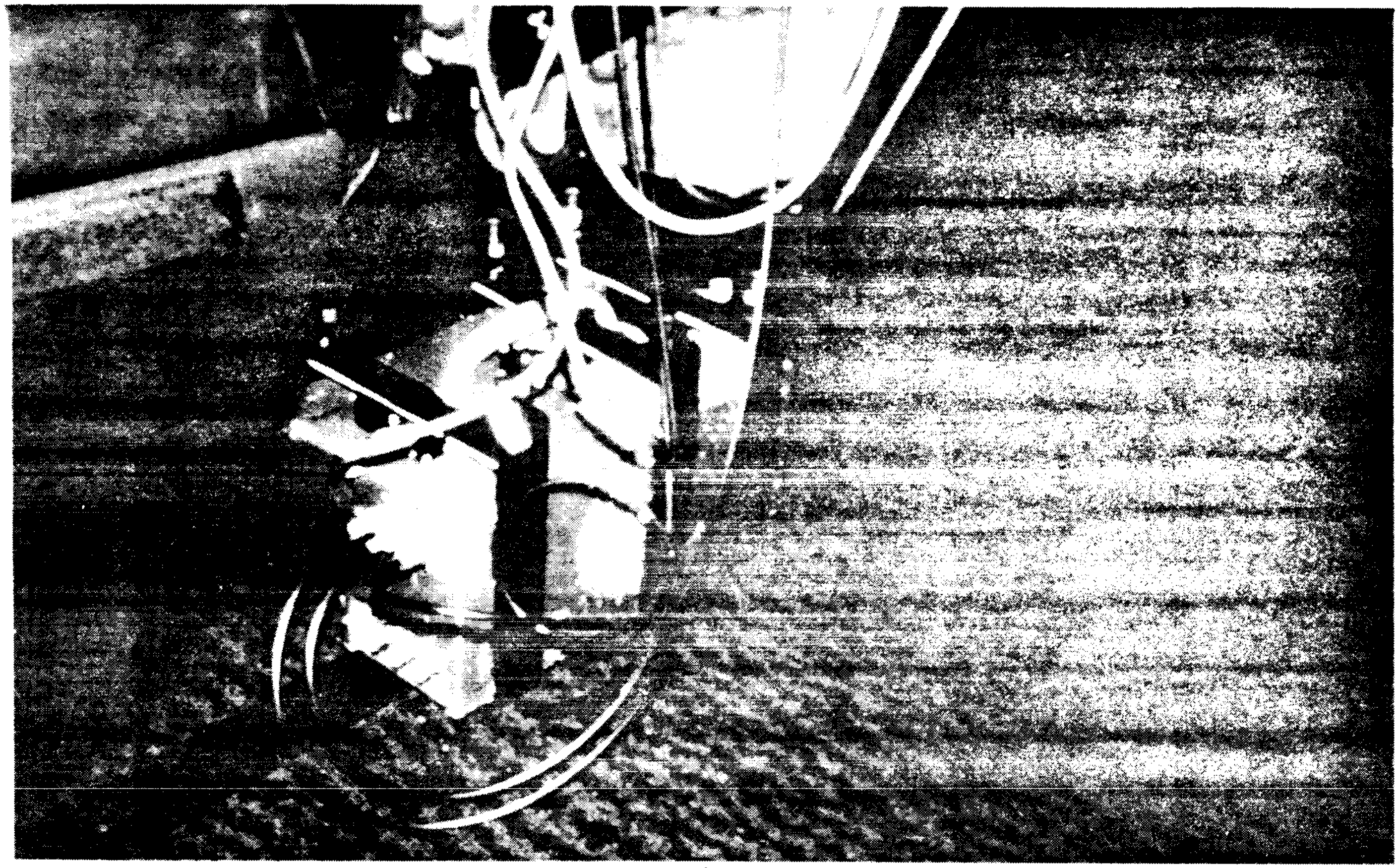


Figure 17. Modified NASA Tri-Axial Accelerometer Package In Measurement Position On Floor Under Amtrak Train Seat

Rotational motions were measured by attaching three additional accelerometers (PA-1000 type, manufactured by Unholtz-Dickie Corp.) to the outer casing of the NASA tri-axis linear accelerometer package (Figure 17). 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. The three PA-1000 accelerometers required a separate power supply which was derived from a 12 volt car battery connected to a power inverter. The inverter produced 120 volt, 60 Hz, AC power which was used to drive 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),.using Scotch magnetic instrumentation tape (Cat. No. 871-1/2-1800-PRST). The seventh channel was used for simultaneous voice commentary, and the eighth to record a 1 volt step signal, which was later used to denote electronically the start of a particular test record.

Motion data were reduced from analogue to digital form suitable for subsequent statistical analyses using a Scientific Data Systems XDS Sigma 5 data processor, a Scientific Data Systems 930 computer, and a Control Data Corporation 6600-6400 computer system.

Instrumentation used to measure non-motion environmental variables is shown in Figure 18. These included a General Radio USA sound level meter (Model No. 1565-B) to measure ambient noise level, an Abbeon certified hygrometer and temperature indicator (Model No. HTAB 169B) to measure relative humidity and Fahrenheit temperature, and a Gossen Luna-Pro light meter to measure ambient illumination.

The behavioral coding form used to record passenger activity is shown in Appendix A.

4.1.3 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 from Washington, DC to Newark, and 16 from Newark to Washington, DC). These represented straight and curved track over uphill, downhill, and undulating terrain. As a group, these segments were varied enough to be considered characteristic of the Northeast Corridor guideway system in general; however, each segment was fairly homogenous internally regarding track curvature, terrain type, and train speed restrictions.

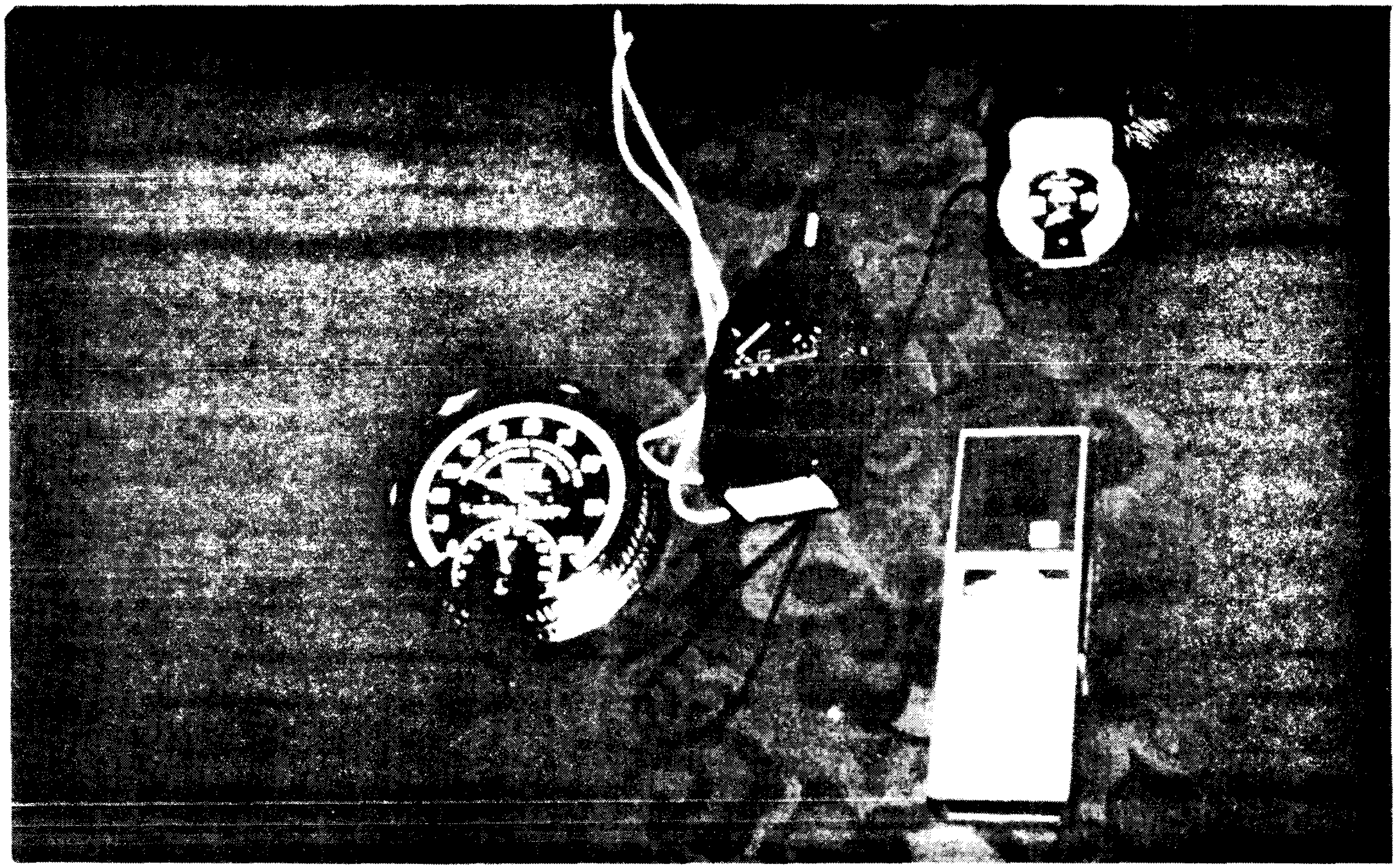


Figure 18. Equipment Used To Measure Non-Motion Environmental Variables On Amtrak Trains (Clockwise: Sound Level Meter, Light Meter, Walkie-Talkie, Thermometer-Hygrometer)

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. This was done by putting large, sandwich board signs in the appropriate seats of each train at Boston's South Station or Washington's Union Station, prior to the trains' morning departures from these points.

The experimental procedure involved the simultaneous observation of passenger activities by the experimenter and measurement and recording of ride environment variables by two test assistants. The experimenter and test assistants boarded each train in the rear vehicle. The equipment for recording ride motions was set up in a center pair of seats which had previously been reserved for this study, as shown in Figure 19. This location was chosen because it was close to the pitch and roll center of the vehicle. The equipment was turned on and allowed to warm up. The smaller pieces of equipment used to record the non-motion environmental variables were also arranged to be accessible for measurement on the fold-out table behind the forward seat, as shown in Figure 20.

Once the train was in motion, the test assistants made voice contact via walkie-talkie with a fourth member of the test team riding in the locomotive at the head end of the train, in order to determine the milepost location of the train. As the train approached a predetermined test track segment, the experimenter proceeded to the rear of the vehicle. Upon hand signal by the

Figure 19. Measurement And Recording Of Vibration On Northeast Corridor Amtrak Trains

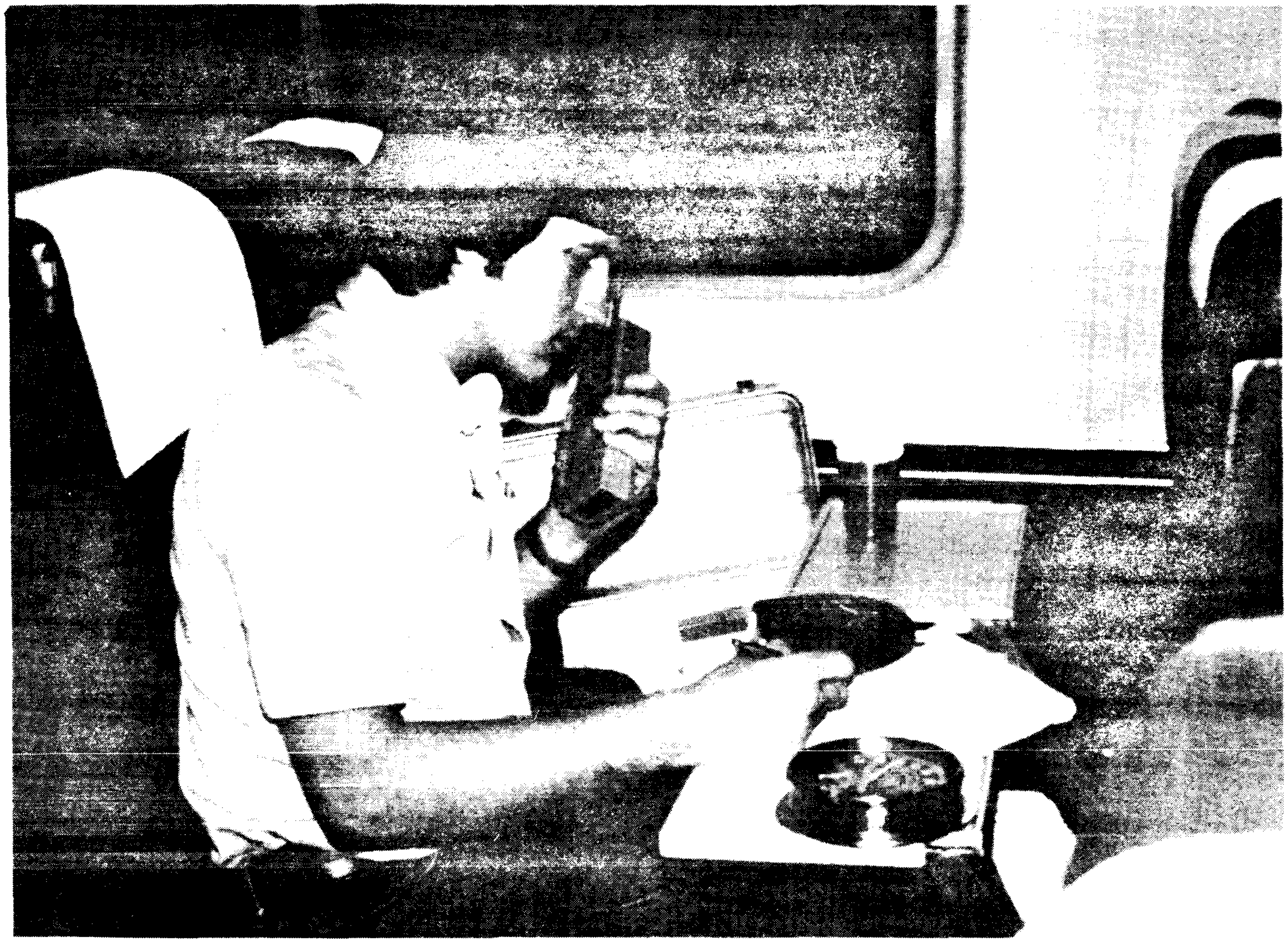


Figure 20. Measurement And Recording Of Noise, Temperature, Humidity, And Milepost Location On Amtrak Northeast Corridor Trains

assistant, which indicated the beginning of a recording period, the experimenter walked through the vehicle, observing and recording passenger activities using the same methods described in Section 2.1.3 (Figure 21). At the center of the vehicle, the experimenter also made an ambient light measurement in the aisle of the train at approximately the eye level of the passengers. 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. Milepost information was announced by the fourth member of the test team in the locomotive over the walkie-talkie, and monitored by the test assistants throughout the test interval, which lasted 100 sec. The fourth member of the test team also recorded speed information for each mile of each test segment.

At this point, the equipment was turned off and moved to the next vehicle. The experimenter and test assistants again made voice contact with the test team member in the locomotive and waited until the train approached the next available test segment before repeating the observational and measurement procedures. These methods were used to collect data on passenger activities and ride environment variables in each car of the train.

Figure 21. Observation Of Passenger Activities On Amtrak Northeast Corridor Trains

Measurements and observations were recorded over a total of 81 test segments on 42 different vehicles on 14 trains during seven weekdays of testing between December 5-13, 1977. This was done by collecting data on two trains each day: The Patriot (#172) from Washington, DC-Newark, NJ between 9:00 a.m.-12:41 p.m., and the Colonial (#169) from Newark, NJ-Washington, DC, between 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. Table 27 illustrates the data collection schedule which was followed.

4.1.4 Data Reduction. Digital techniques were used to analyze the recorded ride motions. The following procedures were carried out on the data collected for each test segment.

The analogue data measured by each accelerometer and recorded on the magnetic tape was digitally sampled at a rate of 409.6 points/sec to produce a set of data points from each of the six channels (Healey, 1977). From the sampled data, a set of data sequences for rotational acceleration in each of the three axes were computed, as illustrated in Figure 22. This figure shows the location and sensitive directions for the six accelerometers. X, Y, and Z denote the three mutually perpendicular accelerometers which were contained inside the NASA box. α_4 and α_5 denote two accelerometers placed on top of the box, a short distance away from each other and from the X, Y, and Z accelerometers. α_4 and α_5 were oriented in the same direction as Y. The sixth

Table 27

Data Collection Schedule

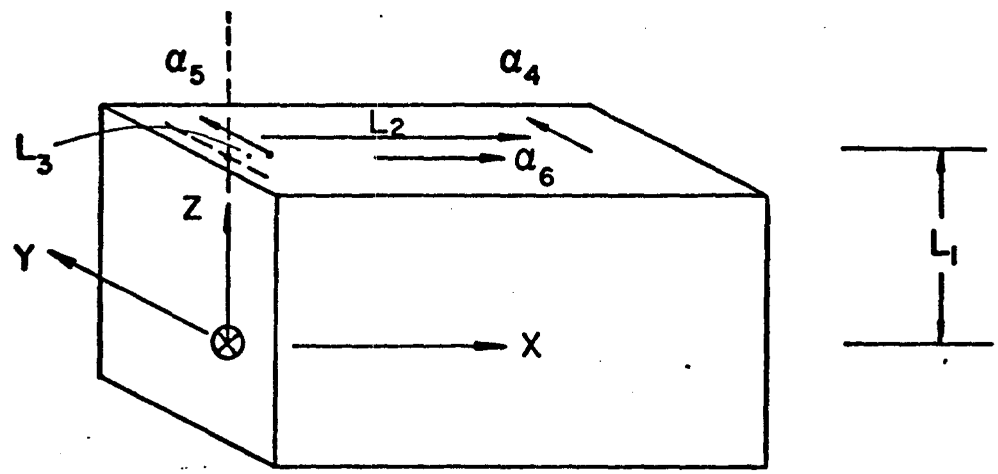
DATE(DAY)

SEGMENT NUMBER (VEHICLE NUMBER)

12-5(M)	12-6(T)	12-7(W)	12-8(Th)	12-9(F)	12-12(M)	12-13(T)
Train 172	Train 172	Train 172	Train 172	Train 172	Train 172	Train 172
1 (21229)	12 (21054)	23 (21082)	35 (21054)	47 (21229)	61 (21074)	73 (21033)
2 .(21082)	13 (21074)	24 (20010)*	36 (21074)	48 (21082)	62 (21084)	74 (20017)*
3 (20010)*	14 (20021)*	25 (21042)	37 (21084)	49 (21220)	63 (20035)*	75 (21042)
4 (21042)	15 (21130)	26 (21090)	38 (20035)*	50 (20017)	64 (21015)	76 (21004)
5 (21090)	16 (21251)	27 (21030)	39 (21130)	51 (21042)	65 (21040)	77 (21030)
6 (21039)	17 (21088)		40 (21251)	52 (21090)	66 (21131)	
			41 (21088)	53 (21030)		
Train 169	Train 169	Train 169	Train 169	Train 169	Train 169	Train 169
7 (20000)*	18 (21265)	28 (20033)*	42 (20012)*	54 (20000)*	67 (20050)*	78 (21054)
8 (21113)	19 (21215)	29 (21252)	43 (21269)	55 (21054)	68 (21268)	79 (21232)
9 (21098)	20 (21270)	30 (21183)	44 (21266)	56 (21252)	69 (21255)	80 (21183)
10 (21112)	21 (21268)	31 (21113)	45 (21265)	57 (21183)	70 (21269)	81 (21112)
11 (21016)	22 (21268)**	32 (21113)**	46 (21270)	58 (21113)	71 (21221)	
		33 (21098)		59 (21098)	72 (21265)	
		34 (21112)		60 (21043)		

*Amcafe snackbar vehicle

**Complete vehicle occupancy change after Phildelphia permitted a second consecutive test to be taken in this car.



$$\alpha_{pitch} = (\alpha_6 - X)/L_1$$

$$\alpha_{yaw} = (\alpha_4 - \alpha_5)/LY$$

$$\alpha_{roll} = \left\{ Y - \left[\alpha_5 + \frac{L_3}{L_2}(\alpha_5 - \alpha_4)\right]\right\}/L_1$$

X ----- Longtitudinal

Y ----- Transverse

Z ----- Vertical

Figure 22. Measurement And Computation Of Rotational Motions

accelerometer, α_6 , was placed on top of the box in the longitudinal (X) direction.

The amplitude of yaw, the rotational acceleration about the Z axis, was computed for each segment by dividing the difference between the amplitudes recorded from α_4 and α_5 by the separation length, L_2. Rotational acceleration was thus given in terms of acceleration (g) per unit separation length. These units are identical to rad per sec², and were converted into degrees per sec² for further statistical analysis. To compute roll, the rotation about the X axis, the accelerations recorded from α_4 and α_5 were prorated to give a value as expected above the Y axis accelerometer. Taking the difference between Y and that prorated value divided by the separation length L_1 resulted in the rotational acceleration. Computation of pitch rotational values were handled similarly, according to the formula in Figure 22. There was no significant angle between the vehicle and the tracks to complicate these calculations.

A discrete Fourier transform process (Brigham, 1974) was applied to the data points in each axis to calculate the frequency content of all records. The three linear accelerations were then frequency-weighted according to the ISO 2631 (1974) guideline. This procedure generally involves the application of a frequency weighting network to the linear accelerations recorded in the 1-80 Hz range, in order to weight the acceleration amplitude according to the varying levels of human sensitivity to mechanical vibration at different frequencies. The numerical values of these weights have been derived based upon present knowledge of human response to whole-body vibration as outlined in the ISO guide (International Organization for Standardization, 1974). Thus, the amplitude of vibration (or power) occurring in the 4-8 Hz range is weighted most heavily for vertical (Z-axis) linear vibration, while the power of vibration between 1-2 Hz is weighted most heavily for longitudinal (X-axis) and lateral (Y-axis) linear vibration. The weighting procedure was discontinued at 20 Hz, beyond which point there was no significant vibration power in the data.

One-third octave band root mean squares (rms) were then 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.

Vector sums of the ISO-weighted linear accelerations in each segment were computed using the formula:

$$\sqrt{(1.4a_x)^2 + (1.4a_y)^2 + a_z^2} \tag{5}$$

where a_x = longitudinal acceleration, a_y = lateral acceleration, and a_z = vertical acceleration. Vector sums of the rotational accelerations were computed using the formula:

$$\sqrt{\alpha_x^2 + \alpha_y^2 + \alpha_z^2} \tag{6}$$

where α_x = roll acceleration, α_y = pitch acceleration, and α_z = yaw acceleration. Vector sums of the rotational rates were computed using the formula:

$$\sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} \tag{7}$$

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

Using this procedure, motion values were generated for linear accelerations, rotational accelerations, and rotational rates in each of the X-, Y-, and Z-axes for each test segment, as well as the three vector sums described above. These values were then punched on standard 80-column computer cards for use in subsequent statistical analyses.

Temperature and humidity data for each test segment were converted to effective temperature indices using the Revised ASHRAE Comfort Chart (American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1967). These effective temperatures, average noise levels in dB(A), average speed levels in mph, and light levels in foot-candles (fc) were also punched onto 80-column cards for each test segment.

The activity data for each test segment were converted from absolute frequencies to percents (relative frequencies) for each activity category described in Table 1 and Section 2.3. 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. Since the vehicles used in different segments varied in absolute seating capacity and also had different levels of occupancy at the time observations and measurements were made, the percentage values were more useful than the absolute values for direct comparison of activity levels between test segments. Passengers looking at the experiment or contractors while the tests were being made were included in the other activity category. All statistical analyses involving passenger activities were conducted on these percentage values using the Statistical Package for the Social Sciences (SPSS) and the DEC 10 computer system.

4.1.5 Data Analysis. Due to the field nature of this study, a large number of variables could be measured or otherwise recorded as possible predictors of passenger activity levels. While most of these variables were continuous in nature (e.g., the ride motion variables, noise, temperature, light), several categorical trip variables such as time of day and vehicle type were also included in the design. None of these variables could be directly manipulated in the experimental sense; rather, the only levels of ride quality and other factors which could be measured or accounted for were those which actually existed as the result of the regular operation of Amtrak train service.

The only means of controlling the variance in these factors was by restricting the test intervals to track segments which were internally homogeneous regarding terrain type, track geometry, and speed. This procedure was quite successful in controlling the maximum values and variance in the vibration data. The distributions of the ride quality variables measured in this December, 1977 study were much less skewed and attained lower levels of variance than the data distributions from a previous study in which track segments were chosen at random. The data from this earlier effort, which was conducted at the same time as the passenger activity/ride quality survey (Section 3.), could not be successfully used in further statistical analyses.

Many of the factors used as predictors of passenger activity levels in this study were highly intercorrelated. This is characteristic of ride motions recorded simultaneously, since motion in any given direction is generally related to motions in other directions, and to motions in the same direction but in a different mode. Thus, the ride quality variables are not "independent" in any statistical sense.

The inclusion of both continuous and categorical variables which are highly intercorrelated and present at a wide variety of levels basically precludes the use of popular analysis of variance techniques for analyzing the data. However, it is just these characteristics which make this design amenable to analysis using multiple regression techniques (Kerlinger and Pedhazur, 1973). Selection of predictor variables which were only slightly intercorrelated with each other but strongly correlated with the dependent, activity variables allowed for the development of linear combinations of factors which predicted a greater proportion of the activity variance than any single environmental or trip variable alone.

Multiple regression techniques may be used to generate *post hoc* explanations of the variance in the dependent variable as a function of combinations of predictor variables. Using this technique, a linear equation can be generated which most accurately predicts the levels of the dependent variable as a function of the existing levels of the predictor variables. In addition, the predictive power of each of the predictor variables can be measured. Thus, the goal of the present study was to develop equations which would predict activity levels on the trains, as a function of the physical characteristics of the ride environment. In the following Section 4.2, the results of the various statistical steps leading to the development of these equations are described in detail, including the analyses of the distributions and correlations between the activities and the environmental variables.

4.2 Results

4.2.1 Activity Distributions. The distributions of the 11 activities are described in Table 28. These statistics were calculated based on the percentage values of each activity observed over all 81 test segments. The relative frequencies of most of the activities ranged widely from one test segment to the other; this range reflects not only the actual differences between activity distributions of different vehicles, but also the effects of converting the absolute frequency data to percents (e.g., 10 people reading may represent 16.6% of the passengers in a vehicle with 60 people, or 33.3% in a vehicle with 30 people.) All activity distributions are positively skewed (to the right), indicating a large number of low percentages and a few very high ones. This skewness may be caused to a certain extent by the fact that some activities were not observed in certain cars at all; this is reflected by the zero modal values and lower limits of the percentage ranges for a number of these behaviors.

Table 29 shows a comparison of total relative frequency values for activities observed in this December 1977 phase of the experiment, in the July, 1977 survey study (described in Section 3.0), and in the November-December, 1976 behavioral taxonomy (described in Section 2.0). Visual inspection of these

Table 28

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)							

Table 29

Comparison of Percent Activities Observed in November-December, 1976; July, 1977; and December, 1977

Activity	Nov.-Dec., 1976	July, 1977	December, 1977
Doing Nothing	2.6	6.3	4.5
Sleeping	14.4	15.9	20.0
Smoking	1.4	0.5	0.7
Viewing	24.4	25.5	20.3
Talking-Listening	10.9	15.0	13.0
Handcrafts/Games	2.0	2.1	1.5
Eating	4.6	2.9	2.9
Drinking	7.5	2.4	2.7
Reading	24.2	22.2	25.4
Writing	3.3	2.7	4.3
Other	4.7	4.4	4.7

distributions indicates no marked differences between them, except in the cases of Doing Nothing, which occurred with greater frequency in the July, 1977 trips, and Drinking, which was observed to a greater extent on the November-December, 1976 trips. These slight differences may be attributed to the heat on the July trips, and to the increased drinking of passengers making connections to and from Chicago on the 1976 trips. In general, however, these comparisons indicate that the activity distributions observed were stable over time.

4.2.2 Distributions of Trip and Situational Variables

Tests were made under varying trip and situational conditions. The major variables to be considered are test day (Monday, Tuesday, Wednesday, Thursday, or Friday); test time (morning-before 12:00 noon, or afternoon-after 12:00 noon); train (The Patriot-#172, or The Colonial-#169); vehicle type (Amcoach or Amcafe snackbar); vehicle occupancy (0-25%, 26-50%, 51-75%, or 76-100% of total capacity)); acceleration type (whether the train accelerated (positive), decelerated (negative), or remained at a constant speed (zero) during a test segment, as determined from the speed data taken in the locomotive); mean speed (under 70 mph, 70-80 mph, or over 80 mph); and track type (positive grade-some curves, positive grade-straight, negative grade-straight, mixed grade-some curves, or mixed grade-straight, as determined from the Northeast Corridor track charts). The number of test segments recorded for each level of each variable is shown in Table 30.

Table 30

Breakdown of Test Segments According to Major
Trip and Situational Variables

DAY	TIME	TRAIN
Monday = 23 (28.4%)	Morning = 34 (42.0%)	#172 = 42 (51.9%)
Tuesday = 20 (24.7%)	Afternoon = 47 (58.0%	#169 = 39 (48.1%)
Wednesday=12 (14.8%)		
Thursday =12 (14.8%)		
Friday =14 (17.3%)		
Total = 81 (199%)	Total = 81 (100%)	Total = 81 (100%)

VEHICLE TYPE	VEHICLE OCCUPANCY	ACCELERATION TYPE
Amcoach = 69 (85.2%)	0-25% = 12 (14.4%)	Positive = 8 (10.0%)
Amcafe = 12 (14.8%)	26-50%= 39 (48.1%)	Negative =10 (12.3%)
	51-75%= 27 (33.3%)	Zero =58 (71.6%)
	76-100%= 3 (3.7%)	Missing = 5 (6.2%)
Total = 81 (100%)	Total = 81 (100%)	Total = 81 (100%

MEAN SPEED	TRACK TYPE
Less than 70 mph = 7 (8.7%)	+ Grade-Curves= 16 (19.8%)
70-80 mph = 30 (37.0%)	+ Grade-Str't = 16 (19.8%)
More than 80 mph = 40 (49.4%)	- Grade-Str't = 14 (17.2%)
Unknown = 4 (4.9%)	+ Grade-Curves= 15 (18.5%)
	± Grade-Str't = 11 (13.6%)
	Unknown = 9 (11.1%)
Total = 81 (100%)	Total = 81 (100%)

Almost twice as many tests were made on Monday and Tuesday than on any other day because of the seven weekday test period used in this study. Almost equal numbers of tests were done on the two trains and between the morning and afternoon. Only about 15% of the available vehicles on these trains were Amcafe snackbars; hence, the uneven number of segments between the two vehicle types. Vehicle occupancy ranged from 15.0-81.0%, with a mean of 44.0% and a standard deviation of 16.2%. Most tests were conducted in sparsely to moderately occupied vehicles loaded between 25-75% capacity. Observations and measurements were not made in vehicles with less than 13 passengers (15.0% vehicle occupancy).

Most tests were made under zero sustained longitudinal acceleration (constant speed) conditions, as determined from the speed readings taken by the DOT technician in the locomotive. Only about 20% of the test segments involved situations in which the trains were speeding up or slowing down. On five occasions, the test team member in the locomotive was unable to take mile-for-mile speed readings: these data are therefore omitted from Table 30.

Although speed is not physically sensed by the human body, it can affect passenger well-being and is therefore included as a variable in this study. About 85% of the observations were made at speeds of 70 mph or more. Mean speed over the 77 test segments for which speed readings were available ranged from 54-

93 mph, with a mean of 79 mph and a standard deviation of 7 mph. This indicates that most tests were made at very similar speeds. On four occasions, no speed information was obtained.

Tests were made over an approximately equal number of different types of track segments, which were thought to be representative of the guideway conditions in the Northeast Corridor. It was not possible to determine the milepost intervals of nine segments; therefore, the track types for these tests remain unknown.

4.2.3 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 31. These variables include linear accelerations in three degrees of freedom (X-longitudinal, Y-lateral, and Z-vertical), their ISO-frequency weighted counterparts and computed vector sum, rotational accelerations and rates in three degrees of freedom (X-roll, Y-pitch, Z-yaw), the computed vector sums of the rotational accelerations and rates, acoustic noise, effective temperature, and ambient light.

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

Table 31

Statistical Summary of Amtrak Field Experimental Data
Recorded on Two Northeast Corridor Trains[1]
(December 5-13, 1977)

Ride Variable	Mean	Standard Deviation	Range
Longitudinal (X) Acceleration (rms g)	.008	.002	.005-.012
Lateral (Y) Acceleration (rms g)	.017	.004	.010-.026
Vertical (Z) Acceleration (rms g)	.022	.004	.013-.037
ISO-Weighted X-Acceleration (rms g)	.003	.001	.001-.007
ISO-Weighted Y-Acceleration	.013	.004	.007-.022
ISO-Weighted Z-Acceleration (rms g)	.009	.002	.005-.015
Weighted ISO Vector Sum (rms g)	.018	.005	.010-.030
Roll (X) Acceleration (°/sec²)	76.7	30.8	31.0 - 167.8
Pitch (Y) Acceleration (°/sec²)	57.2	35.3	19.7 - 169.3
Yaw (Z) Acceleration (°/sec²)	54.0	23.6	10.7 - 124.6
Vector Sum of Rotational Accelerations (°/sec²)	114.1	43.6	45.9 - 237.5
Roll (X) Rate (°/sec)	13.5	13.0	3.9 - 100.3
Pitch (Y) Rate (°/sec)	8.6	16.3	0.8 - 91.8
Yaw (Z) Rate (°/sec)	7.8	10.8	0.7 - 55.3
Vector Sum of Rotational Rates (°/sec)	20.6	21.0	4.6 - 114.6
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

1. Linear and angular accelerations and rates include frequencies between 0.1-20 Hz.

variables, however, were computed using the data recorded in 80 test segments.

Table 32 shows the intercorrelations between these variables. In general, it may be seen that there are high correlations within and between motions in the various axes (X, Y, and Z) and modes (linear vs. rotational). The correlations between the three linear accelerations and between their ISO-weighted counterparts are all highly significant. The correlations between yaw and roll, and pitch and roll, accelerations are also highly significant. Only pitch and roll are relatively uncorrelated.

Between the two modes of vibration, roll (X) acceleration is most highly correlated with the linear motions in all three axes. Pitch (Y) and yaw (Z) accelerations are also highly correlated with longitudinal linear motion, and yaw is highly correlated with vertical linear vibration. The rotational rates are highly correlated with rotational accelerations in the corresponding axes, as would be expected since they are the derivatives of the latter values. Similarly, it was expected and found that the correlations between the individual motion components and the corresponding vector sums would be highly correlated.

Table 32

Simple Correlations between Measured Environmental Variables (Motions in .1-20 Hz Range)

	X-Linear Accel.	Y-Linear Accel.	Z-Linear Accel.	Roll (X) Accel.	Pitch (Y) Accel.	Yaw (Z) Accel.	Roll (X) Rate	Pitch (Y) Rate	Yaw (Z) Rate
X-Linear Accel.	1.00	.42**	.59**	.50**	.22*	.33**	.25*	-.08	.09
Y-Linear Accel.		1.00	.69**	.44**	-.11	.14	.12	(-.18)	(-.15)
Z-Linear Accel.			1.00	.52**	.02	.26*	.30**	(-.16)	.02
Roll (X) Accel.				1.00	.13	.60**	.44**	-.05	.22*
Pitch (Y) Accel.					1.00	.56**	.03	.76**	.49**
Yaw (Z) Accel.						1.00	.27**	.44**	.59**
Roll (X) Rate							1.00	-.03	.60**
Pitch (Y) Rate								1.00	.46**
Yaw (Z) Rate									1.00

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

Table 32

(Cont)

	X-ISO Lin. Accel.	Y-ISO Lin Accel.	Z-ISO Lin. Accel.	ISO Vector Sum	Rotational Accel. Vector Sum	Rotational Rate Vector Sum	Noise	Effective Temp.	Light
X-Linear Accel.	.51**	.31**	.55**	.42**	.41**	.09	.00	-.11	-.07
Y-Linear Accel.	.45**	.95**	.64**	.95**	.19*	-.09	.13	(-.16)	.02
Z-Linear Accel.	.50**	.60**	.78**	.71**	.31**	.05	.11	(-.16)	.00
Roll (X) Accel.	.26*	.26*	.44**	.33**	.73**	.24*	.10	-.01	-.09
Pitch (Y) Accel.	.03	(-.17)	.00	-.14	.73**	.59**	-.08	.27**	-.13
Yaw (Z) Accel.	.20*	-.01	.14	.03	.87**	.55**	-.13	.06	.01
Roll (X) Rate	(.16)	.09	(.18)	.13	.32**	.65**	.11	.00	.13
Pitch (Y) Rate	.14	-.15	-.23*	(-.17)	.52**	.72**	(-.16)	.37**	-.04
Yaw (Z) Rate	.04	(-.17)	-.08	(-.15)	.56**	.85**	-.10	.27**	-.03

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

Table 32

(Cont)

	X-ISO Lin. Accel.	Y-ISO Lin. Accel.	Z-ISO Lin. Accel.	ISO Vector Sum	Rotational Accel. Vector Sum	Rotational Rate Vector Sum	Noise	Effective Temp.	Light
X-ISO Lin. Accel.	1.00	.48**	.38**	.56**	(.18)	(.16)	-.07	-.09	.03
Y-ISO Lin. Accel.		1.00	.53**	.97**	.04	-.08	.09	-.14	.02
Z-ISO Lin. Accel.			1.00	.72**	.23*	-.C8	.23*	-.12	.00
ISO Vector Sum				1.00	.09	-.07	.14	(-.16)	.02
Rotational Accel. Vector Sum					1.00	.61**	-.06	.19*	-.12
Rotational Rate Vector Sum						1.00	-.07	.31**	.03
Noise							1.00	-.06	-.05
Effective Temp.								1.00	-.28**
Light									1.00

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

It is interesting to note that there are no significant correlations between noise and the physical motion variables, except for Z-ISO linear acceleration. Effective temperature was significantly correlated with pitch (Y) acceleration and rate, yaw (Z) rate, the vector sums of the rotational accelerations and rates, and light. These correlations were unexpected, and may be related to particular structural features or aspects of the actual vehicles in which the tests were made.

Much of the earlier work relating motion variables to passenger ride comfort deals with vibration in the 1-20 Hz range, which is thought to contain the frequencies to which the human body is most sensitive mechanically and in which the major body resonances lie (Hornick and Lefritz, 1966). Therefore, the present set of data were also analyzed excluding the ultra-low frequency (.1-1 Hz) components. The distribution of motion variables in the 1-20 Hz frequency range is described in Table 33.

In general, the means, standard deviations, and ranges of the linear and rotational accelerations are approximately the same as those computed for the full frequency range of the data. As in Table 31, the ISO-weighted linear values are somewhat smaller than the unweighted linear vibration statistics. These differences result from relatively little power, or vibration amplitude, in the more heavily weighted 4-8 Hz range for vertical motion and in the 1-2 Hz range for X- and Y-linear vibration,

Table 33

Statistical Summary of Motion Variable Data - December 5-13, 1977 (1-20 Hz)

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 Vector Sum (rms g)	.015	.004	.009-.025
Roll (X) Acceleration ($^\circ/sec^2$)	74.94	29.14	20.57-150.49
Pitch (Y) Acceleration ($^\circ/sec^2$)	56.51	31.41	18.,74-158.92
Yaw (Z) Acceleration ($^\circ/sec^2$)	51.43	20.14	10.56-105.59
Vector Sum of Rotational Accelerations ($^\circ/sec^2$)	110.39	38.74	42.43-226.40
Roll (X) Rate ($^\circ$/sec)	2.56	2.04	.08-10.57
Pitch (Y) Rate ($^\circ$/sec)	1.69	1.93	.02-10.67
Yaw (Z) Rate ($^\circ$/sec)	1.66	1.15	.05- 5.39
Vector Sum of Rotational Rates ($^\circ$/sec)	3.79	2.65	.10-12.22

compared to the other frequency bands. The rotational rate statistics for the 1-20 Hz data shown in Table 33 are much smaller than those computed for the .1-20 Hz range shown in Table 31, indicating a relatively high level of power in the .1-1 Hz range in the rotational mode of vibration.

Table 34 shows the intercorrelations between the measured environmental variables when the motions are restricted to the 1-20 Hz range. Again, all the linear accelerations are significantly intercorrelated, although the correlation coefficients are slightly lower than those in Table 32. The correlations between the three linear accelerations and between the three ISO-weighted linear accelerations are all highly significant. The correlations between the unweighted linear and ISO-weighted values in corresponding axes of motion are also highly significant.

The rotational accelerations are also significantly intercorrelated, including the pitch and roll accelerations. As in Table 32, the pitch and roll rates are not significantly correlated, although yaw is significantly related to roll and pitch. The rotational accelerations are more highly correlated with their corresponding rates in the 1-20 Hz range as opposed to the .1-20 Hz range.

Table 34

Simple Correlations between Measured Environmental Variables
(Motions in 1-20 Hz Range)

	X-Linear Accel.	Y-Linear Accel.	Z-Linear Accel.	Roll (X) Accel.	Pitch (Y) Accel.	Yaw (Z) Accel.	Roll (X) Rate	Pitch (Y) Rate	Yaw (Z) Rate
X-Linear Accel.	1.00	.21*	.48**	.52**	.32**	.47**	.29**	.09	.24*
Y-Linear Accel.		1.00	.61**	.45**	.01	.19*	.34**	-.01	.13
Z-Linear Accel.			1.00	.48**	.14	.36**	.20*	-.01	(.16)
Roll (X) Accel.				1.00	.19*	.63**	.72**	.09	.32**
Pitch (Y) Accel.					1.00	.55**	.09	.87**	.66**
Yaw (Z) Accel.						1.00	.27**	.46**	.74**
Roll (X) Rate							1.00	.14	.31**
Pitch (Y) Rate								1.00	.71**
Yaw (Z) Rate									1.00

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

Table 34

(Cont)

	X-ISO Lin. Accel.	Y-ISO Lin. Accel.	Z-ISO Lin. Accel.	ISO Vector Sum	Rotational Accel. Vector Sum	Rotational Accel. Vector Sum	Noise	Effective Temp.	Light
X-ISO Lin. Accel.	1.00	.29*	.50**	.52**	.30**	.29**	.06	-.09	-.01
Y-ISO Lin. Accel.		1.00	.31**	.91**	.07	(.18)	.08	-.14	(.15)
Z-ISO Lin. Accel.			1.00	.64**	.35**	.14	(.16)	-.14	.03
ISO Vector Sum				1.00	.22*	.24*	.12	(.18)	.14
Rotational Accel. Vector Sum					1.00	.75**	.05	(.16)	-.14
Rotational Rate Vector Sum						1.00	-.04	.13	-.03
Noise							1.00	-.06	-.05
Effective Temp.								1.00	-.28**
Light									1.00

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

Table 34

(Cont)

	X-ISO Lin. Accel.	Y-ISO Lin. Accel.	Z-ISO Lin. Accel.	ISO Vector Sum	Rotational Accel. Vector Sum	Rotational Rate Vector Sum	Noise	Effective Temp.	Light
X-Linear Accel.	.62**	.05	.54**	.31**	.51**	.22*	.14	-.13	-.08
Y-Linear Accel.	.30**	.90**	.53**	.91**	.28**	.21*	.12	(-.17)	.14
Z-Linear Accel.	.50**	.45**	.78**	.67**	.39**	.12	.13	(-.17)	.01
Roll (X) Accel.	.36**	.24*	.46**	.40**	.77**	.53**	.11	-.04	-.09
Pitch (Y) Accel.	.14	-.09	.12	-.01	.74**	.61**	.04	.26*	-.12
Yaw (Z) Accel.	.23*	-.03	.30**	.11	.86**	.53**	.00	.05	-.07
Roll (X) Rate	.34**	.31**	.25*	.39**	.50**	.75**	.04	-.06	.02
Pitch (Y) Rate	.14	-.03	-.03	-.02	.62**	.74**	-.05	.23**	-.07
Yaw (Z) Rate	.24*	.05	(.17)	.11	.70**	.76**	-.07	.12	-.05

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

The vector sums are significantly correlated with the corresponding individual motion components, as expected. The few significant correlations between the motion variables and noise, effective temperature, and light found with the .1-20 Hz data are slightly lower or non-existent when the 1-20 Hz data is used.

4.2.4 The Effects of Trip Variables on Activities. Figures 23-33 illustrate the effects of various trip and situational variables on the levels of the activities described in Table 1. In general, there were few significant differences in activity levels which could be attributed to these variables, lending credence to the stability and generality of the data over the range of test conditions used in this experiment. Statistically significant differences are summarized in terms of the relevant trip variables below.

Doing Nothing was the only activity which appeared to vary with the day of the week (Figure 23). The results of a one-way analysis of variance on the relative frequency of this behavior by day is shown in Table 35. Wednesday seems to be the most "active" day, in the sense that the lowest percentage of passengers were Doing Nothing that day. A similar trend was obtained using the activity data gathered in July, 1977 ($F=2.41$, d.f. $=4,76$, $p<.1$).

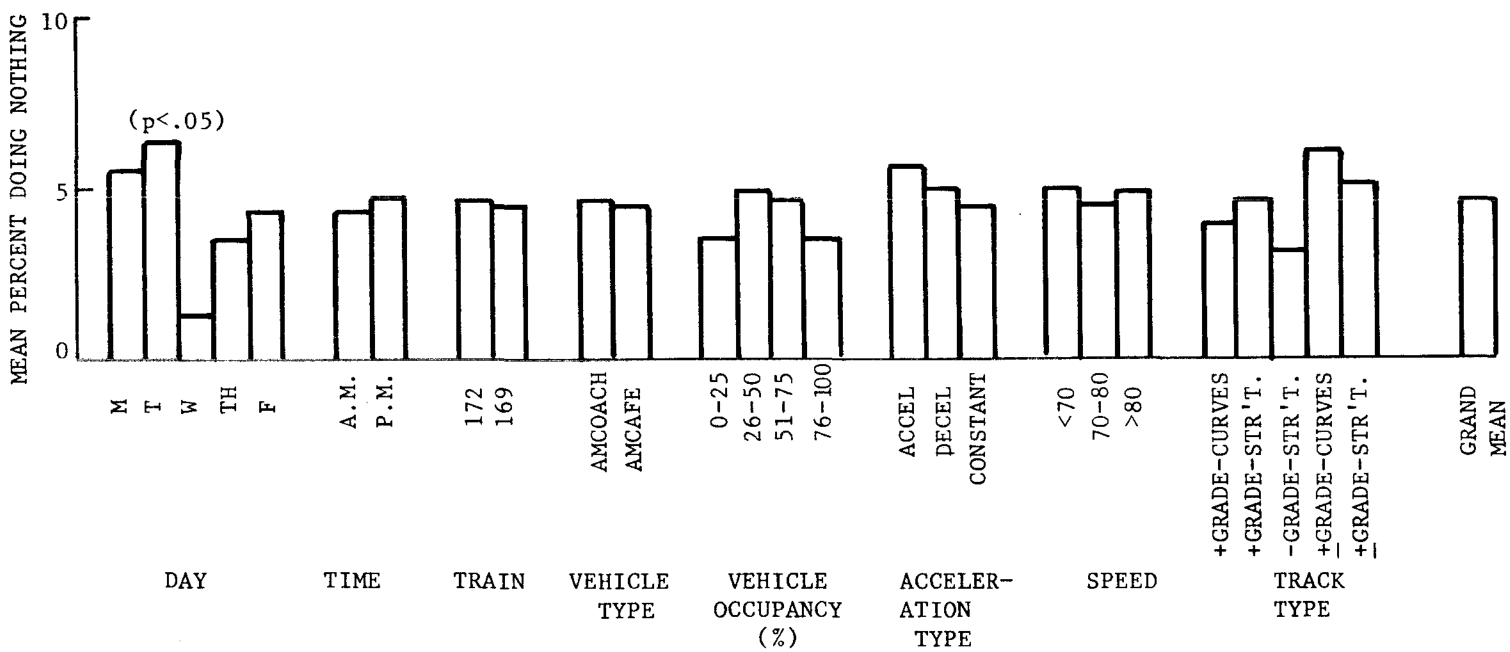


Figure 23. Percent Passengers Doing Nothing As A Function Of Various Trip Parameters

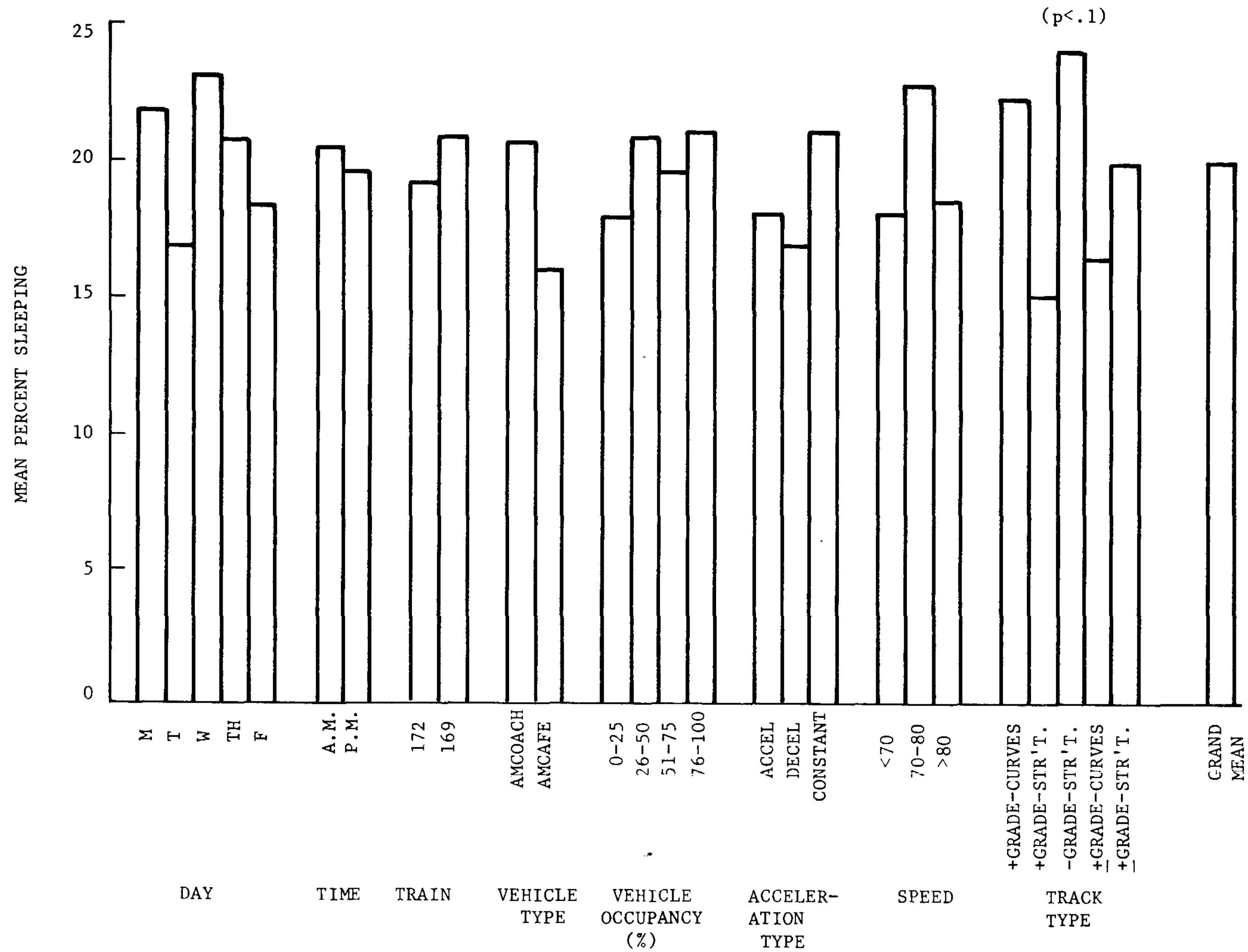


Figure 24. Percent Passengers Sleeping As A Function Of Various Trip Parameters

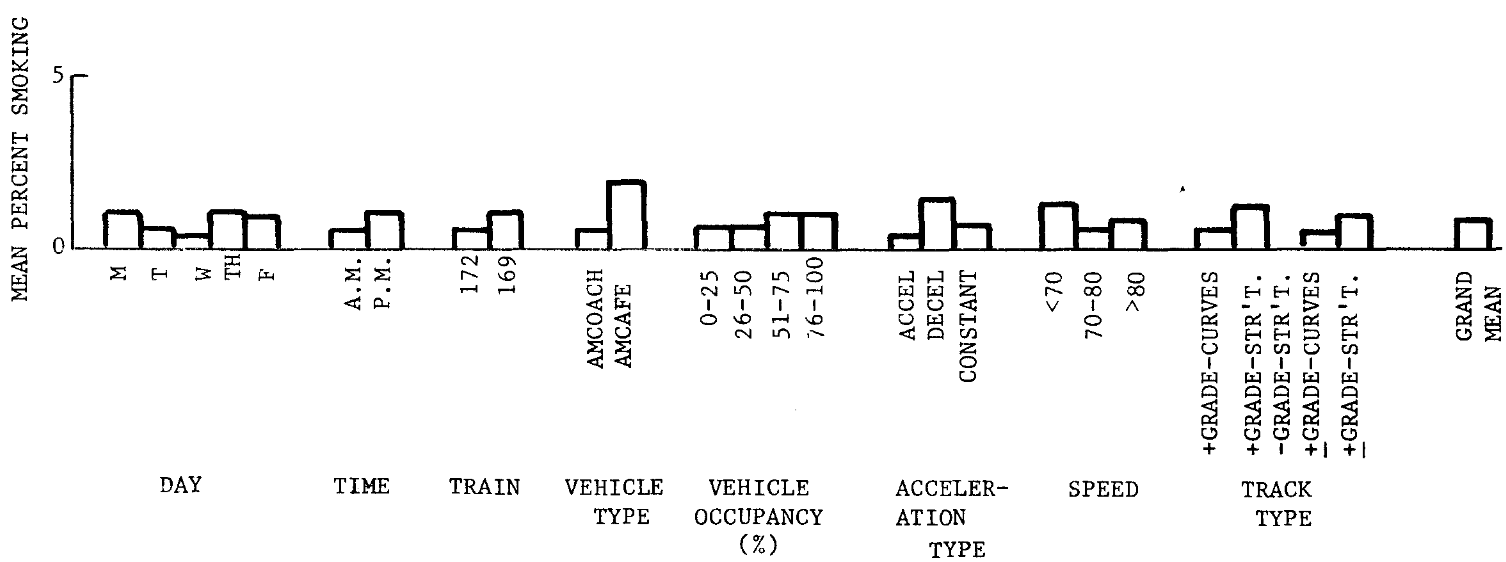


Figure 25. Percent Passengers Smoking As A Function Of Various Trip Parameters

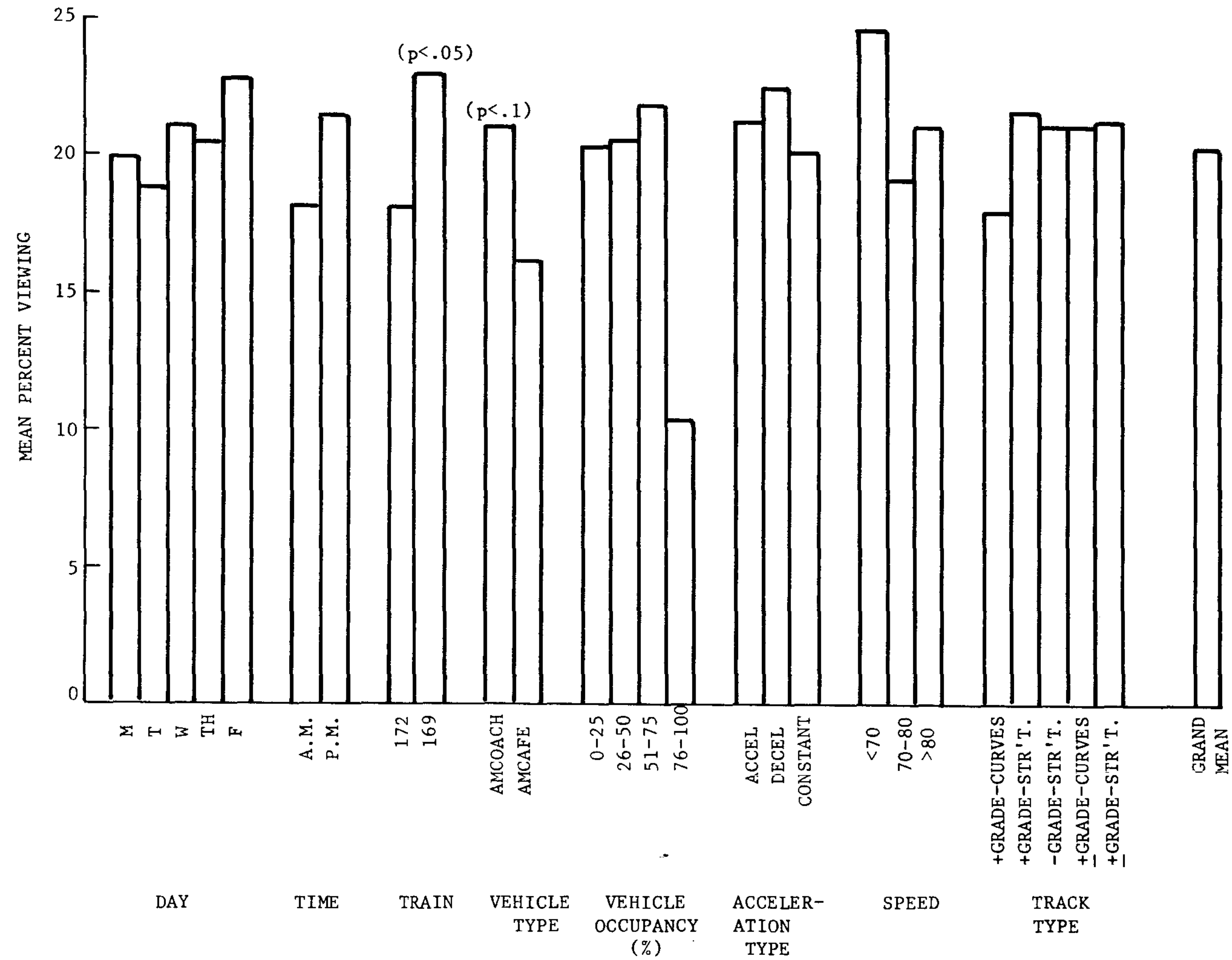


Figure 26. Percent Passengers Viewing As A Function Of Various Trip Parameters

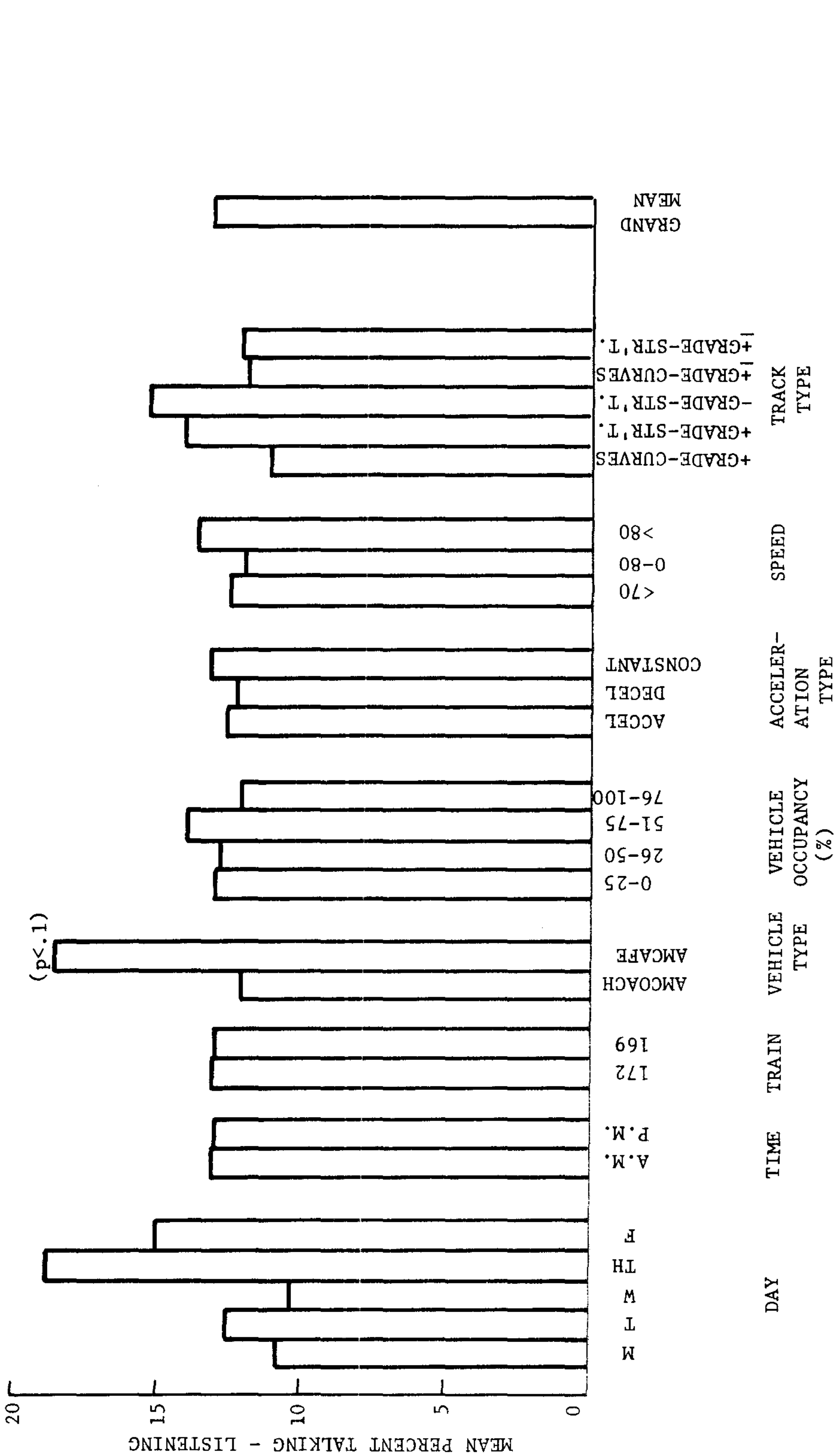


Figure 27. Percent Passengers Talking-Listening As A Function Of Various Trip Parameters

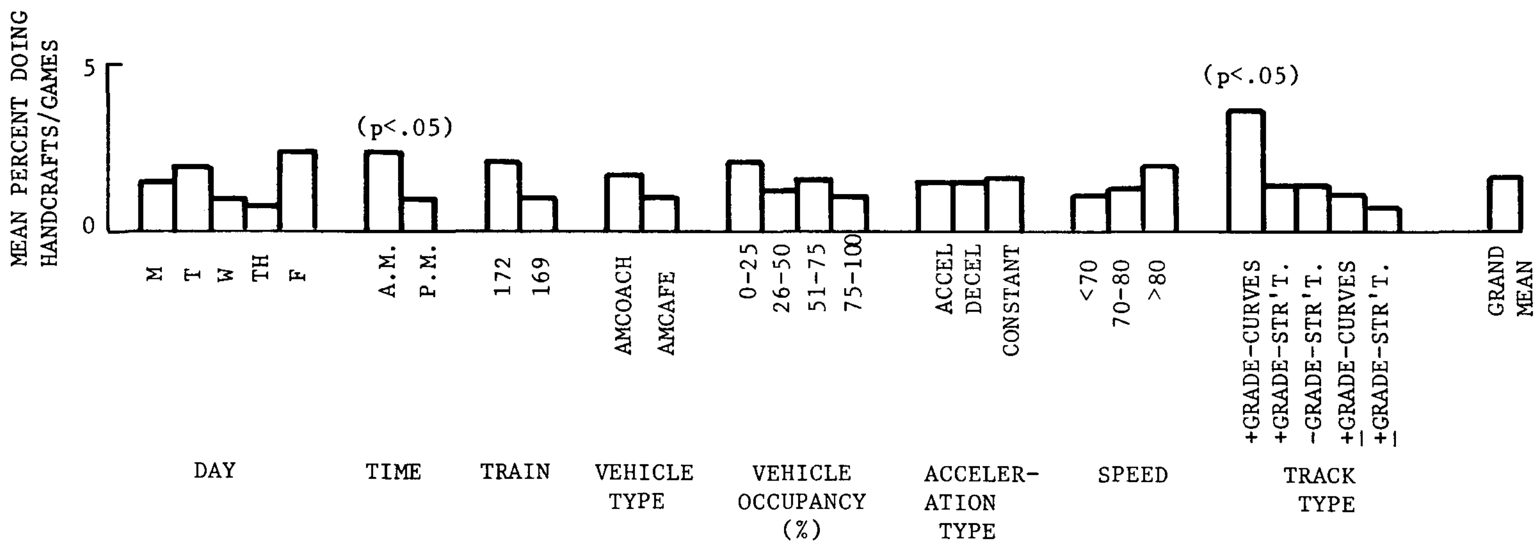


Figure 28. Percent Passengers Doing Handcrafts/Games As A Function Of Various Trip Parameters

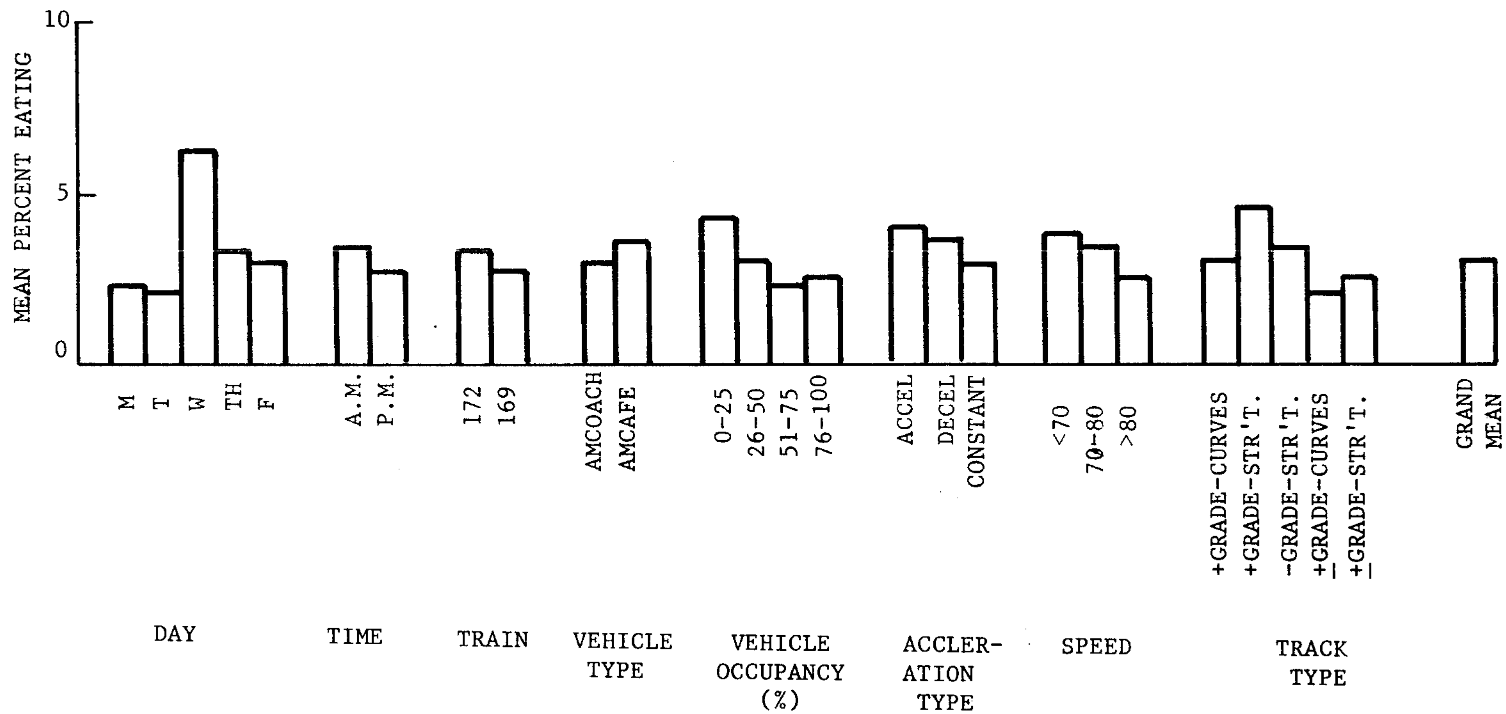


Figure 29. Percent Passengers Eating As A Function Of Various Trip Parameters

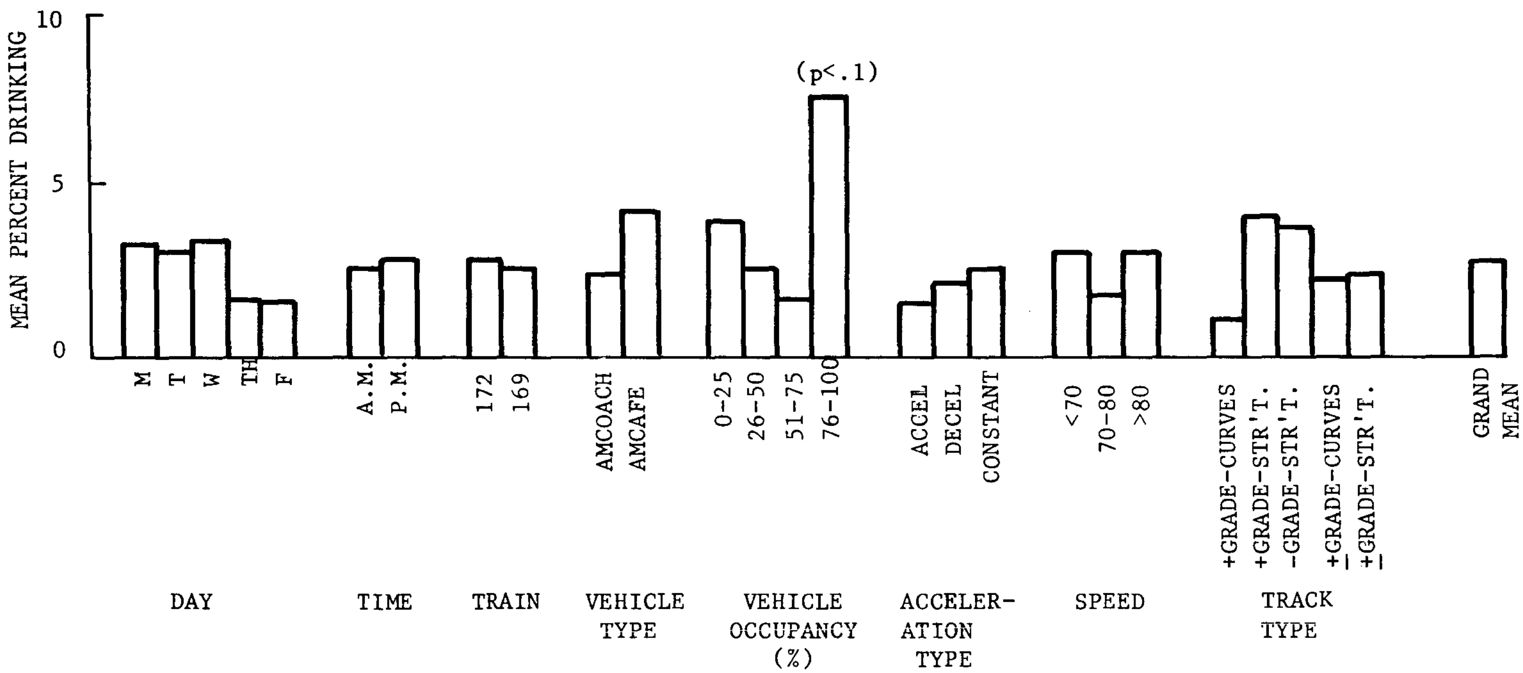


Figure 30. Percent Passengers Drinking As A Function Of Various Trip Parameters

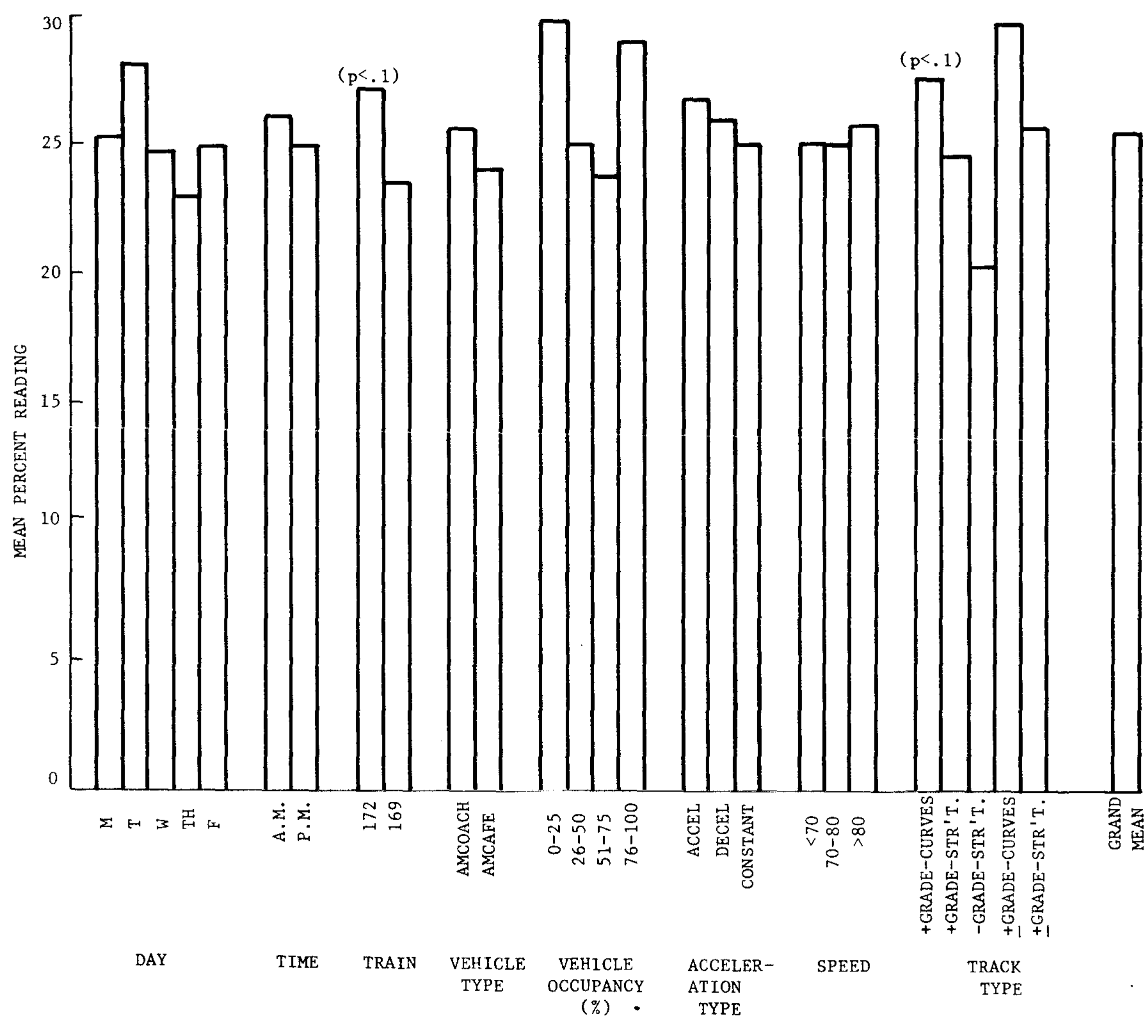


Figure 31. Percent Passengers Reading As A Function Of Various Trip Parameters

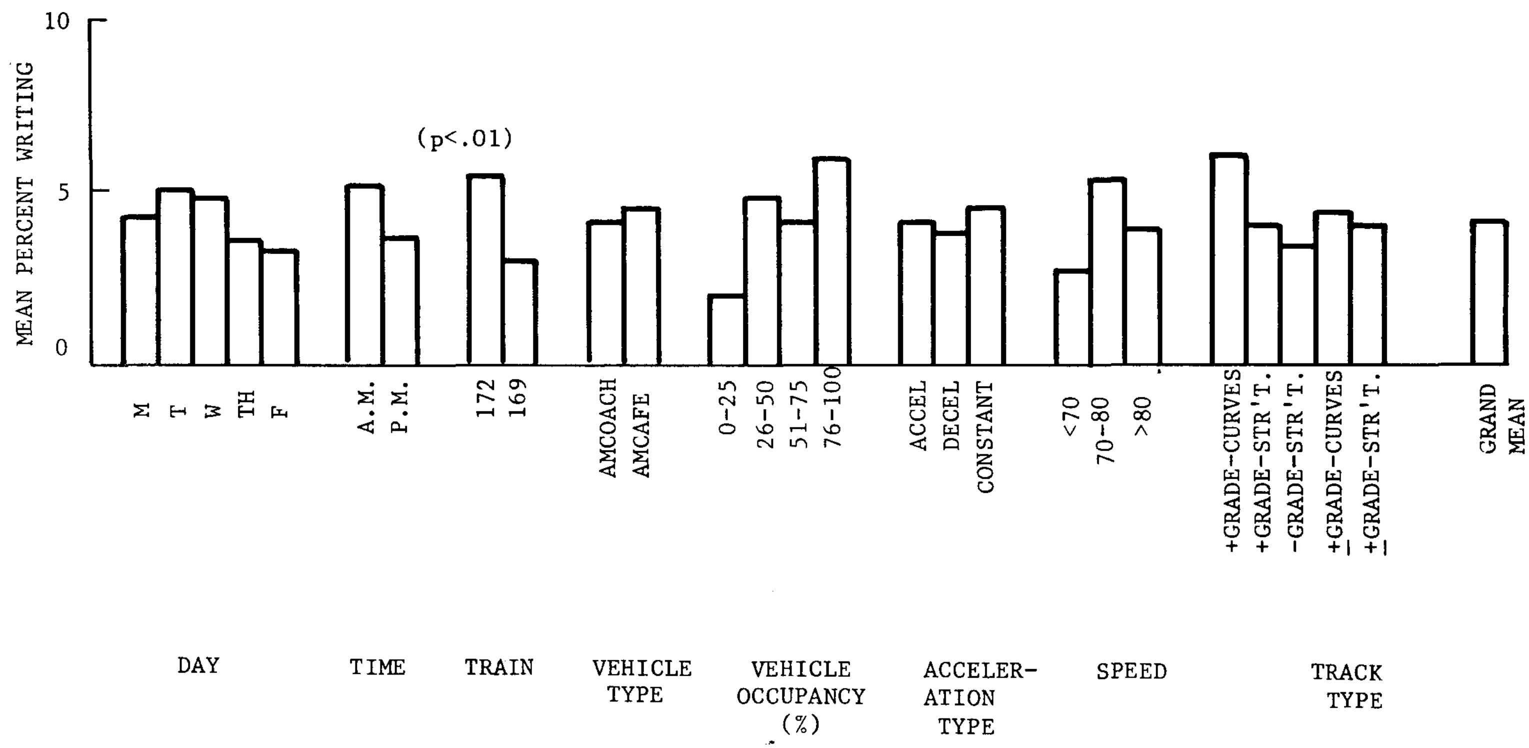


Figure 32. Percent Passengers Writing As A Function Of Various Trip Parameters

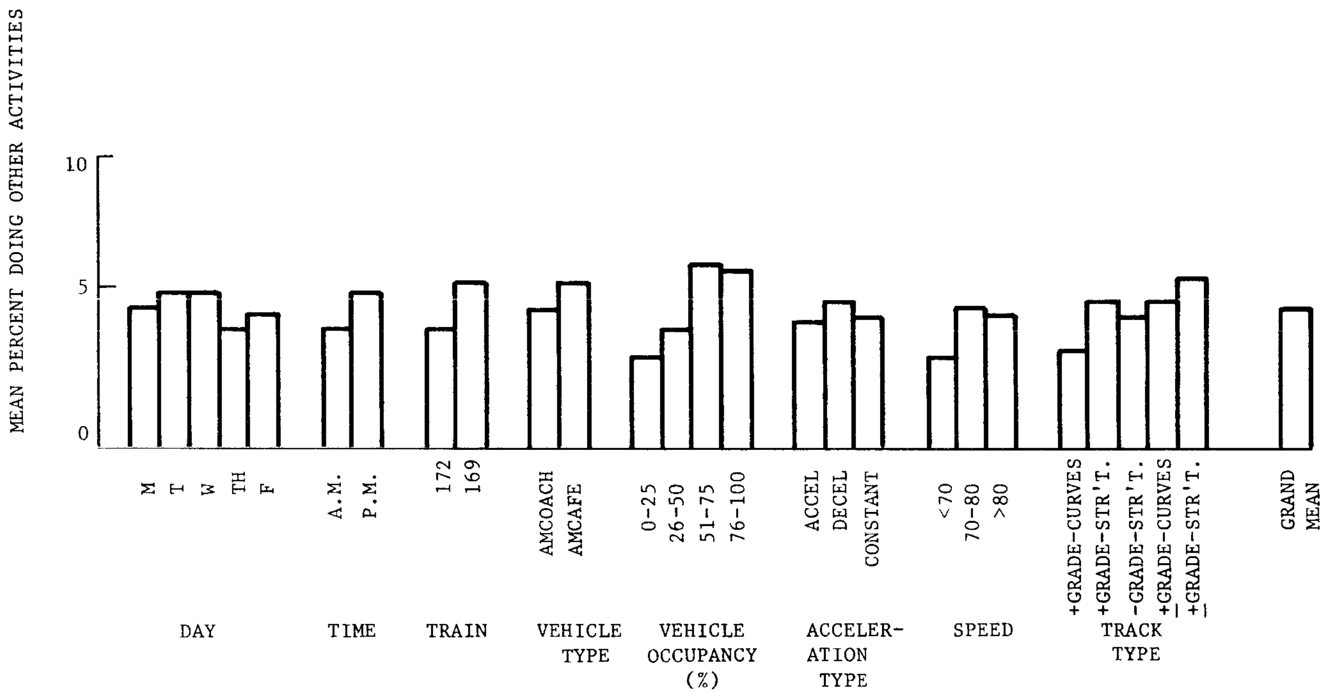


Figure 33. Percent Passengers Doing Other Activities As A Function Of Various Trip Parameters

Table 35

Results of One-Way Analysis of Variance on Percent Doing Nothing by Day

Source	SS	d.f.	MS	F
Between (Days)	223.74	4	55.93	2.75 ($p<.05$)
Within	1546.76	76	20.35	
Total	1770.56	80		

There was a trend for time of day to affect levels of Handcrafts/Games (t[4]$=1.86$, d.f.=79, $p<.1$), with more of this type of activity in the morning than in the afternoon (Figure 28). This result was in the opposite direction of what was found in the July observations, however.

Although the train variable was almost completely confounded with time of day (i.e., #172 was largely a morning train and #169 an afternoon train), some differences in activity levels did surface between trains which were apparent but not statistically significant between times of day. For instance, there was more Viewing on Train 169 than on Train 172 (Figure 26; $t=2.19$, d.f. = 79, $p<.05$); more Writing and Reading were observed on 172 than on 169 (Figure 32; $t=2.87$, d.f. = 79, $p<.01$; and Figure 31; $t=1.86$, d.f. =79, $p<.1$, respectively). Results in the same directions were obtained for these three activities using the July data, although the differences in Viewing and Writing were not

[4]All t-tests described in this section are two-tailed.

significant, while that for Reading was highly significant ($t=4.77$, d.f. $=56$, $p<.01$).

Vehicle type was previously determined to be a trip variable of interest for its effects on passenger activities. Although there were some clear differences in relative activity levels depending on vehicle type, only a few of these reached the level of a statistical trend. More Smoking (Figure 25) Talking-Listening (Figure 27; $t=1.85$, d.f. $=79$, $p<.1$), Eating, (Figure 29), Drinking (Figure 30), and Writing (Figure 32) were observed in Amcafe cars, while more Sleeping (Figure 24), Viewing (Figure 26; $t=1.84$, d.f. $=79$, $p<.1$), Handcrafts/Games (Figure 28), Reading (Figure 31), and Other (Figure 33) activities were observed in Amcoach vehicles. Doing Nothing (Figure 23) was observed equally often in both types of vehicles. The July results for Viewing were in the same direction but not statistically significant. The July differences for Talking-Listening were statistically significant ($t=2.08$, d.f. $=74$, $p<.05$) and in the same direction.

Vehicle occupancy did not significantly influence the level of any activity. A trend toward more Drinking with greater levels of crowding did appear (Figure 30; $F=2.68$, d.f. $=3,77$, $p<.1$), although this trend did not exist in the July observations.

No significant differences in activity levels were found due to the train speed. However, track type did significantly influence Sleeping (Figure 24; Table 36), Handcrafts/Games (Figure 28; Table 37), and Reading (Figure 31; Table 38).

For the purposes of subsequent multiple regression analyses, some of the trip variables were numerically coded and correlations with activity levels were computed. Days of the week were coded with the numbers 1 through 5 from Monday to Friday. Mornings were given a value of 1 and afternoons a value of 2 for the time variable. Vehicle types were coded as 1 for Amcoaches and 2 for Amcafe snackbars. Vehicle occupancy was not coded categorically; rather, the actual percent values computed for each vehicle in each test segment were used in the correlations.

Table 39 shows that Doing Nothing significantly decreased from earlier to later in the week. Viewing increased from morning to afternoon, while Handcrafts/Games and Writing decreased with time into the day. More Smoking, Talking-Listening, and Drinking occurred in Amcafe cars than in Amcoaches, and less Sleeping and Viewing. More Sleeping was observed in densely crowded vehicles, and more Eating and Reading occurred in sparsely occupied vehicles. These results parallel those illustrated in Figures 23-33.

Table 36

Results of One-Way Analysis of Variance on Percent Sleeping by Track Type

Source	SS	d.f.	MS	F
Between	883.33	4	220.83	2.03 (p<.1)
Within	7284.92	67	108.73	
Total	8168.26	71		

Table 37

Results of One-Way Analysis of Variance on Percent Doing Handcrafts/Games by Track Type

Source	SS	d.f.	MS	F
Between	77.76	4	19.44	2.64 (p<.05)
Within	492.91	67	7.36	
Total	570.67	71		

Table 38

Results of One-Way Analysis of Variance on Percent Reading by Track Type

Source	SS	d.f.	MS	F
Between	737.99	4	184.50	2.18 (p<.1)
Within	5682.47	67	84.81	
Total	6420.46	71		

Table 39

Simple Correlations between Percent Observed Activities and Trip Variables

TRIP VARIABLES	ACTIVITIES									
	Doing Nothing	Sleeping	Smoking	Viewing	Talking Listening	Eating	Handcrafts/ Games	Reading	Drinking	Writing
Day of Week	-.18*	-.04	-.08	.10	.03	.10	.04	-.08	(-.16)	-.11
Time of Day	.05	-.04	.13	.18*	.00	-.10	-.23*	-.07	.02	-.19*
Vehicle Type	.00	(-.16)	.25*	(-.17)	.25**	.06	-.07	-.06	.18*	.03
Vehicle Occupancy	.13	.33**	.10	-.10	.08	(-.15)	-.02	(-.16)	-.03	.09

( ): p<.10 *: P<.05 **: p<.01 n=80

4.2.5 The Effects of Environmental Variables on Activities. Table 40 shows the correlations between the measured linear accelerations from .1-20 Hz and the relative frequencies of activities. These coefficients are in general quite low, with only a few significant values. Some of these were in the opposite direction of what would be expected (e.g., the frequencies of Handcrafts/Games and Eating would be expected to decrease, not increase, as linear accelerations increased). Only Talking-Listening was significantly negatively correlated with any of the linear accelerations.

Table 41 shows the correlations between the activities and the measured and derived angular accelerations and rates from .1-20 Hz. There are many more significant correlations between these types of motions and the individual acitvities than in the case of the linear accelerations. The rotational motions appear to facilitate Sleeping, Smoking, and to a lesser extent, Doing Nothing, while inhibiting Talking-Listening, Eating, Handcrafts/Games, and Writing. Viewing and Reading were not correlated with any of the recorded motions.

Table 42 shows the correlations between the activities and the non-motion variables. Noise was significantly correlated only with the relative frequency of Talking-Listening. As effective temperature increased, levels of Doing Nothing increased, while the relative frequencies of Smoking and Viewing decreased. As the level of illumination increased, Doing Nothing

Table 40

Simple Correlations between Percent Observed Activities and Linear Accelerations (.1-20 Hz)

	ACTIVITIES									
	Doing Nothing	Sleeping	Smoking	Viewing	Talking Listening	Eating	Handcrafts/ Games	Reading	Drinking	Writing
Linear Accelerations										
Longitudinal (X)	.06	-.07	(.18)	-.09	-.03	.04	(.17)	-.03	-.04	.01
Lateral (Y)	.00	.07	-.04	.00	-.12	(.16)	(.17)	-.07	.07	.06
Vertical (Z)	.06	-.07	.06	.06	-.13	-.03	.26**	-.05	.05	-.01
ISO-Weighted X-	-.07	-.05	(.17)	.08	-.19*	.21*	.03	.07	.02	-.04
ISO-Weighted Y-	-.06	.05	-.11	.01	-.13	.21*	(.15)	-.05	.06	.05
ISO-Weighted Z-	.04	-.08	.08	-.05	-.05	-.03	.41**	.09	-.05	.05
ISO Vector Sum	-.04	.00	-.04	.00	-.12	.19*	.23*	-.01	.04	.05

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

Table 41

Simple Correlations between Percent Observed Activities and Rotational Accelerations and Rates (.1-20 Hz)

	ACTIVITY									
Rotational Motions	Doing Nothing	Sleeping	Smoking	Viewing	Talking-Listening	Eating	Handcrafts/ Games	Reading	Drinking	Writing
Roll (X) Acceleration	.14	.19*	.03	-.03	(-.15)	-.22*	(.14)	-.07	.04	-.08
Pitch (Y) Acceleration	.00	.08	.21*	-.07	-.10	.02	-.06	.00	.14	-.13
Yaw (Z) Acceleration	.01	.25*	.12	.01	-.21*	(-.15)	.04	-.10	.00	.03
Vector Sum: Rotational Accelerations	.10	.23*	.13	-.04	-.21*	(-.15)	.03	-.05	.09	-.10
Roll (X) Rate	.06	.05	.12	-.01	.06	(-.15)	-.06	.03	.02	-.09
Pitch (Y) Rate	-.06	.12	.08	-.04	(-.15)	.00	(-.16)	.05	(.16)	(-.17)
Yaw (Z) Rate	.04	.24*	.09	-.11	-.08	-.11	-.13	.00	.02	-.04
Vector Sum: Rotational Rates	.01	.17*	.10	-.07	-.08	-.10	(-.16)	.05	.14	(-.16)

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

Table 42

Simple Correlations between Percent Observed Activities and Non-Motion Variables

	ACTIVITIES									
Non-Motion Variables	Doing Nothing	Sleeping	Smoking	Viewing	Talking Listening	Eating	Handcrafts/ Games	Reading	Drinking	Writing
Noise	-.04	-.06	.09	(-.16)	.27*	-.09	.01	.12	.05	-.12
Effective Temperature	.20*	.00	-.20*	-.18*	-.08	.13	.08	.11	.08	.05
Light	-.21*	.06	.13	-.08	.20*	.09	-.18*	.00	-.01	-.06

( ): $p<.10$ *: $p<.05$ n=81

and Handcrafts/Games were observed less frequently compared to other activities, while Talking-Listening was observed more frequently.

Since the correlations between individual activities and the environmental variables were generally small but significant, it was decided to combine the activities into groups based on similarities in effort or physical action components, to see how well these activity indexes might be correlated with the physical variables. The first type of grouping was based on the a priori effort ranks assigned to the activities in Table 2 (Section 2.1.3). It will be recalled that activities were grouped into three effort categories: 1) Low Effort, including Doing Nothing, Sleeping, Smoking, and Viewing; 2) Medium Effort, including Talking-Listening, Handcrafts, and Games; and 3) High Effort, including Eating, Drinking, Reading, and Writing.

Table 43 shows the correlations between High, Medium, and Low Effort activities and the motion (.1-20 Hz range), non-motion, and trip variables. It may be seen that while the High Effort activities are not significantly correlated with any of the above variables, the relative frequencies of the Medium and Low Effort behaviors are significantly related to the rotational motions and some of the non-motion and trip variables. While the frequency of Medium Effort activities is negatively affected by the rotational motions, these motions are positively related to Low Effort behaviors. In particular, yaw acceleration and pitch rate

Table 43

Simple Correlations between Percent High, Medium, and Low Effort Activities and Environmental[1] and Trip Variables

	HIGH	MEDIUM	LOW
X-Linear Acceleration	.04	.02	-.08
Y-Linear Acceleration	.04	-.07	.04
Z-Linear Acceleration	.05	-.05	.02
X-ISO Linear Acceleration	.12	(-.17)	.01
Y-ISO Linear Acceleration	.08	-.08	.02
Z-ISO Linear Acceleration	.07	.07	-.08
Weighted ISO Vector Sum	.09	-.05	-.01
Roll (X) Acceleration	(-.15)	-.10	-.19*
Pitch (Y) Acceleration	.01	-.11	.05
Yaw (Z) Acceleration	-.13	-.19*	.23*
Rotational Acceleration Vector Sum	-.11	-.19*	.21*
Roll (X) Rate	-.06	.04	.07
Pitch (Y) Rate	.03	-.19*	.06
Yaw (Z) Rate	-.05	-.12	.14
Rotational Rate Vector Sum	-.01	-.13	.10
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)

1. Motion variables include frequencies between .1-20 Hz.

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

are negatively correlated with Medium Effort activities, while roll and yaw accelerations are positively correlated with Low Effort activities. Noise is positively correlated with Medium Effort behaviors and negatively correlated with Low Effort acts, although the latter relationship is only marginally significant. Medium Effort behaviors occurred significantly more often in Amcafe snackbar vehicles than in Amcoaches, while the reverse was true for the Low Effort activities.

Based upon similarities in physical action components and common correlations with environmental and trip variables, the activities were regrouped into a second set of *post hoc* 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 were excluded from the *post hoc* physical action indexes, primarily because the relative frequencies of these activities were not correlated with any of the environmental or trip variables in this study.

Table 44 shows the correlations between the *post hoc* activity indexes and the measured physical and trip variables. The Rest activities are most highly positively correlated with the rotational accelerations, especially roll, yaw, and the

Table 44

Simple Correlations between Percent Rest, Social/Oral, and Motor Activities and Environmental[1] and Trip Variables

	REST	SOCIAL/ORAL	MOTOR
X-Linear Acceleration	-.04	.01	.09
Y-Linear Acceleration	.07	-.02	.13
Z-Linear Acceleration	-.05	-.08	.13
X-ISO Linear Acceleration	-.09	-.04	-.02
Y-ISO Linear Acceleration	.03	-.02	.12
Z-ISO Linear Acceleration	-.07	-.05	.25*
Weighted ISO Vector Sum	-.01	-.02	(.15)
Roll (X) Acceleration	.26*	(-.17)	.01
Pitch (Y) Acceleration	.09	.01	-.13
Yaw (Z) Acceleration	.26*	-.19*	.04
Rotational Acceleration Vector Sum	.28**	(-.16)	-.06
Roll (X) Rate	.08	.02	-.10
Pitch (Y) Rate	.10	-.05	-.22*
Yaw (Z) Rate	.26*	-.08	-.10
Rotational Rate Vector Sum	(.18)	-.03	-.20*
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

1. Motion variables included frequencies between .1-20 Hz.

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

rotational acceleration vector sum. The Social/Oral behaviors are negatively correlated with the same physical variables, although these coefficients are lower in magnitude. Noise and light are positively related to the Social/Oral activities, which occur primarily in Amcafe-type vehicles (signified by the highly significant positive correlation with vehicle type). The Motor activities are negatively correlated with pitch rate and the vector sum of the rotational rates. The positive correlation between ISO-weighted Z-acceleration and the relative frequency of Motor behaviors may be attributed to the positive relationship between this type of motion and the frequency of Handcrafts/Games. Motor activities also occurred more frequently in the morning rather than the afternoon, as indicated by the negative correlation between Motor behaviors and time of day.

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. These are shown in Table 45. These linear equations represent the best fit of the physical and trip variable data to the observed levels of activity, in the form of the a priori effort and post hoc physical action indexes.

It may be seen that levels of Low Effort and High Effort activities may not be predicted to an appreciable level of significance by the trip, non-motion, and motion variables from .1-20 Hz. The Medium Effort activity level can be predicted to a

Table 45
Linear Multiple Regression Models for Activity Indexes (Motion Variables in .1-20 Hz Range)

ACTIVITY INDEX (A)	ACTIVITY MODEL	F (d.f.)	MULTIPLE R	R^2	LEVEL OF SIGNIFICANCE
Low Effort	$\%A=.06\alpha_Z-.59N+.05\alpha_X-5.76(V)+3.03(T)+80.14$ $(\sigma)=(.08)\ (.46)(.06)(4.28)\ (3.11)$	2.05 (5,70)	.36	.13	NS
Medium Effort	$\%A=.50N-.03\alpha_Z+.23I-1020.63a_{XISO}-.07\omega_Y+5.06(V)-21.85$ $(\sigma)=(.32)(.05)\ (.18)(878.48)\ (.07)\ (3.07)$	2.29 (6,69)	.41	.16	$p<.05$
High Effort	$\%A=1.68ET-.05\alpha_X+.0005\alpha_Z-.11(VO)-1.83(T)-67.17$ $(\sigma)=(1.29)\ (.05)\ (.07)\ (.08)\ (2.79)$	1.31 (5,70)	.29	.09	NS
Rest	$\%A=.19\omega_Z+.09\alpha_X-695.96a_{ZISO}-3.94(V)+26.58$ $(\sigma)=(.11)\ (.04)\ (580.32)\ (3.24)$	3.25 (4,72)	.39	.15	$p<.05$
Social/Oral	$\%A=9.18V+.41I-.08\alpha_Z+.46N-21.11$ $(\sigma)=(3.62)\ (.22)(.05)(.37)$	4.15 (4,71)	.44	.19	$p<.01$
Motor	$\%A=-.07\omega_Y-.04\omega_X-.19I-.19N-2.31(T)+.10(SP)+16.92$ $(\sigma)=(.04)\ (.05)\ (.11)(.18)(1.30)\ (.09)$	2.26 (6,66)	.41	.17	$p<.05$

α_* = Rotational Accel. (* axis)
a_{*ISO} = ISO-Weighted Linear Accel. (* axis)
ET = Effective Temp. (°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)

significant extent using six variables: noise, yaw (Z) acceleration, light, ISO-weighted X-linear acceleration, pitch (Y) rate, and vehicle type, which account for approximately 16% of the variance in Medium Effort activity.

Using the post hoc physical action indexes, activity levels in all three categories may be predicted to a statistically significant degree by the environmental and trip variables recorded in this study. The relative frequency of Rest activity may be predicted by the levels of yaw rate, roll acceleration, ISO-weighted Z-linear acceleration, and vehicle type. Social/Oral activities may be accounted for using only four variables: vehicle type, light, yaw acceleration, and noise; these are also among the variables included in the Medium Effort activity equation. Motor activity levels may be predicted using the measured levels of pitch rate, roll rate, light, noise, time of day, and speed.

Activities were also correlated with the environmental motion variables measured between 1-20 Hz. Table 46 shows the simple correlations between the individual activities and measured and derived linear acceleration variables when the ultra-low (.1-1 Hz) frequencies are excluded. In general, there are few significant correlations or trends between the activities and the linear accelerations.

Table 46

Simple Correlations between Percent Observed Activities and Linear Accelerations (1-20 Hz)

	ACTIVITIES									
Linear Accelerations	Doing Nothing	Sleeping	Smoking	Viewing	Talking-Listening	Eating	Handcrafts/ Games	Reading	Drinking	Writing
Longitudinal (X)	-.03	.06	(.15)	.02	.05	-.02	.14	(-.17)	.01	-.06
Lateral (Y)	-.02	.06	.03	.02	-.11	.20*	.05	-.07	-.01	.05
Vertical (Z)	.07	-.10	.08	.07	-.10	-.03	.28**	.05	.03	-.01
ISO-Weighted X-	-.12	.12	.11	(.16)	(-.15)	.14	.06	-.13	.04	-.09
ISO-Weighted Y-	-.09	.06	-.07	.13	-.12	.28**	-.09	-.07	-.03	.02
ISO-Weighted Z-	.03	-.05	.03	-.05	-.08	-.03	.42**	.09	-.06	.06
ISO Vector Sum	-.07	.05	-.05	.12	-.13	.23*	.08	-.07	-.04	.01

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

Table 47 shows the simple correlations between the activities and the measured and derived rotational accelerations. Comparison of these values with those in Table 41 reveals more significant correlations between the rotational rates and the activities when the .1-1 Hz motions are excluded, and more significant correlations between the rotational accelerations and the activities when the entire frequency range from .1-20 Hz is used as the basis for computing the rotational amplitudes (Table 41). Thus, Sleeping is now highly correlated with the roll and yaw rates and the rotational rate vector sum, whereas the correlations were higher using the rotational accelerations rather than the rates in these axes in Table 41. The result is similar for Talking-Listening, which is highly correlated with yaw rate and the rate vector sum when the 1-20 Hz data are used, as opposed to yaw acceleration and the rotational acceleration vector sum when the frequency range is extended to .1-20 Hz.

The values of several correlation coefficients increased to the level of statistical significance or appeared as trends ($p < .10$) where none had appeared before when the frequency range of the data was limited to 1-20 Hz. The correlations between Writing and pitch and roll rates and the rate vector sum increased in value when the .1-1 Hz range amplitudes were excluded. Smoking was significantly correlated with pitch and yaw accelerations, the rotational acceleration vector sum, and pitch rate. There were positive trends between Doing Nothing and

Table 47

Simple Correlations between Percent Observed Activities and Rotational Acceleration 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
Vector Sum: Rotational Accelerations	.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
Vector Sum: Rotational Rates	-.02	.28**	.10	.04	-.26**	-.08	(-.15)	-.07	.12	-.20*

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

roll acceleration, and Writing and pitch acceleration and roll rate.

The activity indexes were also regressed against the physical motion variables measured and derived between 1-20 Hz. Table 48 shows these correlations for the *a priori* effort categories. In general, there are a greater number of statistical trends and significant correlations when the ultra-low frequency components of the motion data are excluded, as compared to the values presented in Table 43. The High Effort activities are negatively correlated with X-linear acceleration, roll acceleration, and roll rate. The Medium Effort behaviors are negatively correlated with the rotational rates in all axes of measurement and the rate vector sum, while the Low Effort activities are positively correlated with the same motion variables.

Table 49 shows the correlations between the *post hoc* activity indexes and the motion variables in the 1-20 Hz frequency range. Rest activities are positively correlated with roll, yaw, and the vector sums of the rotational accelerations and; while the correlations with the acceleration values are lower than when the full frequency range of data is used, the correlations with the rates are greater. The Social/Oral activities are negatively correlated with the same motion factors, although these relationships are not statistically significant or only reach the trend level. Again, the activity/rate correlations are higher than the activity/acceleration coefficients. Motor activities

Table 48

Simple Correlations between Percent High, Medium, and Low Effort Activities and Ride Motion Variables (1-20 Hz)

	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 Vector Sum	.02	-.10	.10
Roll (X) Acceleration	(-.17)	-.09	.19*
Pitch (Y) Acceleration	-.03	-.07	.07
Yaw (Z) Acceleration	-.08	-.13	(.17)
Rotational Acceleration Vector Sum	(-.14)	-.13	.20*
Roll (X) Rate	-.22*	-.19*	.26**
Pitch (Y) Rate	.01	-.21*	(.14)
Yaw (Z) Rate	-.01	-.27**	.19*
Rotational Rate Vector Sum	-.12	-.30**	.27**

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

Table 49

Simple Correlations between Percent Rest, Social/Oral, and Motor Activities and Ride Motion Variables (1-20 Hz)

	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 Vector Sum	.02	-.04	.05
Roll (X) Acceleration	.22*	(-.17)	.03
Pitch (Y) Acceleration	.09	.04	(-.14)
Yaw (Z) Acceleration	.19*	-.13	.11
Rotational Acceleration Vector Sum	.24*	-.12	-.03
Roll (X) Rate	.27*	(-.15)	-.19*
Pitch (Y) Rate	.11	-.06	-.22*
Yaw (Z) Rate	.23*	(-.14)	-.08
Rotational Rate Vector Sum	.28**	(-.18)	-.24*

( ): p<.10   *: p<.05   **: p<.01   n = 77 are also negatively correlated with roll and pitch rates and the rate vector sum. The positive correlation between Motor activities and ISO-weighted Z-linear acceleration is largely attributable to the correlation between Handcrafts/Games and this motion variable (Table 46).

Linear equations were also developed to predict the relative frequencies of activities, using the a priori effort and post hoc physical action indexes and the trip, non-motion, and motion variables in the range of 1-20 Hz recorded in this study. These equations, which represent the best fit of the physical variables to the activities using multiple regression techniques, are shown in Table 50.

In general, it may be seen that the multiple regression coefficients, proportions of variance accounted for the physical variables (R^2), and levels of significance of these equations are higher than those for the equations in Table 45, which were developed using the complete frequency range of the motion variables from .1-20 Hz. The present set of equations generally incorporate fewer variables to predict an equal or greater proportion of the activity variance than in Table 45. In many cases, rotational rates or their vector sums are better predictors of activity levels than rotational accelerations.

Table 50

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

ACTIVITY INDEX (A)	ACTIVITY MODEL	F (d.f.)	MULTIPLE R	R^2	LEVEL SIGNIFICANCE
Low Effort	$\%A=1.04\omega_{XYZ}-.59N+1971.43a_{XISO}-6.61(V)+3.69(T)+78.62$ $(\sigma)=(.56)\ (.42)(1387.26)\ (4.10)\ (2.96)$	3.05 (5,71)	.42	.18	$p<.05$
Medium Effort	$\%A=1.09\omega_{XYZ}+.55N+5.28(V)-25.00$ $(\sigma)=(.39)\ (.30)(2.93)$	5.52 (3,73)	.43	.18	$p<.01$
High Effort	$\%A=-1.03\omega_{X}+1.42ET-568.55a_{X}-.10(VO)-2.18(T)-46.70$ $(\sigma)=(.65)\ (1.25)\ (788.66)\ (.08)\ (2.67)$	1.83 (5,71)	.34	.11	NS
Rest	$\%A=1.14\omega_{X}+1.67\omega_{Z}-5.44(V)+24.99$ $(\sigma)=(.60)\ (1.08)\ (3.28)$	3.55 (3,69)	.37	.13	$p<.05$
Social/Oral	$\%A=.50N+.40I-.79\omega_{XYZ}+9.64(V)-25.40$ $(\sigma)=(.37)(.22)(.48)\ (3.61)$	4.33 (4,71)	.44	.20	$p<.01$
Motor	$\%A=.50\omega_{XYZ}-.20I-.17N-2.21(T)+.11(SP)+15.02$	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 Vector Sum

Use of the restricted frequency range of motion variables from 1-20 Hz did not significantly improve the predictability of the High Effort activities, although the multiple regression coefficient did increase from .29 (Table 45) to .34. Levels of Low Effort activity could be predicted to a significant degree using five variables: the rotational rate vector sum, noise, ISO-weighted X-linear acceleration, vehicle type, and time of day. The relative frequency of Medium Effort activity could be predicted using only three variables: the rotational rate vector sum, noise, and vehicle type. This equation used fewer variables to account for a slightly higher proportion of the variance in Medium Effort activity at a higher level of statistical significance, than the corresponding equation based on the full frequency range of the motion variables in Table 45.

The linear models for the <u>post hoc</u> activity indexes derived using the motion variables in the 1-20 Hz range are greatly similar to those in Table 45, except that fewer variables are necessary in each equation to explain a comparable proportion of the activity variance. The level of Rest activities can be predicted using only three variables: roll rate, yaw rate, and vehicle type. Twenty percent of the variance in Social/Oral activities can be explained by the levels of noise, illumination, the rotational rate vector sum, and vehicle type. Motor activities can be predicted using the values of the rotational rate vector sum, light, noise, time of day, and speed. The linear combinations of variables in these equations can explain up to 20% of the variance in the relative frequencies of these activities.

4.3 Discussion

The results of the correlational study of the effects of physical ride quality variables on passenger activity indicate that:

1) Passenger activity levels are significantly affected by the rotational motions of the Amtrak train ride in the 1-20 Hz frequency range. Low Effort, Rest activities increase in relative frequency as these motions become more severe, while Medium Effort, Social/Oral, and Motor behaviors decrease in observed frequency with higher levels of motion.

2) Linear vibration does not influence the levels of passenger activities in any reliable and consistent way.

3) Noise on the train is primarily the result of the level of passenger conversation (as discussed in Section 4.3.2.2). The measured levels of noise increase as the levels of Social/Oral and Medium Effort behaviors increase and Rest behaviors decrease in relative frequency.

4) Certain trip and situational variables, especially vehicle type and time of day, significantly affect the observed levels of passenger activities.

5) When combined into linear equations through the use of multiple regression techniques, the ride quality and trip variables recorded in this study predict approximately 20% of the variance in passenger activity levels.

These results and others regarding the stability of the activity frequencies over time, the use of rotational rates vs. accelerations as predictors of activity levels, the comfort of the Amtrak ride as assessed by previously developed objective and empirical standards, and the role of individual differences and attention in determining activity levels, are discussed in the following sections of this report.

4.3.1 Passenger Activities Observed on Amtrak Trains

The relative frequency distribution of activities observed in this December, 1977 study is very similar to the distributions of activities observed in November and December, 1976 and July, 1977. The earlier observational efforts included passengers from trains on a number of different routes in the Northeast Corridor and eastern region of Amtrak service, thus supporting the validity of choosing the passenger sample from only two trains on the same route for the purposes of this study.

Table 51 shows the over-all relative frequencies for the activities observed in all three phases of this study, based on the behaviors of a total of 6989 Amtrak passengers. Reading and Viewing were consistently the most popular individual activities, and Handcrafts/Games the least popular (excluding Smoking, which was usually performed in conjunction with other activities). Sleeping and Talking/Listening occurred with intermediate frequency, while Doing Nothing, Eating, Drinking, Writing and Other activities were observed with relatively low frequencies. This distribution of activity is stable over time (one year) and trip route within the Northeast Corridor and eastern region, and does not vary to any marked extent with changes in seasons, weather conditions, or other long-range variables.

4.3.2 The Comfort of the Train Ride

The level of passenger comfort provided by the Amtrak train environment may be assessed using comfort guidelines and indexes for ride motion, noise, temperature and humidity, and ambient illumination developed in previous studies. In the following section of this report, the environmental variables measured in this study are compared with a number of different comfort and task performance guidelines, in order to determine the range and mean levels of ride quality experienced by passengers on these trips.

Table 51

Combined Relative Frequency of Passengers Engaged in Activities on Northeast Corridor Amtrak Trains (Nov.-Dec., 1976; July, 1977; and Dec., 1978 Studies)

Activity	Percent Observed
Doing Nothing	4.5
Sleeping	16.8
Smoking	.9
Viewing	23.4
Talking-Listening	13.0
Handcrafts/Games	1.8
Eating	3.5
Drinking	4.2
Reading	23.9
Writing	3.4
Other	4.6
	100.0

4.3.2.1 Ride Motion Environment

The most widely established guideline for assessing the comfort of ride motion is the International Organization for Standardization's (1974) Document 2631 ("Guide for the Evaluation of Human Exposure to Whole-Body Vibration"). A complete description of the guideline and the Reduced Comfort Boundary, which is most often used to assess ride motion, is available in Section 1.1.3 of this report.

One method of assessing compliance with the ISO Reduced Comfort Boundary is known as the weighting method. This technique involves the application of a frequency weighting network to the measured linear vibrations, such that the motion amplitudes in the 20 one-third octave bands between 1 and 80 Hz are differentially weighted, depending upon the sensitivity of the human body to mechanical vibration in each frequency range. The weighted amplitudes are then summed to give the ISO-weighted linear accelerations in the various axes of vibration. These weighted values may be compared to the Reduced Comfort limits in the most sensitive frequency range in each axis. These limits are shown in Table 52.

Table 53 indicates the level of compliance of the data collected in the 77 test segments made in December, 1977 on the Northeast Corridor, using the ISO-weighted linear vibrations in the X-, Y-, and Z-motion axes. It may be seen that the X-

Table 52

ISO Reduced Comfort Boundary Limits for
Most Sensitive Frequencies in Vertical
and Transverse Motion Axes

Daily Exposure Time (hr)	Vertical (Z) Axis 4-8 Hz Limit (rms g)	Transverse (X&Y) Axes 1-2 Hz Limit (rms g)
16	.005	.005
8	.010	.007
4	.017	.011
2.5	.023	.016
1	.037	.027

Table 53

Cumulative Frequency of Measured Ride Segments Complying
with ISO 2631 (1974) Reduced Comfort Limits for
Whole-Body Vibration

Daily Exposure Time Limit (hr)	Cumulative % Segments (X-Axis)	Cumulative % Segments (Y-Axis)	Cumulative % Segments (Z-Axis)
16.0	97.4	1.3	0
8.0	100.0	14.3	76.6
4.0		67.5	100.0
2.5		94.8	
1.0		100.0	

vibrations in the vast majority of test segments complied with the 16 hr ISO limit, indicating that the ride motions in this axis were quite acceptable in terms of ride comfort. Similarly, the vertical vibrations in over 75% of the test segments would be acceptable for an 8 hr exposure, and all vertical motions would be acceptable for at least a 4 hr exposure time, as determined by the Z-axis Reduced Comfort Boundary. The lateral, Y-axis motions were the most severe. Only 67.5% of those measured would be acceptable for a daily exposure time of 4 hr, while almost 95% would be acceptable for a daily 2.5 hr trip.

A second means of assessing the acceptability of the linear vibrations involves the weighted vector sum of the ISO-weighted vibrations:[5]

$$\sqrt{(1.4a_x)^2 + (1.4a_y)^2 + a_z^2} \qquad (8)$$

This sum weights the transverse (X-and Y-axis) vibrations more heavily than the vertical accelerations, since the human body is more sensitive mechanically to motions in these axes. It has been proposed (Griffin, 1977) that the value of this sum be

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[5]This method is currently under consideration by the ISO Technical Committee 108 on Mechanical Vibration and Shock, Subcommittee 4 on Human Exposure to Mechanical Vibration and Shock, for possible inclusion in an upcoming revision of the ISO 2631 document.

compared with the vertical (Z-axis) ISO Reduced Comfort Boundary to assess the acceptability of linear vibration. Table 54 indicates the level of compliance of this statistic for the ride segments measured in this study with the Z-axis Reduced Comfort limits for various daily exposure times. It may be seen that approximately 70% of the test segments complied with the 4 hr Reduced Comfort Boundary, while over 95% complied with the 2.5 hr limit.

Because the ISO Reduced Comfort limits are based on the assumption of a daily dose or exposure to a vibration environment for a certain period of time, it is difficult to make any conclusions about the acceptability of the Amtrak ride to Northeast Corridor passengers, many of whom do not make daily trips between points on the Boston-Washington, DC route. However, judging from the compliance of the data with the ISO Reduced Comfort Boundary in the most severe axis of vibration (i.e., lateral, Y-axis motion) and the comparison of the vector sums of the ISO-weighted linear amplitudes with the vertical limits for Reduced Comfort, it appears that approximately 95% of the time, the Amtrak ride is suitable for daily 2.5 hr trips. This estimate is made solely on the basis of the linear motions, and might be even greater for trips which occurred on a less frequent basis.

Table 54

Cumulative Frequency of Weighted Vector Sums of ISO-Weighted Linear Vibrations Complying with ISO 2631 (1974) Reduced Comfort Limit for Vertical (Z-Axis) Vibration

Daily Exposure Time Limit (hr)	Cumulative % Segments Complying with Z-Axis Limit
8.0	3.9
4.0	70.1
2.5	96.1
1.0	100.0

In the present study, it was found that the rotational motions affected levels of activity to a greater extent than the linear vibrations. This result supports the findings of a study by Pepler, et al. (1978), in which subjective passenger comfort was found to depend largely upon roll rate rather than the linear vibrations in Amtrak trains. Pepler, et al. used multiple regression techniques to develop a linear comfort equation for these trains, based upon the responses made by their subjects on a seven-point comfort scale and the correlated levels of motion and other environmental variables. This model predicts the subjective comfort response of passengers, given the measured levels of noise and roll rate, according to the following equation:

$$\begin{array}{llll} C = .73 & + .1\ (N-60) & + .96\omega_R & \\ (\sigma) = (.96) & (.01) & (.21) & \end{array} \qquad (9)$$

where C = mean comfort rating, N = noise (dB.A), ω_R = roll rate (°/sec) and σ = the standard error of the coefficient.

This equation was applied to the data for the 77 ride segments collected in December in the present study. The resulting comfort statistics (mean, mean ± one standard deviation, minimum and maximum values) are plotted in Figure 34 against the Pepler, et al. comfort/satisfaction ("willingness to ride again") curve, derived in earlier studies of STOL (Short

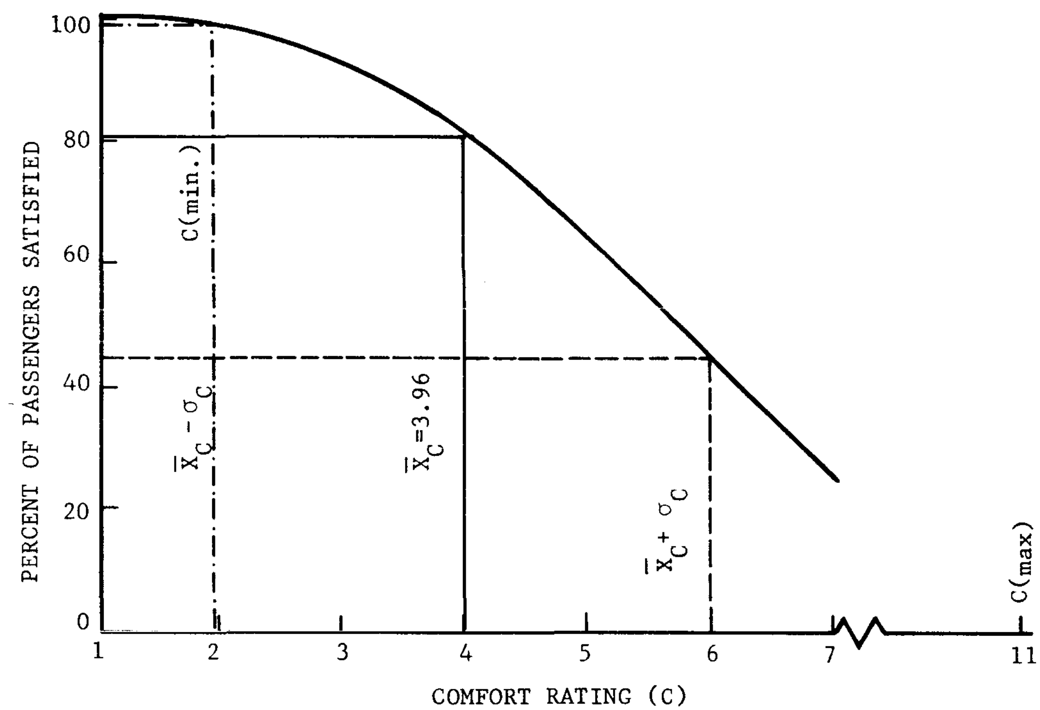

Figure 34. Calculated Comfort Ratings For December, 1977 Test Segments Using Comfort Equation For Trains (Pepler, et al., 1978)

Take-Off and Landing) aircraft passengers. It may be seen that the mean predicted comfort rating for the data collected in the present study was almost exactly at the neutral point of the comfort scale (4), where approximately 80% of the passengers would be expected to be satisfied. The minimum comfort rating computed for any segment coincides with the comfort value of 2, just one standard deviation below the mean and predicting almost 100% group satisfaction with the ride. However, the maximum comfort value of 11.4 is off the comfort scale, along with the comfort values calculated from five other test segments. In all, 72.7% of the ride segments measured in this study would be judged in the comfortable range, and 27.3% in the uncomfortable (C greater than 4) range, using the comfort statistics calculated with the Pepler, et al. equation.

The ride comfort of various levels of roll accelerations may also be assessed against the Discomfort Curves developed by Leatherwood, et al. (1978), using the discomfort responses of subjects on the Passenger Ride Quality Apparatus (PRQA) simulator at the NASA/Langley Research Center. Leatherwood, et al. used various psychophysical techniques, including the method of constant stimuli and magnitude estimation, to develop a family of equal discomfort curves known as DISCs for various frequencies of vertical, lateral, and roll vibration. These curves are subjective multiples of a baseline discomfort curve (DISC=1) which "corresponds to the threshold of discomfort ... [The] DISC=2 curve provides twice the discomfort of the DISC=1 curve;

the DISC=4 curve corresponds to twice the discomfort of the DISC=2 curve and four times that of the DISC=1 curve" (Leatherwood, et al., 1978, pp. 6-7) and so on.

Figure 35 shows a comparison of the roll accelerations recorded in this study with the Discomfort Curves for roll generated by Leatherwood, et al. (1978). For the purposes of comparison, the roll amplitudes in the present study have been broken down into one-third octave band frequency components. Comparison of the roll accelerations measured in this study with the DISC curves suggests that they were somewhat uncomfortable. The roll acceleration levels for an average ride segment fall between the DISC=1 and DISC=2 curves, indicating levels of motion one to two times that of the discomfort threshold. Roll accelerations from the ride segment in which the maximum rms g value of roll was recorded ranged between DISC=2 and DISC=6.

The relative severity of the roll motions compared to the linear Y- and Z-vibrations is even more apparent when the latter values are plotted against the DISC curves for linear accelerations (Figures 36 and 37). In both cases, the mean motion levels are well below the discomfort threshold curve, and even the maximum Y- and Z-vibrations measured for any segment do not reach the level of DISC=1. Thus, comparison of the measured data with the Leatherwood, et al. DISC curves reveals that while the linear motions are generally quite comfortable, the rotational

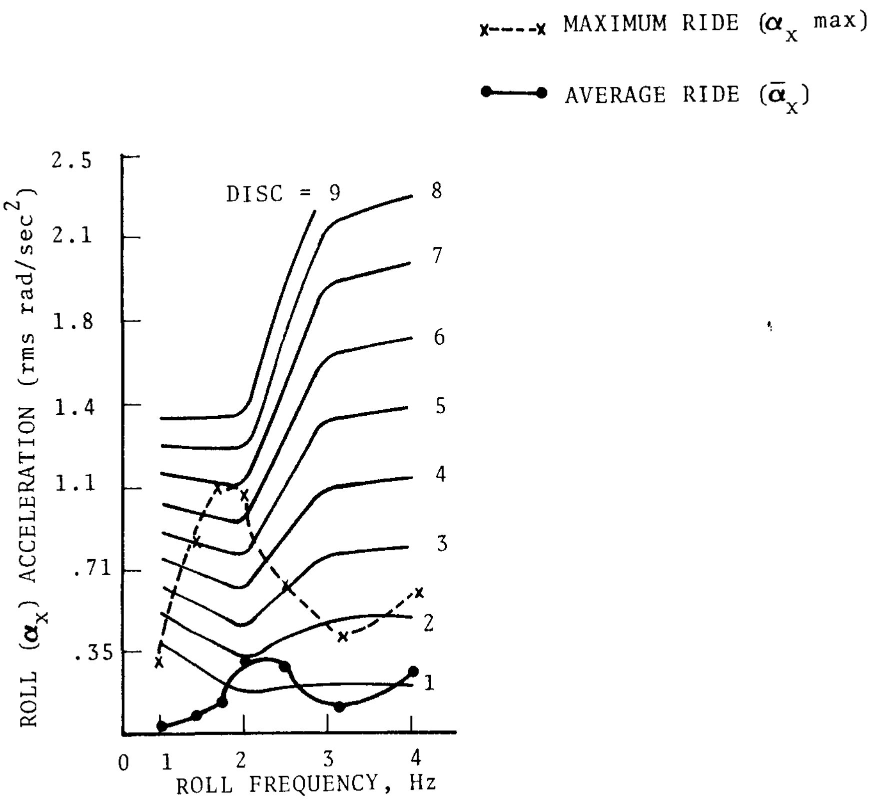

Figure 35. Comparison Of Roll Accelerations Measured On Amtrak Trains (December, 1977) With Discomfort Curves For Roll Vibration (Leatherwood, et al., 1978)

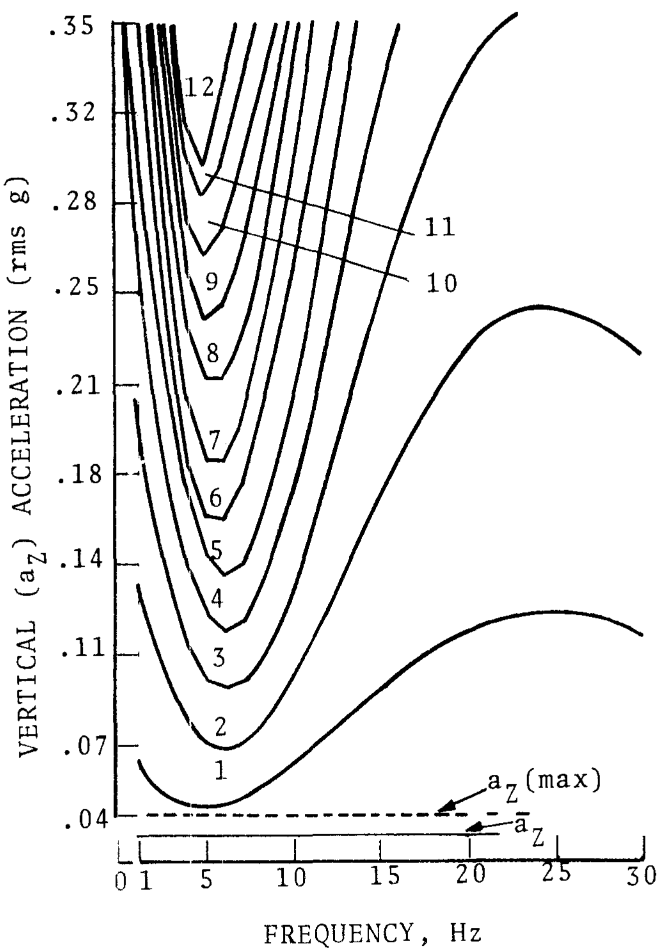

Figure 36. Comparison of Vertical Accelerations Measured On Amtrak Trains (December, 1977) With Discomfort Curves For Vertical Vibration (Leatherwood, et al., 1978)

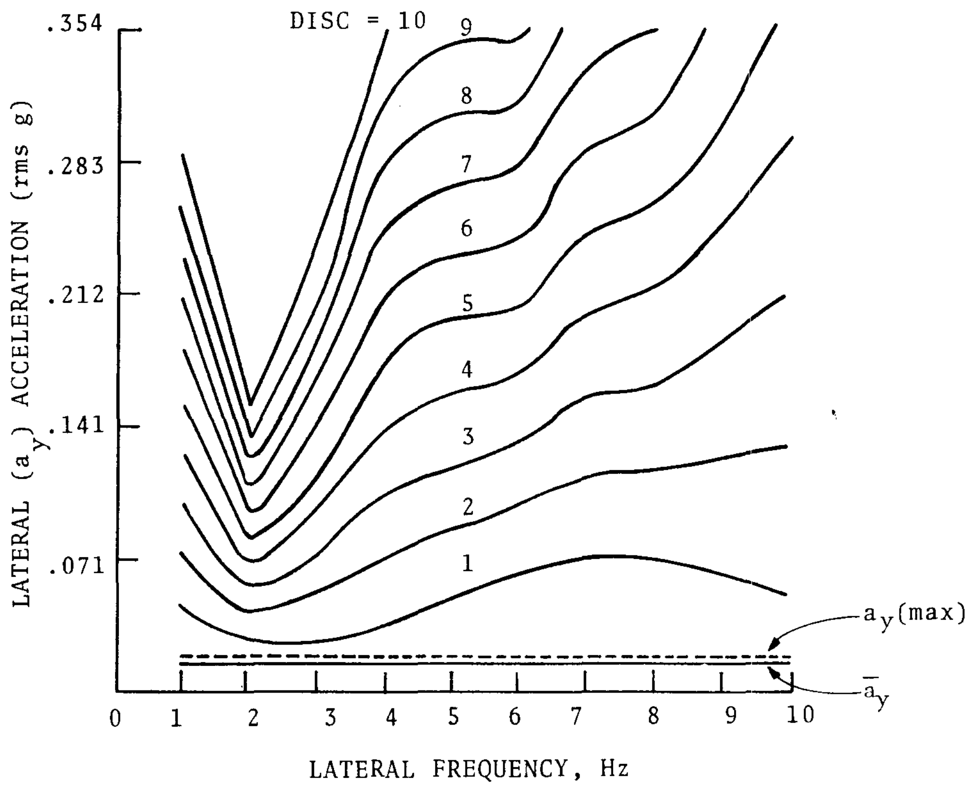

Figure 37. Comparison Of Lateral Accelerations Measured On Amtrak Trains (December, 1977) With Discomfort Curves For Lateral Vibration (Leatherwood, et al., 1978)

motions (in this case, roll) are much more severe and probably make a significant contribution to passenger discomfort.

4.3.2.2 Noise Environment

In addition to its role as a factor in the Pepler, et al. (1978) comfort equation for trains, noise may be assessed objectively for its influence on Talking-Listening by means of the Speech Interference Level (SIL) Curves (General Radio, 1972). The noise levels measured on the trains are plotted against these curves in Figure 38. The mean noise level of 68 dB(A) is sufficiently low to allow communication between speakers separated 2 to 4 ft using very loud speech. 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 on the trains. The maximum noise level of 80 dB(A) precludes speech communication at any distance except by shouting.

Since noise was generally uncorrelated with the dominant vehicle motions, and since both noise and vehicle type were highly correlated with Talking-Listening, it was hypothesized that the conversational activity of the passengers might account for a significant proportion of the variance in the noise on these trains. If this were true, then noise levels in the Amcoach cars should be lower than those in the Amcafe snackbars, since more Talking-Listening took place in the latter type of

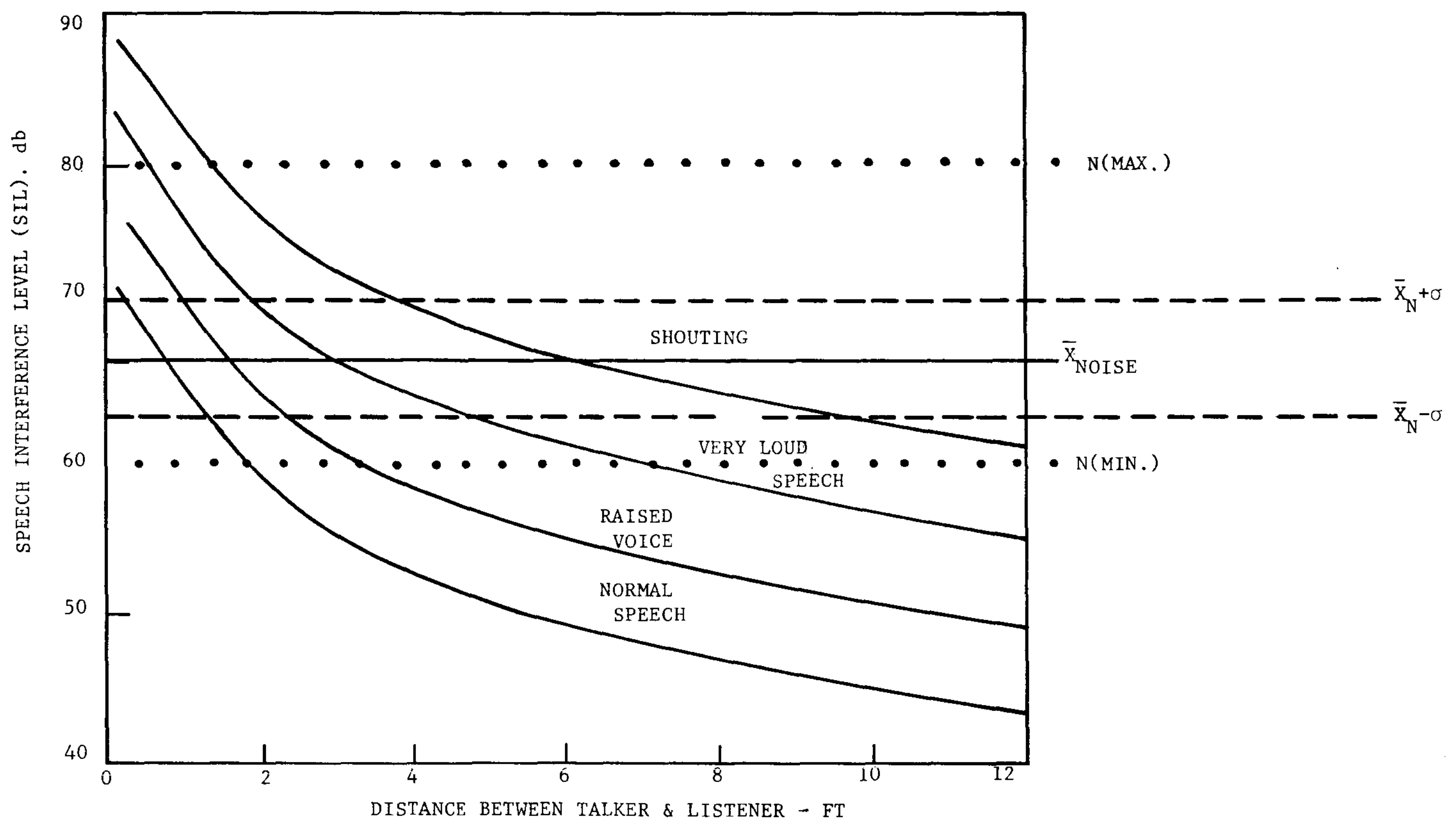

Figure 38. Comparison Of Noise Levels Measured On Amtrak Trains (December, 1977) With Speech Interference Levels (General Radio, 1972)

vehicle. This was in fact the case when the mean noise levels were compared between the two vehicle types (one-tailed $t = 1.89$, d.f. = 79, $p<.05$). Thus, in this case, an aspect of the ride environment which was the result of a certain level of passenger activity acted as factor which made the same activity more difficult to perform.

The subjective comfort of the noise environment is difficult to define, since the annoyance and distraction qualities of noise, especially speech, are highly dependent upon individual differences in the form of subjective expectations, attitudes and motivation, and even personality differences (Miller, 1947; Kryter, 1970). However, it should be noted that the levels of noise measured in the Amtrak trains in this study are comparable to or lower than those measured in previous studies of intercity train environments (Pepler, et al., 1978; U.S. Environmental Protection Agency, 1975). Certainly, the levels are well below the maximum of 76 dB(A) recommended by the U.S. Environmental Protection Agency (1975) for a 2 hr daily exposure on this type of conveyance.

The expected effects of noise on performance of non-auditory activities are also difficult to assess on the basis of past literature describing the effects of noise on performance. In general, it has been difficult to show the detrimental effects of noise on human performance, except at the very highest stress levels. While some experts in this field, particularly Broadbent

(1957), contend that reliable performance deficits appear at noise levels of 90 dB, others, in particular Kryter, (1970, p. 546) feel that the experimental data show "no adverse effects [of] regular, expected noise ... on nonauditory mental or motor work performance or output." In some studies, relatively low levels of noise have even been shown to have a positive effect on task performance, depending upon the motivational or arousal state of the subject (Kahneman, 1973).

It is unlikely that the low noise levels measured on the Amtrak trains in the present study would result in serious discomfort or interference with the performance of simple tasks such as reading and writing. First, most laboratory studies of environmental stress do not even incorporate noise levels in the 60-80 dB(A) range in their designs, except as controls (e.g., Grether, et al., 1971, 1972; Sommer and Harris, 1972; Harris and Sommer, 1973). Thus, it may be assumed that at least in laboratory experiments, the effects of noise do not show up in this loudness range. Second, in situations of multiple environmental stresses, vibration alone has been shown to have equal or worse effects on the performance of cognitive and psychomotor tasks than combinations of vibration, noise, and other variables (Grether, et al., 1971, 1972). It is doubtful that the low levels of noise on the Amtrak trains would cause a significant additional decrement in activity performance compared to that caused by the relatively high amplitude rotational motions. Finally, noise was not significantly correlated with the observed levels of any activity except Talking-Listening, to which it was positively related. Thus, the emperical evidence supports the conclusion that the levels of interior noise, the content of which was largely conversation, did not affect passengers' abilities to read or write.

4.3.2.3 Thermal Environment

The temperatures and relative humidities measured on the Amtrak trains varied only slightly from one vehicle to the next, being largely dependent upon the day-to-day ambient weather conditions. The effective temperature index used in this study was a means of consolidating the temperature and humidity data into a single value which facilitated the data reduction and correlational analysis considerably. Effective temperature as a variable may also be more closely tied to human comfort than either Fahrenheit temperature or relative humidity individually, since the body generally responds to the interaction between these variables, rather than to the independent effects of temperature or humidity stimuli.

Effective temperature is an empirically determined sensory index, from which equal comfort curves have been experimentally developed to assess the relative thermal acceptability of various combinations of temperature and relative humidity. These curves are shown in Figure 39, along with the distribution statistics for effective temperature derived from the environmental

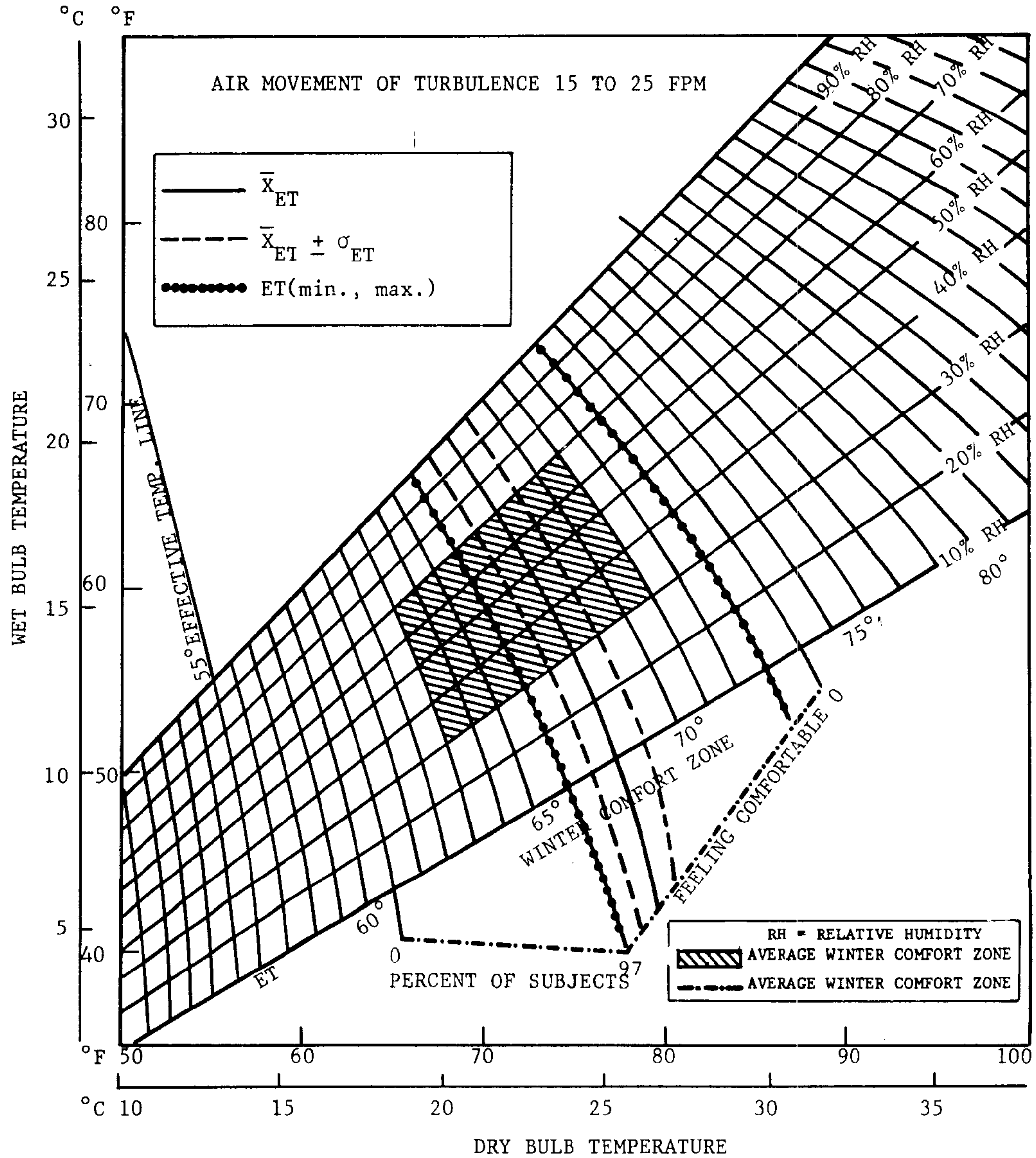

Figure 39. Comparison Of Effective Temperature Levels Measured On Amtrak Trains (December, 1977) With Effective Temperature Comfort Curves (ASHRAE, 1967)

measurements made in this study. In general, the effective temperatures were on the high side for winter comfort; yet the mean temperature would be considered comfortable by approximately 80% of population, judging from the acceptable comfort range shown in Figure 39.

Since this study was conducted during the winter, it would be predicted that the higher effective temperatures would be more comfortable for the passengers and would thus create a more optimal environment for the performance of more effortful behaviors. Unfortunately, the positive correlations between temperature and the higher effort activities which would have been expected were too small to provide any reliable support for this hypothesis. The negative correlations between effective temperature and Viewing and Smoking, however, do show that some Low Effort behaviors decrease in frequency as temperature increases.

4.3.2.4 Illumination Environment

There are three main sources of illumination on the Amtrak trains: 1) the ceiling lights in the center of the vehicle along the length of the aisle; 2) the reading lights above the seats; and 3) the natural light coming in through the windows. Light measurements taken in this study were made in the center aisle of each vehicle, and primarily reflect the over-all level of illumination coming from the first and third sources.

Table 55 shows the levels of illumination recommended for various tasks by the Illuminating Engineering Society (Kaufman, 1972). Most of these values are recommended for performance of activities in residential environments. The corresponding passenger activities which would require similar levels of illumination are also shown in Table 55. In general, the ambient illumination levels measured on these trains were rather low (mean =6, minimum =1, maximum =32) compared to the recommended levels. However, light levels 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.

Illumination levels were found to be negatively correlated with Doing Nothing and positively correlated with Talking-Listening. These correlations are in the expected directions and are meaningful from the standpoint of the effects of overall ambient illumination (rather than focussed reading light) on general levels of activity. The correlations between light as measured in this study and the higher effort activities cannot really be evaluated since most passengers used the reading lights while performing these behaviors.

Table 55

Minimum Recommended Levels of Illumination for Performance of Various Tasks (Kaufman, 1972)

Task	Corresponding Passenger Activity	Illumination Level (fc)
Conversation, Relaxation, Entertainment	Talking-Listening Doing Nothing Sleeping Smoking	10
Dining	Eating Drinking	15
Table Games	Games	30
Handcrafts	Handcrafts	70
Reading and Writing	Reading Writing	30 - 70*
[Using] Corridors	Walking in Aisles (Other)	20

* Varies depending upon content of written material, contrast level of printed matter, etc.

4.3.3 Selection of Variables to Predict Passenger Activity Levels

Selection of the variables included in the linear models was based upon several factors. The main criteria for selection were: a) low redundancy in terms of the aspects of the environment which were being described by the variables; 2) the feasibility of the correlations between the dependent and predictor variables, based on present knowledge of human response to the various environmental conditions; and 3) in terms of the activity variables, the functional relatedness of component activities into coherent categories, or indexes, and the size and nature of the correlations between these categories and the predictor variables.

First, many of the motion variables were redundant in the sense that they were basically different computational versions of the same factor. With regard to the use of the rotational acceleration values vs. those of the rotational rates, it was found that the acceleration values were more highly predictive of activity levels when the full frequency range of motions from .1-20 Hz was used as the basis for the correlational analysis, while the rates were more highly correlated with the activities when the motion data was restricted to the 1-20 Hz range. This difference is considered to be an artifact of the data reduction procedures for deriving the rates from the accelerations as described in Section 4.1.4.

A second consideration in the selection of predictor variables to be included in the linear models was the feasibility of the relationships between such factors and the activities, based upon present knowledge of human response to these environmental conditions. Factors recorded in this study were excluded which had high correlations with activities in the opposite direction of what would be expected, based upon current knowledge of human reaction to vibration. For instance, the positive correlation between Z-ISO linear acceleration and Motor activities (Handcrafts, in this case) is counterintuitive, since it is highly unlikely that increasing the magnitude of vertical vibration would be related to higher levels of a voluntary activity involving precise manual dexterity and hand-eye coordination. Furthermore, the literature contains numerous examples of the detrimental effects of vertical vibration upon task performance involving combined visual and motor skills, such as tracking (e.g., Buckhout, 1964; Collins, 1973; Shoenberger, 1967). Including this factor in a predictive equation for Motor behaviors would result in a model that did not make logical sense.

Finally, because the correlations between the individual activities and the ride quality and trip variables were so low (although consistent in certain directions), it was not possible to generate linear equations for individual activities which would account for a significant proportion of the variance in these behaviors based on the recorded physical and trip variables. Therefore, in addition to the *a priori* activity categories based on effort, the *post hoc* activity indexes were developed in an attempt to generate dependent variables which could be more highly predicted by the trip and environmental variables recorded in this study. These indices were conceived after attempts to generate linear models of the *a priori* High, Medium, and Low Effort activities met with only limited success using the entire frequency range of the motion data from .1-20 Hz (Table 45).

Since there were insufficient data to perform a factor analysis, the activities were simply grouped according to physical ride quality or trip factors with which they had common correlations, and in terms of common physical action components such as manual or oral movements, or no observable movement at all. Although these indices generally overlap with the *a priori* effort categories, it appears that the exclusion of Reading and Viewing, which were largely uncorrelated with any of the ride quality or trip variables, resulted in the slightly higher level of predictability of these *post hoc* activity categories.

4.3.4 Generating Linear Models of Passenger Activity

From the ride quality and trip variables recorded in this study, several were selected which were significantly correlated with the activities but which were not very highly correlated with each other, as described in Section 4.3.3. Using the SPSS multiple regression subprogram, the order of variables was generally specified such that the measured ride quality variables would be entered into the multiple regression equations first, followed by the categorical trip variables. The rationale for this order is as follows.

The ride quality variables were of primary interest in this study. These variables could be (at least theoretically) controlled in the design of future transportation systems, and it would be of the greatest potential use to designers of these systems to have equations which would account for the greatest proportion of the activity variance using such factors as vibration, noise, effective temperature, and light. The trip variables, such as time of day and vehicle type, are generally not under the design engineer's control or are specific to the Amtrak system which served as the object of this study. These variables were of lesser interest in terms of the design of new systems, but they were included in a secondary capacity since they were sometimes highly correlated with the activity levels and could also account for some proportion of the activity variance.

Within each of these general variable categories, stepwise multiple regression procedures were used to generate the linear models of activity. Using this method, a variable is entered into the linear equation only if it makes a significant contribution to the prediction of the dependent variable when considered in conjunction with the variables already in the equation. The first variable entered into the equation is that which is most highly correlated with the dependent variable. The second variable entered is that which provides the best prediction in conjunction with the first variable. This is important when the predictor variables themselves are highly intercorrelated, since the second and all following factors are entered into the equation not simply on the basis of how well they independently predict the level of the dependent variable, but on the basis of the additional, non-overlapping variance they can account for relative to variables previously entered into the equation. Thus, the stepwise mode of multiple regression provides the best means of predicting the dependent variable using the fewest possible predictor variables.

The linear equations represented in Tables 45 and 50, which represent the best fitting equations after several iterations of the stepwise regression process, consist of only three to six factors and can be applied using simple computational methods. The number of factors was in some cases reduced even further by using the motion vector sum statistics, which represent in terms of a single index the vibrations measured in three axes on the trains. For instance, the equation shown in Table 50 for Medium Effort activities is:

$$\%A = -1.09\,\omega_{xyz} + .55N + 5.28(V) - 25.00 \qquad (10)$$

$$(R = .43,\ p<.01)$$

An alternate version of this linear model which was also developed using the same data is:

$$\%A = -1.65\omega_z + .54N - .64\omega_x - .29\omega_y + 5.73(V) - 24.25$$

$$(R = .43,\ p<.01) \qquad (11)$$

The latter equation accounts for exactly the same proportion of activity variance, but requires the use of the three separate rotational rates rather than the single rate vector sum.

4.3.5 The Application and Usefulness of the Linear Models of Activity for Future Passenger Train Design

In Section 4.3.2, the comfort of the Amtrak ride was assessed using a number of individual criteria for acceptable levels of vibration, noise, temperature, and light in a passenger environment. Application of such criteria is standard operating procedure for the evaluation of ride quality on existing systems as well as for the specification of design variables in future systems. The use of individual criteria, however, implies a certain absolute threshold level of comfort in each of these dimensions; i.e., each variable must attain a certain minimum value in order for the passenger environment to be acceptable.

While this principle may in fact be true for systems factors which impinge upon passenger safety, security, or other aspects of systems acceptability, and should in these cases be applied as the most conservative method of design, it may be possible to be more flexible in the specification of comfort factors.

In order to design advanced transportation systems which are cost-effective, it is often necessary to trade off some design features for others, depending upon relative expense, availability of technology, and the state-of-the-art in general. Thus, a method for specifying allowable trade-offs which will still result in an acceptable level of ride quality would be an extremely useful tool for designers and evaluators of transportation systems. The comfort models developed by Pepler, et al. (1978) provide just such a tool for the design of systems to meet any given level of passenger satisfaction, as specified by the subjective comfort ratings of their passenger samples. The usefulness and application of these models was discussed previously in Section 1.0. In a similar way, the linear activity models developed in the present study could theoretically be used, in conjunction with information about passenger preferences for different activities (as reported for example, in the survey results of Section 3.2), to design passenger environments in future intercity train systems which would be conducive to the types of activities which play an important role in passenger satisfaction.

To illustrate this concept of application of the linear activity models, let us assume that the design engineer wishes to provide a passenger environment which will be satisfactory for the performance of Motor activities (i.e., Writing and Handcrafts/Games). The results of the survey on passenger activities (Appendix C) indicate that 50.7% of the passengers polled considered Writing to be important to their satisfaction on the trains, and 24.4% wished to spend more time writing on future train trips. Handcrafts and Games were relatively unpopular activities; about 17% of the respondents considered these activities to be important, and only about 10% wished to spend more time doing these activities on future trips.

Thus, the highest proportion of passengers the design engineer might feasibly wish to satisfy with an environment conducive to performance of Motor activities would be approximately 50%. If 50% of the passengers on the trains were engaged in Motor activities, this would be an approximate ten-fold increase over the average level of this type of activity observed in the course of this study; thus, this would be a very idealistic goal on the part of the design engineer. Suppose the designer chooses a level of 10% as a more realistic goal. This would constitute a two-fold increase in the observed relative frequency of Motor activities, and is conservative in the sense that it is comparable to the percent of passengers participating in the survey who wished to spend more time on the less popular of these behaviors.

This 10% value may now be entered in the Motor activity equation (Table 50) as follows:

$$10\%A = -.50\omega_{xyz} -.20I -.17N -2.21(T) +.11(SP) +15.02 \tag{12}$$

Now the designer has a choice of several variables which might be manipulated in solving the equation. These include the rotational rates vector sum, light, noise, speed, and time of day. Let us assume that the system being designed is planned to run at an average cruising speed of 120 mph (SP=120), and that the designer is most interested in predicting morning levels of activity (T=1), since this is when more Motor behavior takes place. Inserting these values into the equation and performing the necessary computations, the equation may be rewritten as:

$$10\%A = -.50\omega_{xyz} -.20I -.17N -2.21 + 13.2 + 15.02 \tag{13}$$

or

$$10\% = -.50\omega_{xyz} -.20I -.17N + 26.01 \tag{14}$$

Now, the values of the remaining factors in the equation may vary, depending upon the practical constraints imposed upon the design of the system by available technology and limitations in resources. In other words, the levels of light, noise, and rotational vibration may be traded off in the design of an acceptable passenger environment; what is acceptable for any particular variable depends upon the levels of the other variables in the equation.

Of the three variables whose levels must still be specified in this equation, illumination probably poses the least difficulty for the design engineer. Since high levels of illumination were primarily positively correlated with Social/Oral activities (and thus negatively correlated with Motor behaviors), ambient light levels for corridors may be held to a minimum of 20 fc (I=20 in the equation), as recommended by the Illuminating Engineering Society (Kaufman, 1972). Noise levels are probably the second easiest factor to control in terms of the available technology, although noise may be more expensive to manipulate than illumination. Probably the most expensive factor to control is rotational vibration, since this involves special design of the guideway in addition to the vehicle itself. Also, since there is so little research available on rotational motions which may be practically applied to the design of vehicle/guideway systems, it would be difficult to specify exactly how to build a system to minimize these motions even if financial resources were unlimited (although Ravera and Anderes (1975) and Wormley, et al. (1977) have recently made significant progress in this area). Thus, the rotational vibrations would be the most difficult to specify and the most expensive to control.

The Motor activity equation may now be rewritten, plugging in all values except for noise and the rotational rate vector sum:

$$10\%A = -.50\omega_{xyz} - 4 - .17N + 26.01 \quad (15)$$

or

$$10\%A = -.50\omega_{xyz} - .17N + 22.01. \quad (16)$$

Now, depending upon the levels of noise and rotational motion which may feasibly be provided, these two factors may be traded off to yield the same relative frequency of activity. For instance, if noise can be strictly controlled to a level of 55 dB(A), the vector sum of the rotational rates could be allowed to go as high as 5.32 °/sec (with which 87% of the test segments measured in the present study could comply) in order to allow for a 10% Motor activity frequency:

$$10\%A = -.50(5.32) - .17(55) + 22.01. \quad (17)$$

If noise were permitted to attain a mean level of 65 dB(A), the sum of the rotational rates would have to be restricted to a level of 1.92 (with which only 16% of the test segments measured in this study could comply):

$$10\%A = -.50(1.92) - .17(65) + 22.01. \qquad (18)$$

The above example has been provided to illustrate the possible usefulness of the linear activity models to the designer of transportation systems. While similar models have been developed using subjective comfort as the criterion (Pepler, et al. 1978), the equations derived in the present study are unique in that they use an objectively quantifiable dependent variable (i.e., activity) as the basis for specifying design criteria.

It is suggested that the activity models developed in this study be applied with caution in the design of new transportation systems. First, the models have not been validated on an independent sample of Amtrak system users. It was intended in the original research plan to develop preliminary activity models in the July, 1977 phase of this study (in which an attempt was made to record motion variables in addition to performing the survey and observations) and validate these equations using the data collected in December, 1977. However, no provision was made in the July test effort to control the internal homogeneity of the track segments used. The tests were largely made at random, and the distributions of the resulting vibration data were too skewed to be used in subsequent multiple regression analyses.

It should also be noted that only a limited proportion of the variance in activities may be predicted using the ride quality and trip variables recorded in this study. At most, only 20% of the variance in activity may be accounted for using these factors. However, it is believed that this 20% of the variance in activity is 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 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.

Although it was not a major goal of the present study to account for individual differences between passengers, it is undoubtedly these differences which control the largest proportion of the variance in passenger activity. There is significant evidence in the literature that individual differences may be the most important factor in determining human response to whole-body vibration. A number of reviews and several experimental studies have addressed this particular problem as part of the explanation for inconsistency of results between ride quality and vibration research efforts (Allen, 1971; Shoenberger, 1972; Oborne and Humphreys, 1976).

Individual differences in subjects' comfort responses in vibration environments have also been found in a few studies which have included demographic variables such as sex. These studies are discussed in greater detail in Section 3.3.3.2. In the July survey of Amtrak passengers conducted as part of the present study, ride comfort ratings were found to vary depending upon the number of companions a respondent was traveling with, type of occupation, and level of education. In the Pepler, et al. (1978) study, infrequent passengers were more sensitive to roll rate then frequent passengers and the same was found to be true for older (ages 25 and up) vs. younger (ages 10-24) riders and females compared to males. Furthermore, in the present study, there were numerous individual differences in respondents' subjective reactions to questions concerning the importance of various activities and their subjective sensitivities to environmental interferences with activities. Richards, et al., (1978) also found certain individual differences in passengers' reported frequency of performing various activities during flight; e.g., the most frequent activities reported by men were reading and writing, while the most frequent behaviors reported by women were talking and looking out the window.

Thus, it would not be surprising if the actual activities performed by Amtrak passengers in the present study were largely controlled by individual differences between passengers. It would be expected that the personal preferences for various behaviors would differ between passengers of different sexes, ages, occupations, and income levels, traveling different distances, for different purposes, with different numbers of people; these differences were described in Section 3.0.

Unfortunately, there was no way to control for individual differences in the observational design of the present study without incurring extreme inconvenience and expense in terms of time and other resources. Under normal circumstances in an experimental laboratory facility, it is possible to make repeated measures of the same subjects or match subjects on critical characteristics in order to control for inter-subject variability. Also, the experimental situation dictates the specific task which the individual is to perform. In the present type of field study, however, these factors could not be controlled for the following reasons.

First, the present study depended to a certain extent upon the passengers not knowing what the experimenter was doing, so that the study would not disrupt their ongoing activities. Thus, it would have been difficult to make multiple observations of the same person without that person becoming aware of (or asking about) the purposes of observation. Second, even if some means could have been devised to preserve the anonymity of the observer (e.g., a one-way mirror window, video cameras, etc.), the physical layout of the train precluded the use of such static observational techniques. Because the seats had high backs and faced in one direction only, there was no way to observe more than a handful of passengers at one time. Third, the tempo of activities was very slow in general among the train passengers. Passengers could be observed reading and writing for periods of 1-2 hr or more on these trains without a significant change in behavior. Thus, observation of the same passengers over a full trip would have yielded very small amounts of behavioral data on only a few passengers. These few observations would then have to be correlated with massive amounts of vibration data, which is expensive to process.

Also, because actual passengers were used as subjects in this study, there was no way of obtaining actual performance data to assess how well the activities were being performed in the motion environment. Use of the relative frequencies of behavior as dependent variables can only give a rough indication of passengers' difficulties in doing various activities on the trains, since the underlying assumption that people will do what is the easiest for them to do (Richards and Jacobson, 1975) may be confounded by their varying motivations to perform different activities and the resulting level of effort they are willing to expend.

4.3.6 Activities and Comfort

The relationship between activities and subjective comfort may be complex and highly interactive. There is substantial evidence from the results of the survey described in Section 3.0 that at least some activities play an important role in passenger satisfaction with the train ride. The results of the regression analysis of the observed frequencies of activities on the trains indicate that the factors which have been shown to influence subjective comfort in previous studies (e.g., Pepler, et al., 1978) also affect the levels of activities, although to a more limited extent. Further, studies of airline passengers' comfort show that subjective ratings of activity difficulty were significantly correlated with subjective ratings of comfort in flight (Richards, et al., 1978).

Thus, a three-way relationship between activities, comfort, and physical ride quality variables may be established. In terms of the relative strength of these relationships, it appears that subjective ratings of comfort are more strongly correlated than observed levels of activity with the physical parameters of the train ride. However, the question still remains as to whether performance of activities results in a higher or lower level of subjective passenger comfort.

Richards, et al., (1978) hypothesize that "if one is immersed in performing a task, comfort level may be irrelevant or not attended to. A busy individual may not notice whether he is comfortable or not." The authors found that comfort ratings of airline crew members, who were always performing some activity, were generally better than those of passengers and other test subjects. However, the authors conceded that these differences might also be attributable to differences in previous flight experiences resulting in higher adaptation levels for crew members, or to motivational differences between these groups.

An alternative viewpoint might be that performance of activities calls attention to the existing quality of the ride. Thus, a bad ride will seem worse if one tries but is unable to write; on the other hand, good feelings about the ride will be validated and reinforced by the ease of performance experienced in doing a desired activity. This hypothesis is supported to some extent by the results of a study in which passengers were asked to rate automobile ride comfort under conditions of sensory deprivation, extraneous sensory input, and normal sensory input (Stewart, Young, and Healey, 1977). The extraneous sensory input condition was comparable to performance of an auditory (Talking-Listening) or visual (Reading, Writing) type of activity. Subjective ratings of the ride were consistently worse over all types of road surfaces when the extraneous visual task was performed, compared to the control condition. One interpretation of this result is that subjects' difficulty in performing the visual writing task negatively influenced their subjective comfort ratings.

Actually, both viewpoints may be reconciled by postulating an interactive relationship between activities and comfort mediated by attention or effort and depending upon given levels of environmental variables which influence both activity performance and subjective comfort. Under low levels of environmental stimulation which do not significantly interfere with activities or result in subjective discomfort, little attention may be devoted by passengers on existing transportation systems to conscious assessment of comfort or ease of activity performance. The viewpoint of Richards, et al. is probably descriptive of this type of situation.

Under moderate levels of environmental stimulation, the exertion of extra effort to perform activities which are easy to do in other situations may draw attention to sensations associated with subjective comfort which would normally go unnoticed. The study by Stewart, et al. (1977) most closely approximates this situation. Depending upon previous experience, expectations, and other variables, the passenger may then make a conscious, cognitive judgment regarding the comfort and quality of the ride, which may subsequently be used as an input to the more complex decision of whether to use the system again.

Under high levels of environmental stimulation, the sensations associated with comfort may be so strong as to make the role of activities in drawing attention to them unnecessary. In this situation, which might be encountered for short periods of time in transportation vehicles due to poor guideway surfaces, air turbulence, or other conditions, difficulty in performing voluntary activities may serve to confirm or validate subjective judgments of discomfort which have already been made largely on the basis of the physical sensations produced by the ride environment.

Thus, activities may serve not only as a source of passenger satisfaction, but also as a means of focussing attention on comfort-related sensations in an actual transportation environment. Activities may therefore play both a direct and indirect (i.e., mediational) role in passengers' cognitive evaluation of their satisfaction with the ride of existing transportation systems.

The preceding discussion has focussed on the mechanisms of possible relationships between passenger activities and subjective comfort, largely because of previous evidence which has shown comfort to be the best predictor of passenger satisfaction, or willingness to ride again (Richards and Jacobson, 1975), and because it has been assumed that the ability to perform desired activities plays a significant role in determining passenger comfort (Allen, 1975; Stone, 1972).

However, it must be remembered that the relationship between comfort and passenger satisfaction was originally determined from the subjective responses of airline passengers to different STOL (Short Take-Off and Landing) aircraft. Although Richards and Jacobson (1975) have generalized this relationship to other modes (e.g., the Pepler, et al. (1978) train and bus study), subjective comfort has not been formally validated as the best predictor of passenger satisfaction for intercity train passengers.

Considering the differences in ride motions, average trip durations, cost, and other factors between the air and ground modes, it would not be surprising if the relative contribution of activity factors to over-all systems acceptability were much greater on the trains than on airplanes. The ability to do activities might then assume a role independent of its relationship with subjective comfort in determining passenger satisfaction, as indicated by the results of the passenger activity/ride quality survey (Section 3.3.2). Present and future research efforts in the modeling of passenger value structure similar to that conducted by Charles River Associates (1978) may reveal more about the importance of such factors to the acceptability of ground transportation systems.

5. CONCLUSIONS

The results of the preceding three-part field study lead to the following conclusions regarding passenger activities on intercity trains:

1) Passenger activities are sufficiently diverse to require approximately one dozen categories to allow comprehensive description. These categories may then be grouped, according to difficulty of activity performance in a transportation environment, into three main classes: High Effort activities (Eating, Drinking, Reading, Writing); Medium Effort activities (Talking-Listening, Handcrafts, and Games); and Low Effort activities (Doing Nothing, Sleeping, Smoking, and Viewing).

2) Passenger activities vary in relative frequency depending upon short-term trip variables such as time of day, vehicle type, and trip route. However, an activity distribution can be established which is stable in order and frequency over the long term and generalizable (with minor adjustments) to a wide variety of intercity passenger train situations.

3) Passengers indicate in their questionnaire responses that a number of activities, especially Reading, Thinking, and Sleeping, are important to their satisfaction with the train. Furthermore, passengers' subjective responses regarding their activities on the trains correspond well with their actual

observed behaviors. Frequently observed behaviors are generally those which passengers feel to be subjectively important to their satisfaction with the train ride, and which they would like to do more on future trips. These activities include Reading and Sleeping. Passengers do not frequently perform the activities which they feel to be subjectively unimportant and which they would like to do less on future trips. These activities include Handcrafts and Games.

4) Subjective judgments of ride comfort are largely independent of passengers' perceptions of ride variables' interference with the performance of passenger activities. The passengers' concept of comfort appears to be static and passive, and does not involve to any great extent the dynamic assessment of ease of activity performance.

5) Trip variables and passengers' demographic characteristics influence their subjective opinions regarding activities and ride comfort. The longer the trip and the younger the passenger, the more highly passenger activities are valued. Ratings of ride comfort vary with vehicle type and education level, while perceptions of the ride environment's interference with activities depend upon age and trip purpose. Both over-all comfort and activity interference responses are influenced by the number of companions traveling with a passenger and his occupation.

6) Ride motion variables are the most important environmental factors which influence passenger activity performance, especially for behaviors requiring significant motor and visual components. This is true in both a subjective and objective sense, since:

a) Passengers' survey responses indicate that ride roughness interferes with activities, especially those in the High Effort class, more than any other environmental variable; and

b) Simultaneous measurement of the ride environment and observation of activities indicate that rotational vibration in the 1-20 Hz frequency range is negatively correlated with performance of High Effort, Motor and Medium Effort, Social/ Oral activities, and positively correlated with Low Effort, Rest activities. Linear vibrations, however, do not influence the levels of passenger activities in any reliable and consistent way.

7) Passengers themselves are the chief source of noise measured on the trains. Conversational levels are positively correlated with noise, which is greater in Amcafe snackbars, where the most socializing takes place, than in Amcoach vehicles. While noise levels are perceived by 20-30% of the passengers to interfere with activities such as Sleeping, Conversation, and Reading, the observational data indicates that in fact, only Low Effort activities (such as Sleeping) significantly decrease in frequency as measured levels of noise increase.

8) Effective temperature and illumination levels are not perceived by passengers to play a major role in disrupting activity performance. Further, these variables do not appear to be associated with decreases in observed activity levels to any significant extent. Although passengers perceive the lighting to be poor for Reading and Writing, and relatively low levels of ambient (as opposed to reading) light are in fact present on the trains, Reading and Writing do not vary in relative frequency with changes in illumination. In fact, higher illumination levels are associated with higher frequencies of Social/Oral activities, such as conversation.

9) Trip variables such as vehicle type and time of day significantly affect passenger activity levels. Passengers seated in Amcafe and Amcoach vehicles do not seem to value activities differently for their satisfaction on the train, or perceive environmental variables differently in terms of their disruptive effects on activities; however, passengers in different types of vehicles perform some activities with differential relative frequencies. Amcoach passengers engage in Low Effort, Rest behaviors more than Amcafe passengers, who do more Medium Effort, Social/ Oral activities. High Effort and Motor activities are performed more frequently in the morning, while Low Effort behaviors occur more often in the afternoon.

10) Quantitative relationships between observed levels of activity and the physical parameters of ride quality and other recorded variables may be established using multiple regression techniques. The resulting linear equations consist of combinations of predictor variables which account for approximately 20% of the variance in the observed levels of various classes of passenger activity. Individual differences between subjects and differences in effort and motivation might be postulated to account for the remaining variance in activity levels.

11) The activity/ride quality equations are considered to be mathematical models of the compensatory type. Thus, they may be used by designers and evaluators of advanced transportation systems to make trade-offs in the specifications of environmental variables, in order to provide an acceptable ride environment for the performance of predetermined levels of passenger activities. The activity equations may provide a valuable tool in the determination of the minimum acceptable level of ride quality for passenger activity on the trains.

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APPENDIX A

OBSERVATIONAL CODING FORM FOR PASSENGER ACTIVITY

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)

APPENDIX B

AMCOACH AND AMCAFE VEHICLE FLOORPLANS

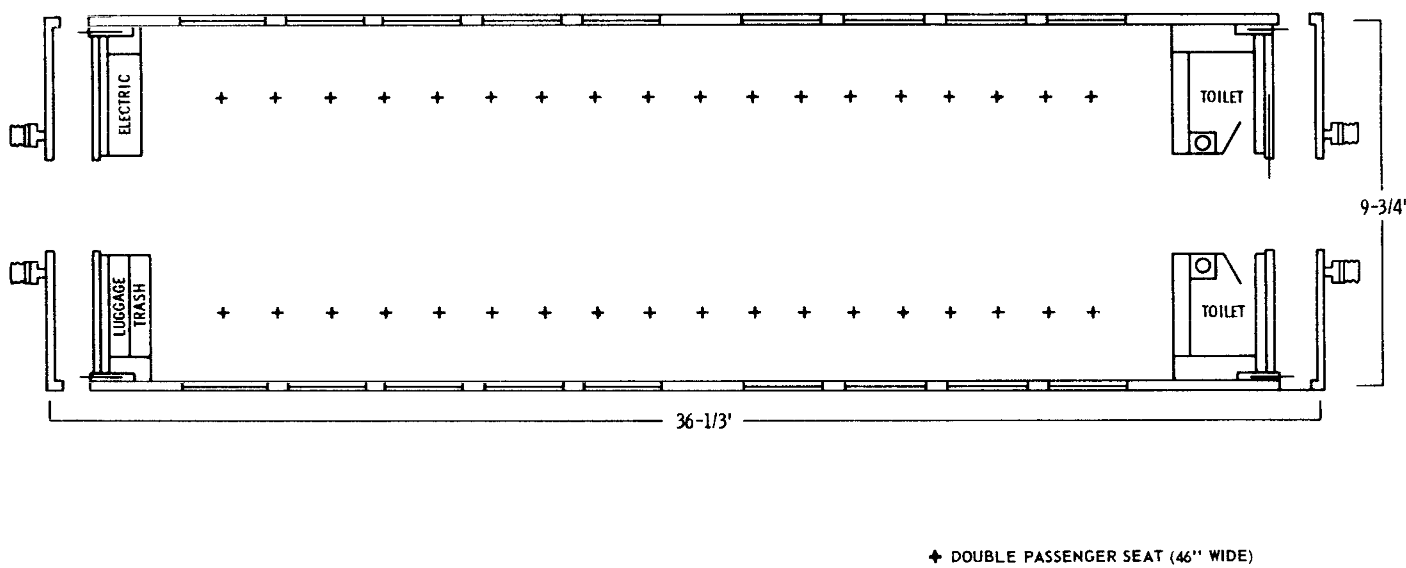

Figure B-1. Amcoach Vehicle - Capacity 84

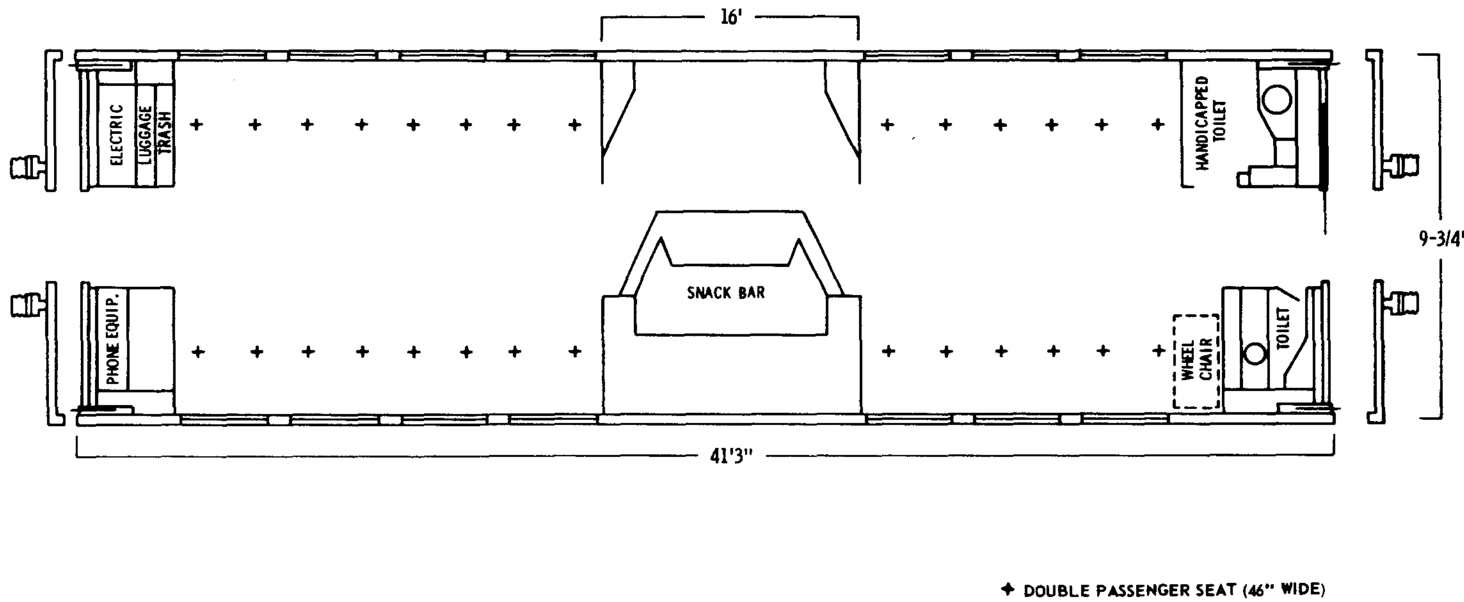

Figure B-2. Amcafe Vehicle - Capacity 55

APPENDIX C

PASSENGER ACTIVITY/RIDE QUALITY

QUESTIONNAIRE

Train No. ________

Date ________

Car No. ________

A Study Being Conducted by

Amtrak

Market Research Department

The National Railroad Passenger Corp.
955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

Dear Passenger:

Welcome Aboard. We at AMTRAK are dedicated to making your trip an enjoyable one. In order to make this possible, we need your cooperation in helping us find ways to improve our services.

The following survey is easy to understand. Please read the instructions and questions carefully, then give your responses. You will not need to give your name and address, so answer all questions as freely as possible.

Please complete the questionnaire and give it back to your AMTRAK representative when you have finished.

Have an enjoyable trip and thank you for riding AMTRAK.

Sincerely yours,

Al Michaud

Alfred A. Michaud
Vice President - Marketing

Here are some questions about your trip. Please fill in or check the appropriate answer for each question.

1. How important are the activities listed below for your satisfaction while riding on the train?

	IMPORTANT	UNIMPORTANT
• Beverage consumption	( )	( )
• Eating	( )	( )
• Looking around	( )	( )
• Games	( )	( )
• Reading	( )	( )
• Writing	( )	( )
• Thinking	( )	( )
• Sleeping	( )	( )
• Conversation	( )	( )
• Handcrafts	( )	( )
• Smoking	( )	( )
• Other (please specify)	( )	( )

2. Compared to the time you spend now, would you prefer to spend <u>more</u>, <u>less</u>, or the <u>same</u> amount of time doing the following <u>activities</u> on your <u>future</u> train trips?

	MORE	LESS	SAME
• Beverage consumption	( )	( )	( )
• Eating	( )	( )	( )
• Looking around	( )	( )	( )
• Games	( )	( )	( )
• Reading	( )	( )	( )
• Writing	( )	( )	( )
• Thinking	( )	( )	( )
• Sleeping	( )	( )	( )
• Conversation	( )	( )	( )
• Handcrafts	( )	( )	( )
• Smoking	( )	( )	( )
• Other activity (please specify)	( )	( )	( )

3. How would you describe the ride so far on this trip? (Circle a number below)

1 Very Uncomfortable   2 Uncomfortable   3 Somewhat Uncomfortable

4 Neither Comfortable nor Uncomfortable

5 Somewhat Comfortable   6 Comfortable   7 Very Comfortable

4. Check any of the following that apply:

	SLEEPING	SMOKING	LOOKING AROUND	THINKING	CONVERSATION
• Rough ride interferes with my	( )	( )	( )	( )	( )
• Noisy ride interferes with my	( )	( )	( )	( )	( )
• Car is too hot or cold for	( )	( )	( )	( )	( )
• The ride was too short for	( )	( )	( )	( )	( )
• The light poor for	( )	( )	( )	( )	( )
• There is not enough space for	( )	( )	( )	( )	( )
• There are too many people for	( )	( )	( )	( )	( )
• I am not interested in	( )	( )	( )	( )	( )
• There are other factors affecting my (please explain)__________	( )	( )	( )	( )	( )
• None of the above interfere with my	( )	( )	( )	( )	( )

5. Check any of the following that apply:

	EATING	BEVERAGE CONSUMPTION	GAMES	HANDCRAFTS	READING	WRITING
• Rough ride interferes with my	( )	( )	( )	( )	( )	( )
• Noisy ride interferes with my	( )	( )	( )	( )	( )	( )
• Car is too hot or cold for	( )	( )	( )	( )	( )	( )
• The ride was too short for	( )	( )	( )	( )	( )	( )
• The light poor for	( )	( )	( )	( )	( )	( )
• There is not enough space for	( )	( )	( )	( )	( )	( )
• There are too many people for	( )	( )	( )	( )	( )	( )
• I am not interested in	( )	( )	( )	( )	( )	( )
• There are other factors affecting my (please explain)__________	( )	( )	( )	( )	( )	( )
• None of the above interfere with my	( )	( )	( )	( )	( )	( )

6. At what station did you board this train? ____________________

7. At what station will you leave this train? ____________________

8. Are you traveling by: ( ) Parlor Car ( ) Coach ( ) Other

9. How many times have you used AMTRAK on this route?

( ) First time ( ) 2-5 times ( ) 6-9 times ( ) More than 10 times

10. What is the purpose of this trip?

( ) Business or work
( ) To and from school
( ) Personal Affairs
( ) Vacation or recreation
( ) Other

11. How many persons are you traveling with?

( ) Traveling alone
( ) 1 other person
( ) 2 other persons
( ) 3-4 other persons
( ) 5 or more others

Would you mind answering a few short questions about yourself so that we can combine the answers you've given us with those of other people?

12. What is your sex?

( ) Male
( ) Female

13. What is your educational background?

( ) Grade school or less
( ) High school or less
( ) College or more

14. What is your age group

( ) Under 18
( ) 18 - 24
( ) 25 - 34
( ) 35 - 44
( ) 45 - 54
( ) 55 - 64
( ) 65 and over

15. What is your current occupation? (If unemployed, check your last occupation.)

( ) Laborers (not farm)
( ) Public Service
( ) Craftsmen
( ) Military
( ) Clerical
( ) Sales
( ) Professional and Technical
( ) Farmers and Farm Managers
( ) Managerial
( ) Students
( ) Housewife
( ) Retired
( ) Other (please specify)

16. Please check the range of your household income.

( ) Under $10,000
( ) $10,000 - $20,000
( ) $20,000 - $50,000
( ) Over $50,000

We welcome any comments about your trip and any suggestions you may have for improving AMTRAK service. Please write your comments and suggestions in the space below:

APPENDIX D

GENERAL SUMMARY OF PASSENGER ACTIVITY/

RIDE QUALITY SURVEY RESULTS

ACTIVITY IMPORTANCE

1. How important are the activities listed below for your satisfaction while riding on the train?

	Important	Unimportant	% Responding
Beverage consumption	72.9	27.1	91.9
Eating	70.4	29.6	91.2
Looking around	72.6	27.4	86.3
Games	17.3	82.7	78.4
Reading	87.6	12.4	91.2
Writing	50.7	49.3	80.5
Thinking	85.9	14.1	86.3
Sleeping	76.1	23.9	85.9
Conversation	61.9	38.1	84.0
Handcrafts	17.5	82.5	77.5
Smoking	30.5	69.5	85.2
Other	28.0	72.0	20.8

ACTIVITY TIME PREFERENCES

2. Compared to the time you spend now, would you prefer to spend more, less, or the same amount of time doing the following activities on your future train trips?

	More	Less	Same	% Responding
Beverage consumption	9.4	6.2	84.4	86.9
Eating	12.1	7.3	80.6	85.4
Looking around	21.7	9.0	69.3	81.5
Games	11.6	18.8	69.7	72.1
Reading	33.4	6.0	60.6	82.9
Writing	24.4	12.0	63.6	76.7
Thinking	23.1	6.6	70.2	79.0
Sleeping	23.9	9.2	66.8	76.9
Conversation	21.8	7.5	70.7	76.4
Handcrafts	8.9	21.9	69.2	69.8
Smoking	5.0	30.7	64.2	71.6
Other	8.3	14.7	77.1	27.2

RIDE QUALITY

3. How would you describe the ride so far on this trip?

	DESCRIPTOR	% RESPONSE	
1.	Very uncomfortable	5.4%	
2.	Uncomfortable	2.4%	
3.	Somewhat uncomfortable	9.8%	
4.	Neither comfortable nor uncomfortable	6.2%	(98.6% responding)
5.	Somewhat comfortable	15.4%	
6.	Comfortable	43.9%	
7.	Very comfortable	16.8%	

ACTIVITY INTERFERENCES

4. Check any of the following that apply:

	Sleeping	Smoking	Looking Around	Thinking	Conversation
Rough ride interferes with my	25.7%	2.0%	13.0%	16.2%	8.8%
Noisy ride interferes with my	19.9	1.2	3.9	29.0	25.6
Car is too hot or cold for	11.1	2.0	4.3	6.0	4.5
The ride was too short for	4.4	0.0	1.6	0.9	2.5
The light poor for	1.6	0.2	3.1	0.8	0.7
There is not enough space for	11.9	3.0	4.5	1.7	2.0
There are too many people for	2.6	7.1	3.3	3.0	3.2
I am not interested in	4.0	56.6	9.3	1.6	9.7
There are other factors affecting my	2.2	0.6	1.6	2.0	1.6
None of the above interfere with my	16.6	27.3	55.3	38.7	41.1
(% Response for)	71.9%	57.2%	53.2%	62.3%	58.7%

5. Check any of the following that apply:

	Eating	Beverage Con- sumption	Games	Hand- crafts	Reading	Writing
Rough ride interferes with my	37.4%	48.6%	8.2%	12.0%	32.1%	55.4%
Noisy ride interferes with my	4.0	4.1	3.7	2.0	27.1	10.7
Car is too hot or cold for	2.6	2.9	2.6	1.7	4.2	2.6
The ride was too short for	4.4	1.4	4.2	4.0	2.4	1.7
The light poor for	0.6	0.6	3.0	3.7	10.1	6.0
There is not enough space for	4.6	2.3	8.7	4.5	0.9	3.4
There are too many people for	2.4	1.4	5.9	4.5	1.7	1.4
I am not interested in	6.4	4.1	35.8	38.7	0.9	4.5
There are other factors affecting my	2.2	1.7	0.7	1.2	1.1	0.5
None of the above interfere with my	35.4	32.9	27.2	27.7	19.4	13.8
(% Responding for)	51.1%	53.4%	42.8%	41.5%	64.4%	61.1%

TRIP DISTANCE

6. At what station did you board this train? ____________________

7. At what station did you leave this train? ____________________

Trip Distance (mi.)	% Response	
0-100	18.3	
101-200	24.4	(97.3% responding)
201-300	36.8	
Over 300	20.5	

CLASS OF SERVICE

8. Are you traveling by: ( ) Parlor Car ( ) Coach ( ) Other

Vehicle	% Response	
Parlor Car	0	
Coach	100	(98.0% responding)
Other	0	

TRIP EXPERIENCE

9. How many times have you used AMTRAK on this route?

Trip Experience	% Response	
1st time	26.1	(98.8% responding)
2-5 times	29.0	
6-9 times	8.7	
More than 10 times	36.3	

TRIP PURPOSE

10. What is the purpose of this trip?

Trip Purpose	% Response	
Business or work	20.1	(95.1% responding)
To and from school	3.7	
Personal affairs	24.1	
Vacation or recreation	48.2	
Other	3.9	

TRAVELING COMPANIONS

11. How many persons are you traveling with?

Traveling Companions	% Response	
Alone	56.7	(98.2% responding)
1 other person	24.3	
2 other persons	9.5	
3-4 other persons	6.1	
5 or more others	3.4	

SEX

12. What is your sex?

Sex	% Response	
Male	44.4	(97.0% responding)
Female	55.6	

EDUCATION

13. What is your educational background?

Education	% Response	
Grade school or less	1.0	
High school or less	23.7	(97.0% responding)
College or more	75.3	

AGE

14. What is your age group?

Age	% Response	
Under 18	6.9	
18-24	25.2	
25-34	28.8	
35-44	13.1	(97.8% responding)
45-54	11.1	
55-64	8.8	
65 & over	6.1	

OCCUPATION

15. What is your current occupation? (If unemployed, check your last occupation.)

Occupation	% Response	
Laborers (not farm)	2.1	
Public service	5.1	
Craftsmen	1.1	
Military	2.5	
Clerical	4.0	
Sales	2.3	
Professional & Technical	29.5	(93.0% responding)
Farmers & Farm Managers	0.3	
Managerial	7.1	
Students	20.5	
Housewife	7.9	
Retired	5.2	
Other	12.4	

INCOME

16. Please check the range of your household income.

Income	% Response	
Under $10,000	23.1	(87.7% responding)
$10,000 - $20,000	37.2	
$20,000 - $50,000	35.5	
Over $50,000	4.3	

COMMENTS

Comment	% Response	
General compliments	13.0	(45.9% responding)
Ride comfortable	2.2	
Other specific positive comments	4.5	
Time delays-operational problems	21.2	
Ride too rough	8.1	
Activity limited by ride or vehicle design	2.7	
Temperature-ventilation (negative)	4.9	
Food & food service (negative)	3.9	
Lighting (negative)	1.4	
Bathrooms (negative)	3.7	
Noise (negative)	1.4	
Train personnel (negative)	3.7	
Other specific negative comments	11.6	
Suggestions for improvement	17.7	

APPENDIX E

SPECTRAL PLOTS OF RIDE MOTIONS RECORDED ON NORTHEAST CORRIDOR AMTRAK TRAINS (DECEMBER, 1977)

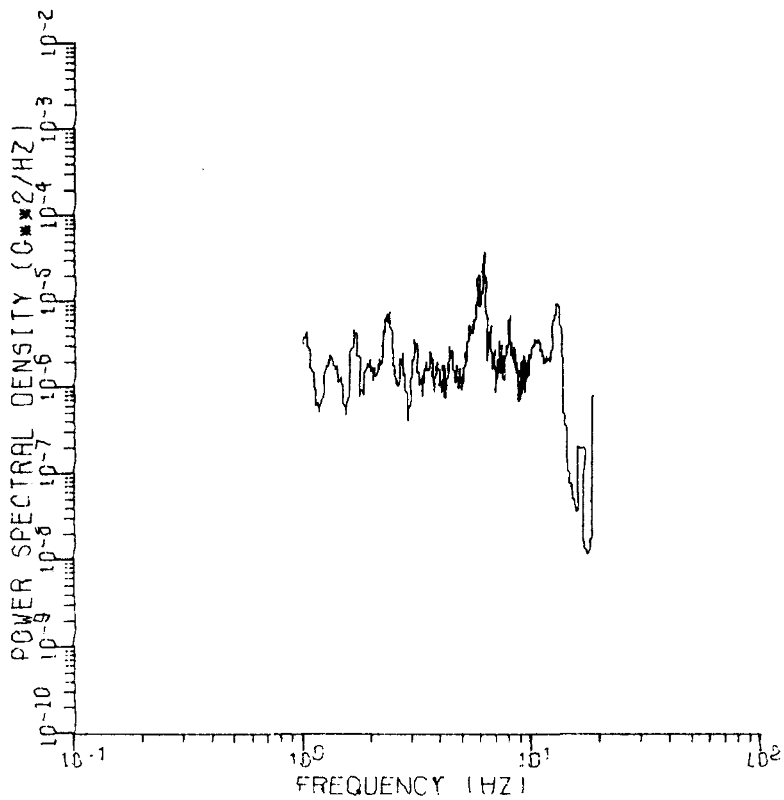

Figure E-1. X-Linear Acceleration

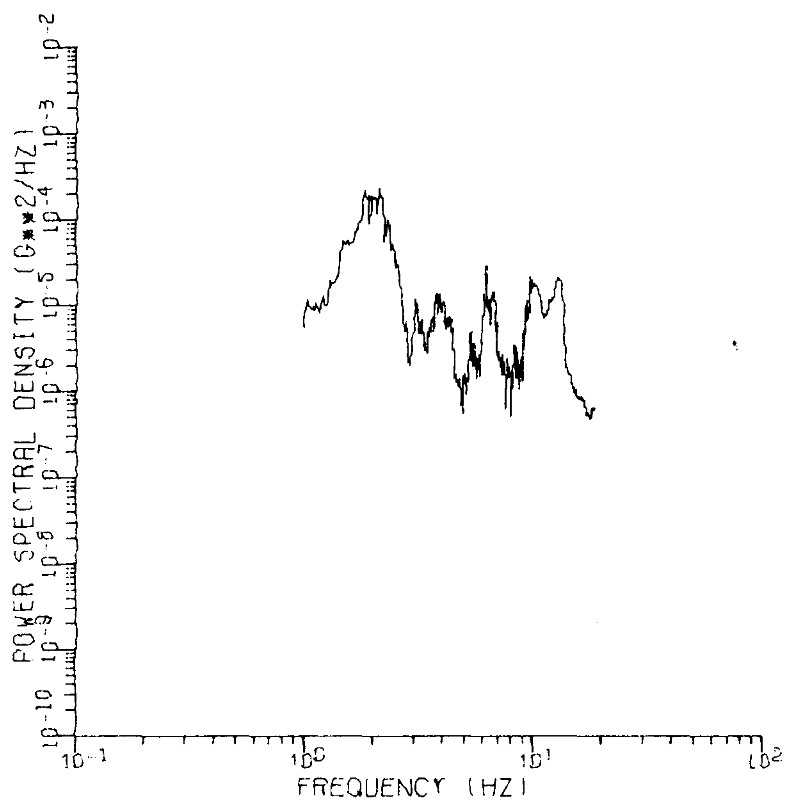

Figure E-2. Y-Linear Acceleration

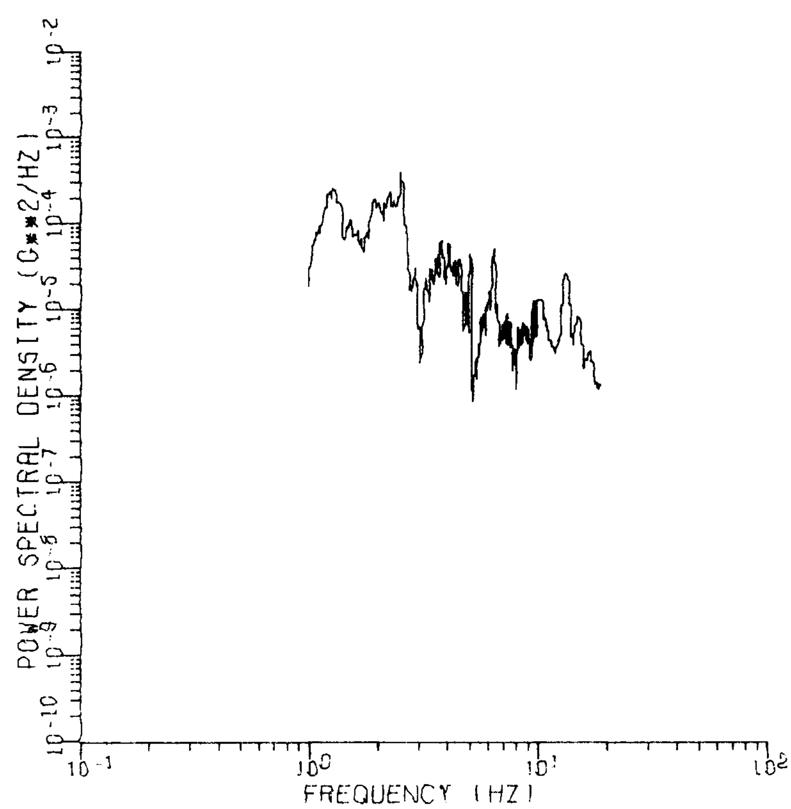

Figure E-3. Z-Linear Acceleration

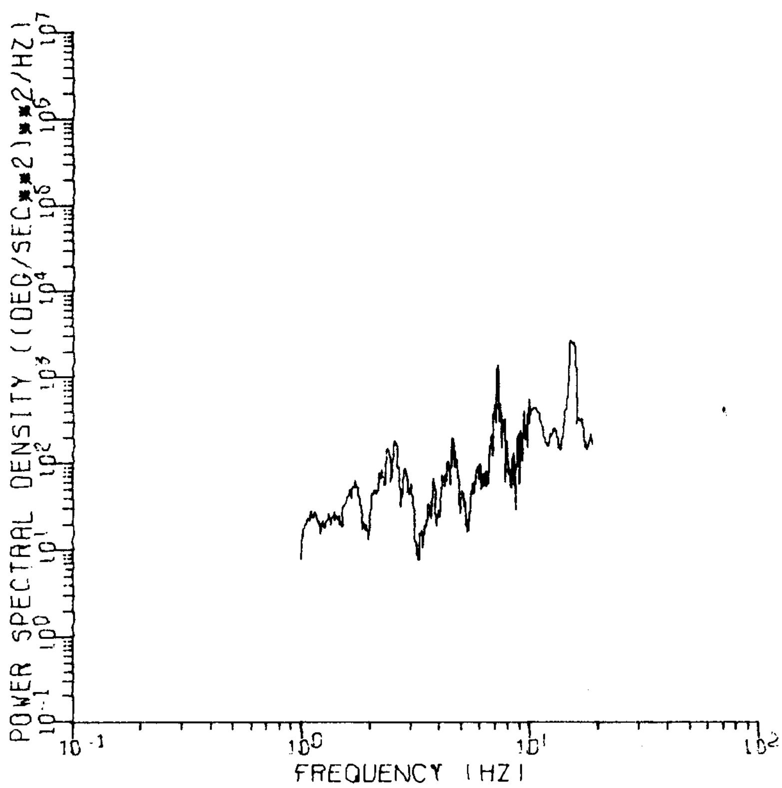

Figure E-4. X-Rotational Acceleration (Roll)

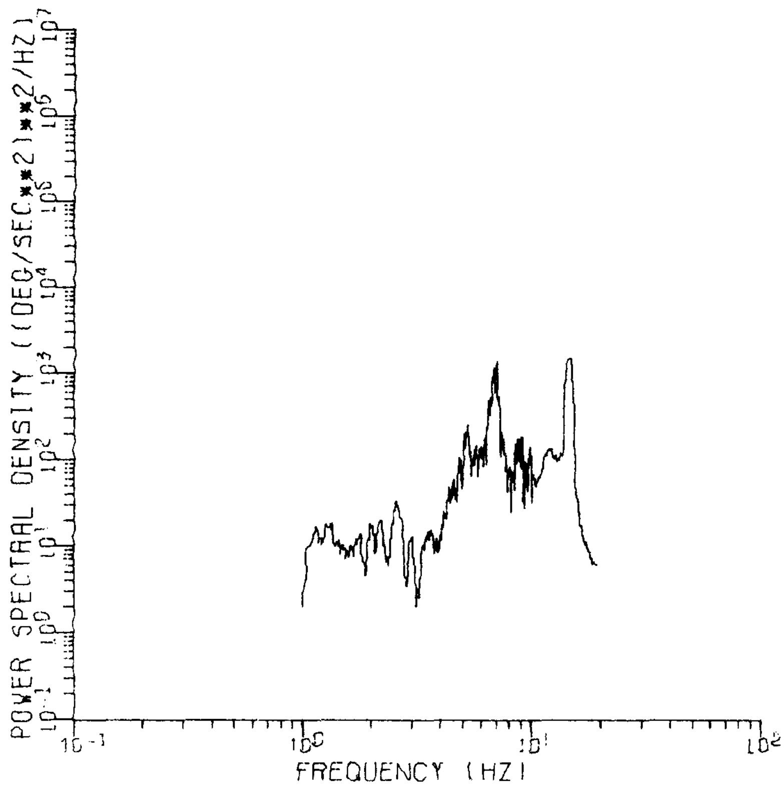

Figure E-5. Y-Rotational Acceleration (Pitch)

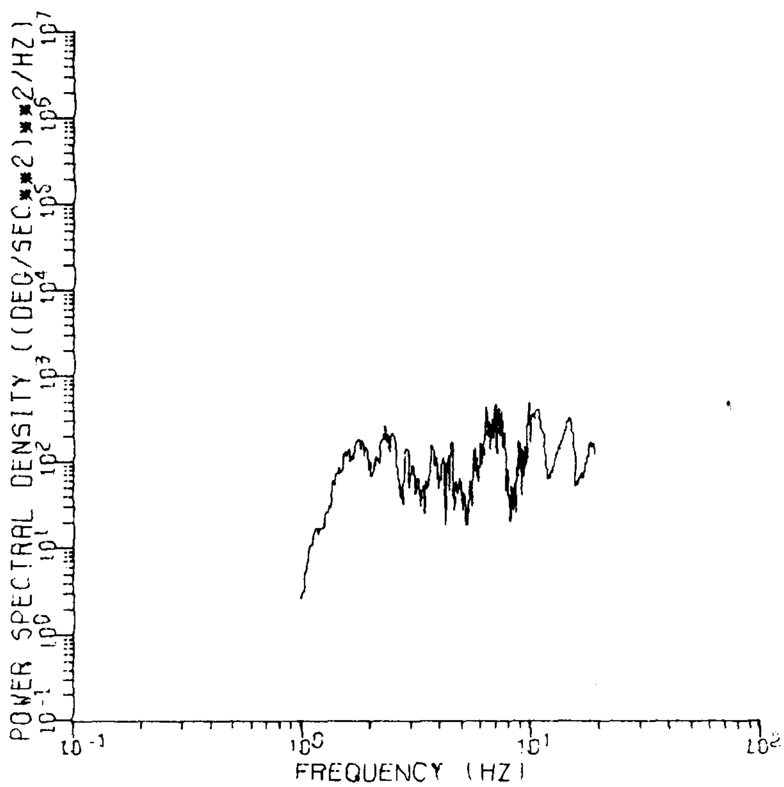

Figure E-6. Z-Rotational Acceleration (Yaw)

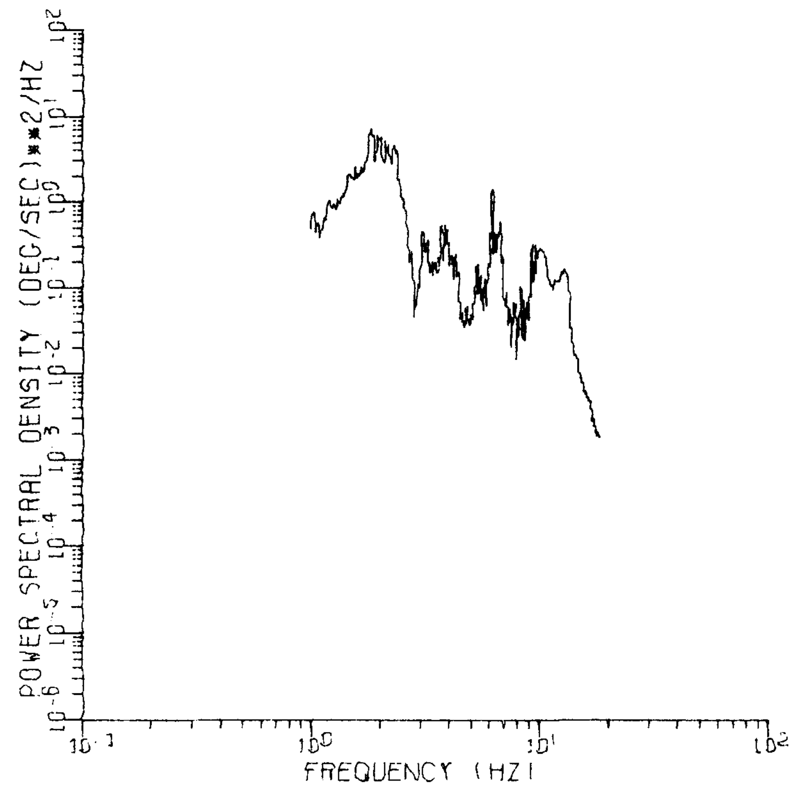

Figure E-7. X-Rotational Rate (Roll)

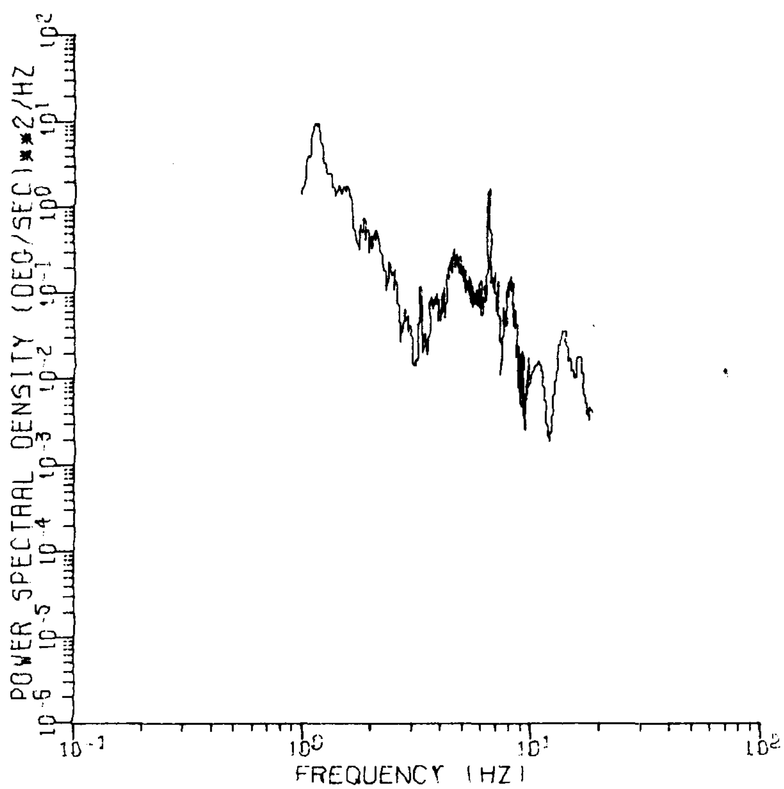

Figure E-8. Y-Rotational Rate (Pitch)

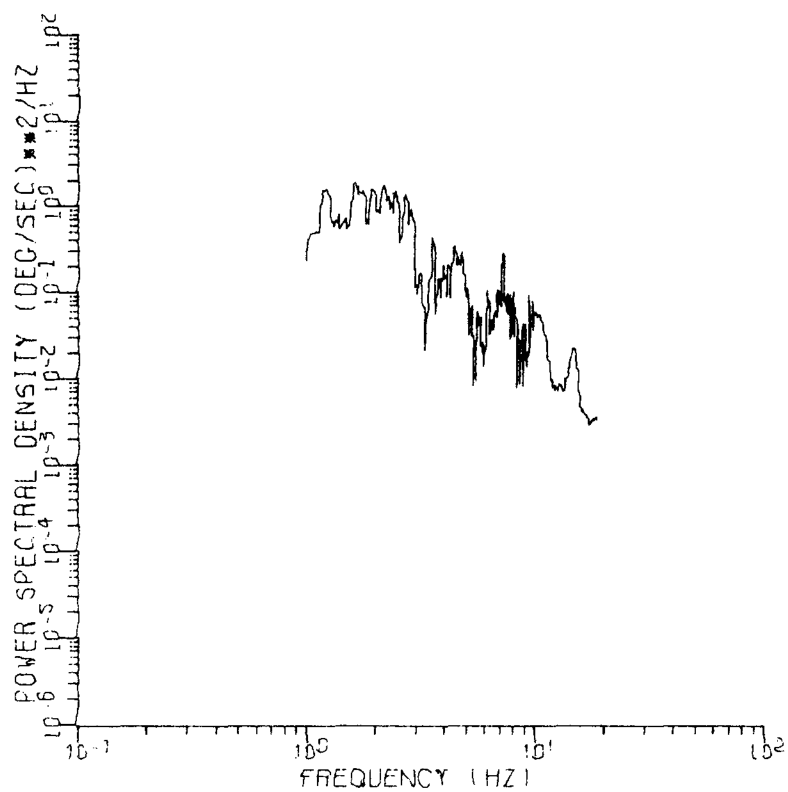

Figure E-9. Z-Rotational Rate (Yaw)

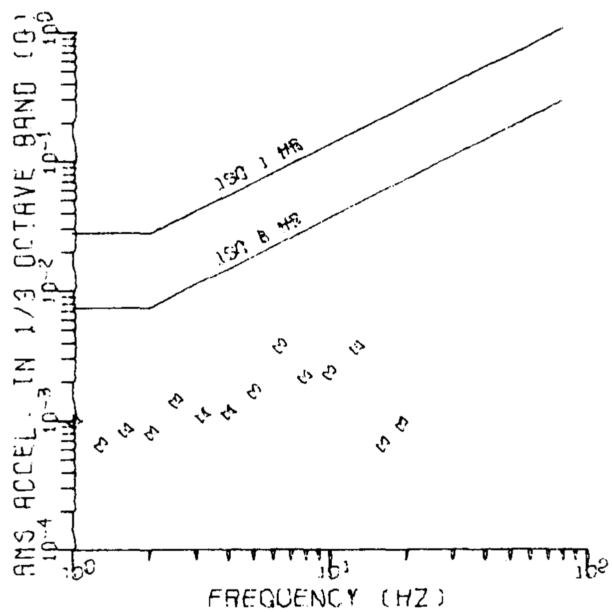

Figure E-10. ISO Plot Of Typical Ride Segment: X-Linear Vibration

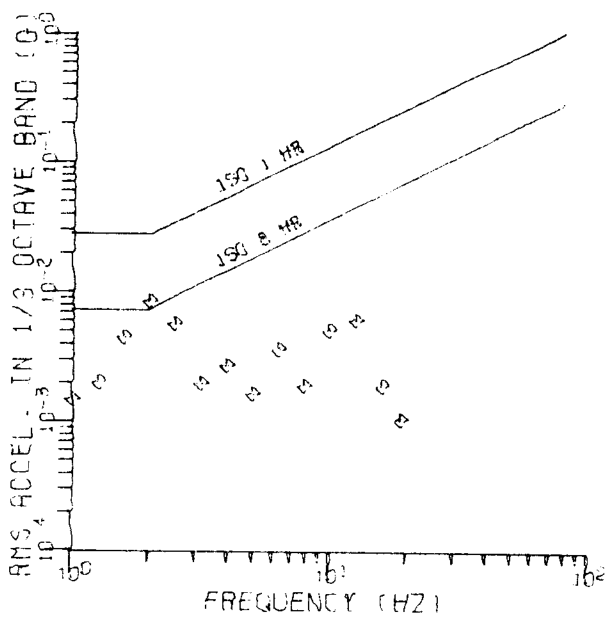

Figure E-11. ISO Plot Of Typical Ride Segment: Y-Linear Vibration

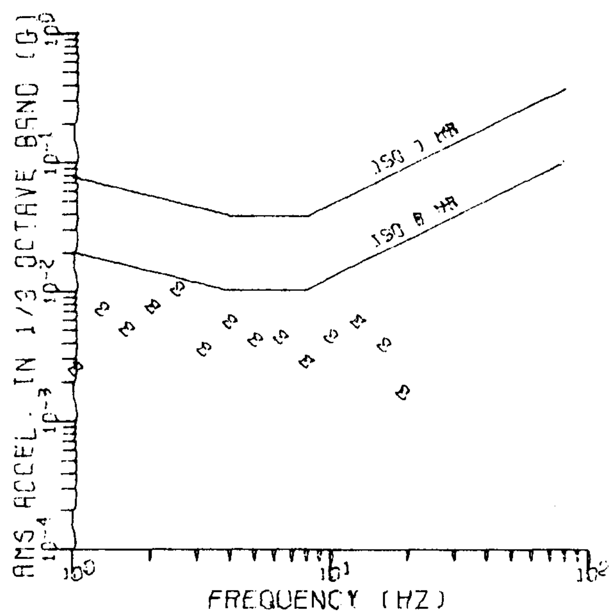

Figure E-12. ISO Plot Of Typical Ride Segment: Z-Linear Vibration

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