SPECTRAL ANALYSIS OF DRIVER STEERING BEHAVIOR

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ABSTRACT

In order to examine the utility of spectral analysis as a means of quantifying driver steering behavior in a steady-state (expressway) driving task, 10 novice and 10 experienced drivers drove an instrumented car on a 90-minute drive on an "uncongested" expressway, and (for the experienced drivers only) on a 60-minute drive on a "congested" expressway during rush-hour conditions. Results of analyses of variance of RMS steering amplitude in 0.025 hz-wide frequency bands indicated that novice drivers exhibited significantly greater RMS steering amplitude than experienced drivers in the two frequency bands 0-0.025 hz and 0.125-0.150 hz, and that experienced drivers exhibited significantly greater RMS amplitude on the "congested" expressway than the "uncongested" expressway in the six 0.025 hz-wide frequency bands between 0 and 0.150 hz. Significant differences were found between RMS amplitudes measured during the first and second halves of a number of the test drives, indicating that behavior in the two test halves was not equivalent.

INTRODUCTION

Measurement of driving behavior has long been a subject of interest to psychologists, engineers, administrators, and others who are concerned with the practical aspects of training, evaluating, and selecting drivers, or designing vehicles, roadways, or roadway environments which are intended to be useable by drivers.

A primary goal of the study of driver behavior is the development of methods of quantifying driving behavior which are: a.) repeatable; and b.) useful in characterizing drivers or driver behaviors in terms of some external criterion such as level of driving "skill" or quality, or degree of driving task difficulty. This goal has led to a search for objectively measurable driving behaviors which, although presumably influenced by such transient conditions as the amount and behavior of surrounding traffic, the psychological and physiological condition of the driver, and ambient environmental conditions, are related to driving quality and are in some way "characteristic", that is, show some degree of constancy both within and between drivers.

At this time, however, there is no consensus that driving behavior is consistent. Longitudinal studies of motor-vehicle accident involvement have concluded that accident involvement experience is neither reliable or enduring (Burg, 1970; Stewart and Campbell, 1972), and studies of objectively observable driver behaviors have found very low test-retest reliabilities in driver behavior ratings made by trained observers (Jones, 1979). These studies contrast, however, with findings reported by Greenshields and Platt (1967) and Rowland (1969) who were able to successfully discriminate between selected groups of accident-repeater and accident-free drivers on the basis of behavioral measures.

While "driving" is obviously a relatively complex behavior to evaluate, it is not a particularly difficult behavior to accomplish (in most conditions). Much of the simplicity of driving arises from the fact that when a driver operates a motor vehicle, he/she has direct control (in a limited range) over only two functions: a.) the vehicle's longitudinal acceleration, controlled by the accelerator and brake pedals; and b.) the vehicle's yaw rate (rate of change of heading angle), controlled by the steering wheel. Control of the vehicle's speed and its position on the roadway (or its environs) are thus direct and interacting results of previous and ongoing control efforts. It can be argued therefore, that if drivers do exhibit characteristic and enduring behaviors, it should be evident through observation and analysis of the way in which they use steering and/or speed controls.

A frequently- employed measure of driver steering activity is "steering reversal rate" (SRR), the rate or frequency with which the steering wheel is rotated back and forth across some small angle. Studies which have examined SRR as a measure of driving performance have generally found that drivers exhibit more steering activity than necessary for successful control of the vehicle, and that SRR reflects the driver's level of arousal or the degree of driving task difficulty. An excellent review of the literature concerning SRR and its interpretation is provided by MacDonald and Hoffman (1980).

Another method of analyzing steering behavior which permits examination of steering wheel movement amplitude as well as frequency is "spectral analysis". Basically, this technique transforms a continuous time history of steering wheel movement into a distribution of the amplitudes and frequencies of which it is composed. To date, this method has been used exclusively with data collected on test tracks

and in simulators in experiments to examine straight-line driving (McLean and Hoffman, 1971) and the effects of: reduced sight-distance (McLean and Hoffman, 1973); headlight glare (Smiley, 1974); alcohol (Mortimer and Sturgis, 1975); and driving experience (Blaauw, Godthelp and Moraal, 1977).

Little or no information is currently available on the manner in which drivers steer in "normal", real-world driving. A problem which significantly complicates the study of normative driver behavior is controlling the environment in which drivers can be observed. In the real world (as opposed to in a driving simulator or on a test track), many of the stimuli to which drivers must respond are, in large part, randomly occuring and largely uncontrollable. Observational studies must therefore either have some means of quantifying and accounting for variability in the driving environment, or must be conducted in relatively constant and well-defined driving conditions.

The present study was conducted to examine the utility of spectral analysis in quantifying real-world steering behavior while providing insight into the range and distribution of steering frequencies exhibited by drivers in the relatively constant driving task presented by expressway driving. Spectral analysis measures were also used to examine the consistency of steering behavior over time and to examine the extent to which differences in driver steering behavior can be associated with differences in driving experience and degree of driving task difficulty. The steering behavior of groups of inexperienced and experienced drivers was recorded during a 90-minute drive on an uncongested expressway, and for the experienced drivers, during a 60-minute drive on a very congested expressway during rush hour conditions.

METHOD

Subjects

Two groups of 10 subjects participated in the study. The first group consisted of novice drivers who had completed a driver training class and had received "learners" driving permits, but were not "officially" licenced drivers. This group consisted of 7 males and 3 females, aged 16 to 18 years (Med = 16 years). The second group consisted of 6 males and 4 females aged 20 to 24 years (Med = 21 years). Drivers in this group had been licenced for 3 to 8 years (Med = 4.5 years). All subjects were paid for participation.

Apparatus

The automobile used in the study was a 1979 Ford Fairmont which was equipped with power brakes and steering and automatic transmission. This vehicle was also equipped with an instrumentation system which enabled continuous recording of steering wheel angle via a potentiometer geared to the steering column, out of the subjects view. Analog steering angle data was low-pass filtered at 4 Hz with a 6-pole Butterworth filter, digitized at 10.24 samples per second, and recorded on 20 cm floppy disk by a computer located in the trunk of the vehicle.

Two roadway sections were employed in this study. The "uncongested" expressway was a 71-km section of the Massachusetts Turnpike (US Route 90) between Southborough and Palmer, Massachusetts. All drives on this roadway were done in an "off-peak" period between 1:30 pm and 3:30 pm on Monday through Thursday afternoons. The "congested" expressway was a 45-km section of Massachusetts Route 128 (US Route 95) between Weston and Peabody, Massachusetts. Drives on this roadway were conducted in "rush-hour" conditions between 3:30 pm and 5:00 pm on weekday afternoons.

Spectral analysis method

All power spectra were calculated in the method outlined by Bendat and Piersol, (1971): steering wheel angle data were examined as segments of 2048 points; the mean of each 2048 point record was subtracted from each point in the record; the ends of each record were subjected to a "10% cosine taper" to improve the accuracy of the later spectral estimates; a fast Fourier transform (FFT) was conducted on each record using the mean-corrected, tapered data as the "real" FFT input and zeros as the "imaginary" input; the power spectrum of each record was generated by calculating the sum of the squared (real and imaginary) Fourier coefficients at each frequency point, multiplied by $2/N^2$; the spectral estimates were multiplied by a constant to correct for attenuation introduced by the tapering process and to convert the measurement scale to degrees of steering wheel angle squared.

Each "test drive" was divided into two sections of equal length, providing roughly 25,000 and 15,000 data points per section for the uncongested and congested roadways, respectively. Power spectra were then calculated for twelve 2048 point segments in each "uncongested" section and for seven 2048 point segments in each "congested" section. These spectra were then "ensemble averaged" to provide smooth spectral estimates with 12 and 7 df and normalized standard errors of 0.29 and 0.38, respectively. Averaged power spectra were converted to RMS amplitude spectra by taking the square root of each spectral estimate. To enable statistical comparison of spectra, the RMS amplitude in equal width frequency bands was calculated by summing contiguous spectral estimates.

Procedure

Subjects drove the instrumented vehicle for approximately 20 minutes before data collection

was begun. Their instructions were simply to drive the vehicle to a specific expressway exit at any speed and in the manner with which they were most comfortable. They were accompanied by an experimenter who rode in the passenger's position in the front seat and operated a calculator- style keypad to start and stop the data recording process at the beginning and end of the drive. While the subjects were aware that something was being recorded, they were not told what, and (except for the keypad) none of the instrumentation system was visible.

Experienced subjects were randomly assigned the roadway on which they made their first drive. Within each road type, all drives began at the same point.

RESULTS

Steering angle data were subjected to the spectral analysis procedure described earlier. Examples of the resulting spectra are shown in figures 1a - 1d which were selected on the basis of their relatively characteristic and diverse shapes. Figure 1a is the average spectrum of a novice driver which shows a "bulge" in the frequency range of 0.1 to 0.2 hz. Of the 10 novices tested, four showed a noticeable bulge of this type. Figure 1b shows the average spectrum of another novice which also "bulges", but over a wider frequency range of roughly 0.1 to 0.3 hz. Two of the 10 novices produced spectra of this type. The average spectrum of a third novice is shown in figure 1c. This spectrum shows no noticeable bulges and is typical of the remaining four novice drivers. The average spectrum of an experienced driver on the uncongested expressway is shown in figure 1d. This spectrum shows no unusual peaks, but does appear to contain a relatively large amount of energy above 0.6 hz, compared to the novices. This spectrum is typical of eight of the 10 experienced drivers, the remaining two drivers producing spectra resembling figure 1b. Spectra produced by the experienced drivers on the congested expressway resembled those produced on the uncongested road.

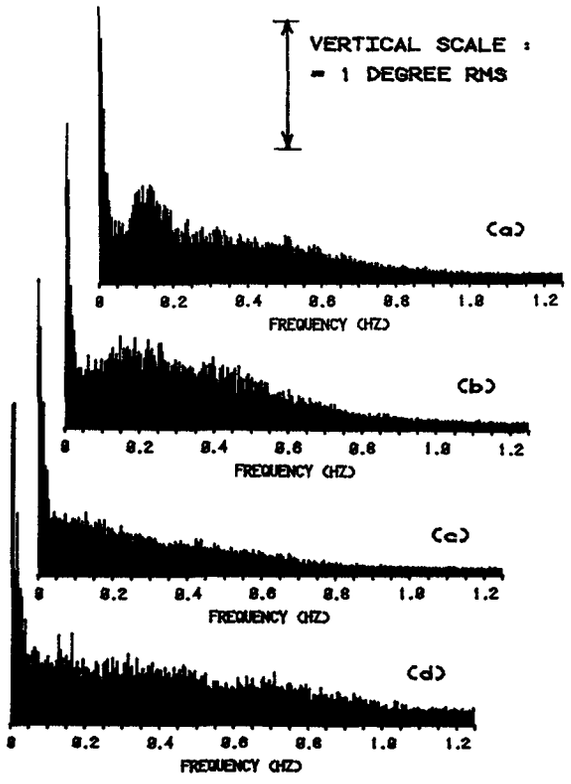

Figure 1. Mean RMS steering amplitude by frequency for novice (a-c) and experienced drivers (d) on the uncongested expressway.

To enable statistical comparison of the averaged spectra, RMS steering amplitude was calculated for the ten 0.1 hz- wide bands between 0 and 1.0 hz. These data were subjected to four-factor analyses of variance with factors of frequency band (10 levels), road section (2 levels - first half/second half), subjects (10 levels), and, either experience (2 levels - novice and experienced) or road type (2 levels - congested and uncongested). In the driving experience analysis, the subject factor was nested under the experience factor; in the road type analysis, the design was completely crossed (subjects were tested on both road types).

Results of these analyses indicated that all differences between treatment conditions occurred at frequencies in the range of 0 to 0.25 hz. In order to examine these differences with better precision, RMS amplitude was recalculated for the ten 0.025 hz- wide bands between 0 and 0.25 hz and the analyses of variance recalculated.

Driving experience analysis

This analysis showed significant main effects of frequency bands($F(9,162) = 413.2$, $p < 0.01$) and road sections ($F(1,18) = 7.6$, $p < 0.05$), and significant frequency band x experience ($F(9,162) = 3.9$, $p < 0.01$), frequency band x road section ($F(9,162) = 3.1$, $p < 0.01$), and frequency band x road section x experience ($F(9,162) = 2.9$, $p < 0.01$) interactions. Since the factors of interest were represented in the three-way interaction, the interaction was examined by performing Tukey (b) post- hoc tests on factor level means within levels of the other factors. Examination of experience means in this manner showed significant differences between levels of experience in the first and sixth frequency bands in both road sections, and, additionally, in the second and seventh bands in the second road section only. In both road sections, greater RMS steering amplitude was associated with the more experienced drivers at the lower frequencies and with the novice drivers at the higher frequencies. Figure 2 illustrates the the road section x experience interaction, averaged across road sections. Differences between road sections were

examined in a similar manner. This analysis showed significant differences between road sections for both experience groups in the two lowest frequency bands and, for the novice group only, in the highest frequency band.

Road type analysis

This analysis showed significant main effects of frequency bands ($F(9,81) = 423.9$, $p < 0.01$), road sections ($F(1,9) = 23.3$, $p < 0.01$) and road type ($F(1,9) = 170.8$, $p < 0.01$), and significant frequency band x road section ($F(9,81) = 5.7$, $p < 0.01$), frequency band x road type ($F(9,81) = 97.5$, $p < 0.01$), road section x road type ($F(1,9) = 8.0$, $p < 0.05$), frequency band x subject x road type ($F(81,81) = 2.1$, $p < 0.05$), and frequency band x road section x road type ($F(9,81) = 3.5$, $p < 0.01$) interactions. Again, since the factors of interest were contained within a three-way interaction, post-hoc comparisons were made within levels of other factors. Tukey (b) tests on road type means showed significantly greater RMS steering amplitude on the congested expressway in the five lowest frequency bands in both road sections and additionally, in the sixth, ninth, and tenth frequency bands in the second road section only. Figure 3 illustrates the interaction of frequency band and road type, averaged across road sections.

Tests on road section means found significantly greater RMS steering amplitude in the second road section in the two lowest frequency bands on the uncongested expressway and the four lowest frequency bands on the congested expressway.

DISCUSSION

Driver steering behavior is the product of a large number of interacting influences, including transient factors such as the geometry of the roadway and the presence and action of ambient traffic, and more enduring factors such as level of driving experience and overall driving task difficulty. Results of this study indicate that the effects of the more enduring factors can be seen by essentially "averaging out" the effects of the transient factors through the spectral analysis of relatively long samples of steering behavior collected in steady-state conditions.

Analysis of RMS steering amplitude in narrow frequency bands found significant differences in steering behavior attributable to both driver experience and driving task difficulty. The behavior measured was not completely consistent, however, as further significant differences were found between the first and second halves of the various test drives. It is not possible to determine if these differences in behavior are attributable to a systematic bias in external conditions which did not "average out" or to changes on the part of the drivers, possibly attributable to increasing familiarization with the vehicle or test route, or decreasing motivation to perform.

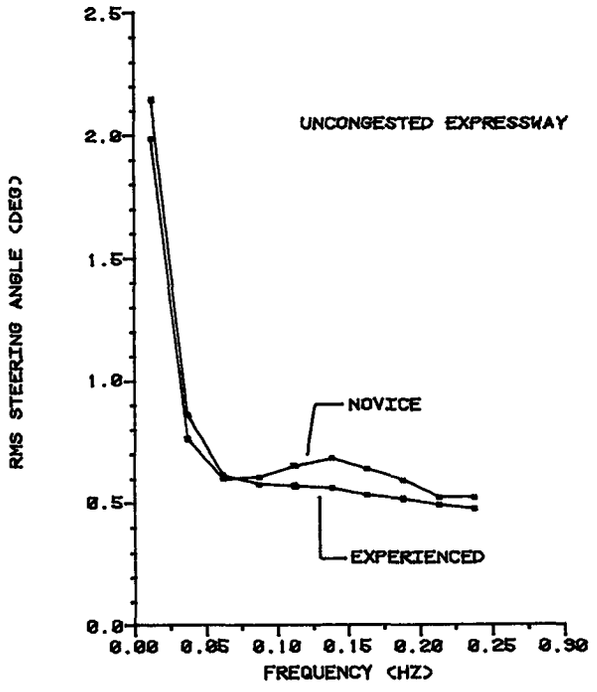

Figure 2. Mean RMS steering amplitude of novice and experienced drivers on the uncongested expressway.

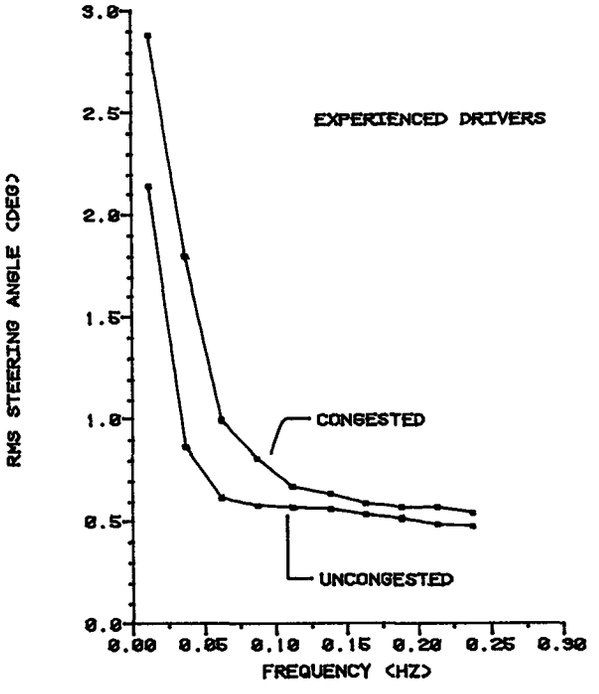

Figure 3. Mean RMS steering amplitude of experienced drivers on the congested and uncongested expressways.

Although spectral analysis has been used to quantify steering behavior in a number of earlier studies, very few spectra have actually been published with which the present spectra can be compared. McLean and Hoffman (1971, 1972, 1973) have shown unaveraged power spectra (rather than RMS amplitude spectra) of selected individual subjects in studies concerned with course tracking, lane width, and restricted visual preview, respectively. These power spectra were calculated using a different procedure and each represents the result of a relatively short (40 - 85 second) trial. In general, these spectra show relatively sharp peaks in the region of 0.1 to 0.3 hz, with occasional secondary peaks in the region 0.35 to 0.6 hz (figure 4).

The shapes of the McLean and Hoffman spectra are quite different from those presented here, which generally show a large peak near 0 hz, and in the case of some subjects, a small bulge between 0.1 and 0.2 hz or between 0.1 and 0.3 hz. The large peak near 0 hz in the present spectra is interpreted as the result of the horizontal curvature of the roadway and is not expected to be sensitive to individual differences between subjects. The lack of other sharply pronounced peaks indicates that steady-state steering behavior is relatively "wide-band"; that is, it does not show marked periodicity but is composed of a wide range of frequencies between 0 and 1 hz.

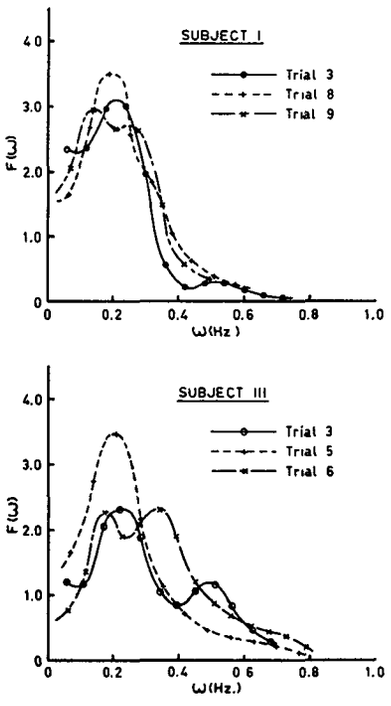

Figure 4. Normalized spectral density versus frequency for typical steering-wheel-angle spectra obtained from straight-line driving. (From McLean and Hoffman, 1971.)

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