Tension Responses of Drivers Generated on Urban Streets

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The present study was an attempt to relate driver tension responses to those events in traffic which caused an overt change in speed or lateral location of a test vehicle. In order to measure tension responses the galvanic skin reflex (GSR) was employed, and measurements were made continuously during each trip along two urban streets. Traffic events influencing the test vehicle were determined independently by an observer and recorded on the GSR record. The traffic events were restricted to eight possible interferences, which accounted for 95 percent of all agents causing a change in test vehicle speed and placement.

Ten driver subjects were used on the two test routes. Runs were made during five time periods, including peak, offpeak, and night. Each subject drove the test route 25 times, distributed over a two-week period.

The results indicated that traffic events occurred, depending upon the street, at a rate of one every 21 to 35 seconds. Of these, 85 percent generated a measurable GSR response. Depending upon the street, the majority of responses were caused by other vehicles in the traffic stream, accounting for 60 percent or more of all events.

The events which generated the greatest mean tension response were those involving a maximum difference in speed between the object and test vehicle. Thus, turning maneuvers and crossing and merging were most tension inducing. The least stress inducing events were related to fixed objects in the environment, such as parked vehicles or islands. This ordering was statistically reliable among the subjects.

Using the magnitude of GSR response per unit of time as an over-all measure of driver tension, it was possible to compare the two test routes. It was found that the route subjectively preferred by drivers induced an average of 40 percent less tension response per minute than did the other route. An analysis of variance showed that these differences between routes were statistically significant.

The results of this study indicate that a road generates tension in drivers inversely with the predictability of the interferences and directly with the complexity of the traffic situation with which they must deal. In addition, the magnitude of tension response is directly related to the rate at which decisions are forced upon the driver by the traffic. Finally, the results indicate that the GSR

is a promising tool for the study of the conflicts occurring in driving.

● THE INDIVIDUAL VEHICLE is usually undifferentiated from the whole of traffic in most analyses of the operational characteristics of traffic on an urban street. Rather, the factors determining the operations of the street are inferred from certain physical measurements of the mass of traffic itself. There have been relatively few attempts to use driver behavior itself as a measure of traffic characteristics, or as a means for discriminating among different streets (1, 2). The present study was an attempt to develop a measure of driver behavior from which it would be possible to draw inferences about the highways under study. Two classes of questions were of particular interest:

1. Are these stable characteristics of different streets that can be discriminated by some measure of driver behavior?
2. Are there stable characteristics within a street and of the traffic on it which can be discriminated using some measure of driver behavior?

It may be seen then, that the basic purpose of this study was to explore the possibility of using driver behavior as an instrument for the analysis of highway and traffic characteristics.

The hypothesis which indicated the choice of behavioral measure was that the frequency and complexity of decisions required in driving urban streets is so great that the driver is under a high level of tension. This hypothesis implies that the frequency and magnitude of tension responses aroused in driving will vary in some relation to the nature of the street and of the traffic.

There are a variety of behavioral measures which may be employed to measure tension responses. However, for the purposes of this study it was desirable to have a measure that was directly relatable to events in traffic or the street on the one hand and also one that was a reliable indicator of driver tension response. A physiological measure that most nearly fulfilled these requirements is the galvanic skin reflex (GSR). This is a response occurring in the skin, manifesting itself as a change in the electrical resistance of the skin. The reflex is induced by activity of the autonomic nervous system and is initiated by unexpected stimuli that may be startling or tension inducing. The response appears as a decrease in skin resistance, and the magnitude of the reduction is correlated with the intensity of the inducing stimuli (3). Thus, the GSR represents one way to quantify the effects of emotion inducing stimulation.

One important characteristic of the GSR is its relation to the conscious experiences of the subject. McCurdy (4) has shown that there is a very high correlation between the GSR responses and the subject's awareness of the inducing stimuli. Thus, there is a fairly direct correspondence between the GSR itself and the event which caused its arousal. In most general terms, then, the GSR is a means for quantifying those conscious experiences which arouse tension. For the purposes of the present study this was ideal, for it allowed a reliable relation of the emotional response to the traffic event which generated it. It may be seen, then, that the present study was an attempt to explore the use of the galvanic skin response as a means for specifying the causes of and for quantifying tension responses aroused in driving.

PROCEDURE

Two urban arterial routes (Fig. 1) were used in this study. One, Wisconsin Avenue, was a major arterial to and from the downtown Washington area. The other ran roughly parallel and functioned as an alternate. Both were 4½ miles in length. The characteristics of each were quite dissimilar. Wisconsin Ave. served a considerable number of traffic and land use functions that were not found on the alternate. Detailed description of the characteristics of this primary street may be found in a report by Berman and Carter (5). The alternate route ran primarily through a residential area. It had almost no commercial traffic and transit use was over only a small portion of its length. In addition the street width varied from 4- to 2-lane over the 4½ mi. There was also considerable variation in both grade and curvature over this distance.

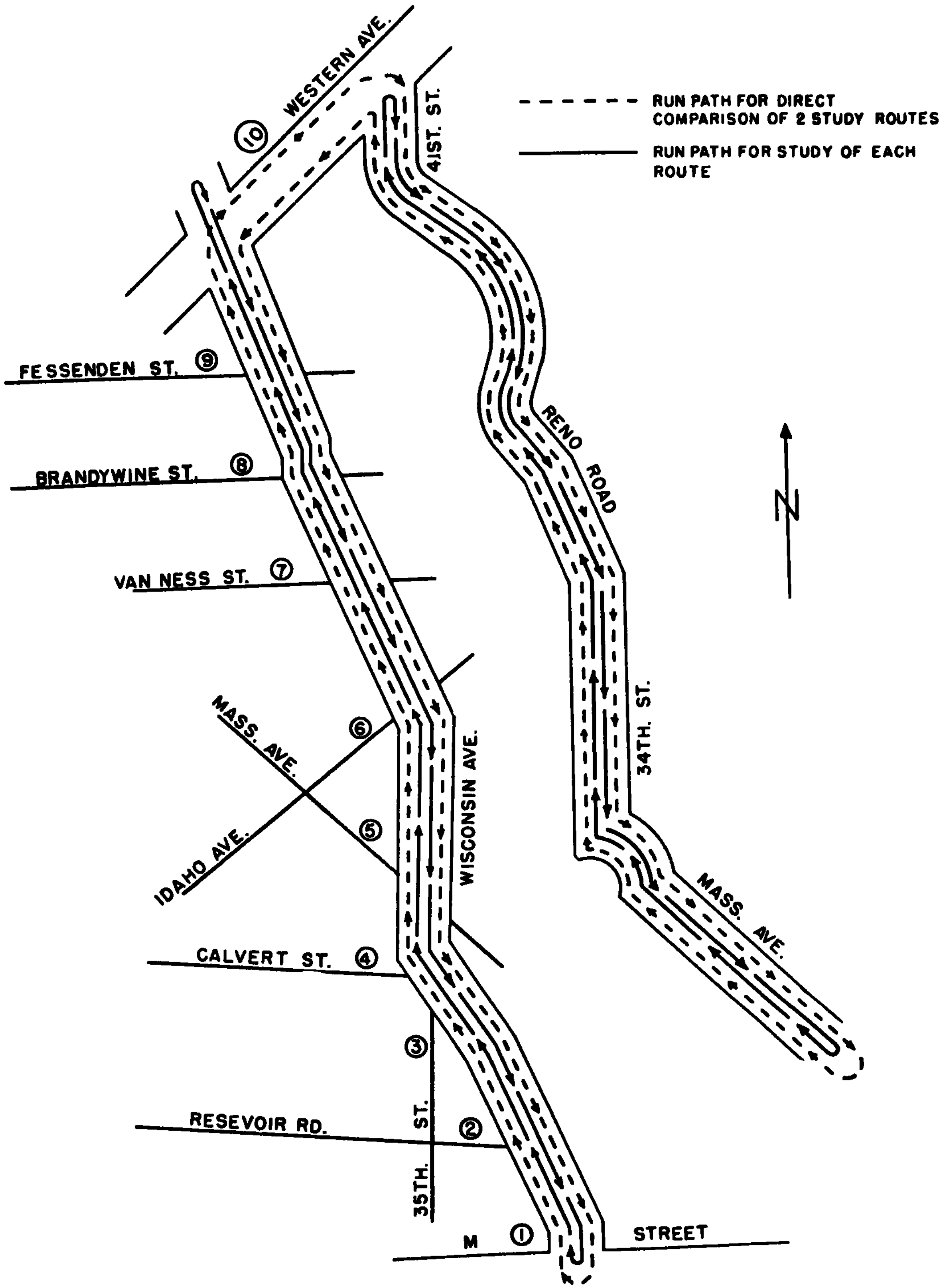

Figure 1. Study route locations and run paths.

In order to relate GSR responses to driving on the study routes, it was necessary to develop a list of traffic interferences. Thus, in addition to the physiological measure of tension, it was necessary to specify the causes of these responses. This required establishing some criterion of what constituted an interference with driving. Since the concern of the research was to relate street and traffic characteristics to driving behavior, it was decided that only those events that forced the driver to change either his speed or lateral location would be considered. This criterion implies that any change forced upon the driver will be potentially tension inducing. An additional restriction imposed was that only the most direct cause of these changes would be classified as the inducing traffic event. Thus, for example, the driver might be in a stream of traffic which is forced to stop for a traffic signal. If the test vehicle were not the first to approach the signal, then the event which caused his change in speed was considered to be the vehicle in front of him rather than the traffic signal. Although such a distinction was arbitrary it served two purposes: (a) it reflected what the test driver directly responded to, even though he might have been aware of other events that were actually involved; and (b) such a distinction greatly increased the reliability of observation.

This rationale oversimplifies the driving situation, for there is no question that the driver is aware of events considerably farther ahead than a car length. In addition, this system is limited in its ability to specify the multiple and fast-changing situations. However, it was felt that reliability of observation was far more important than detailed specification of traffic interferences. From these considerations, Table 1 was developed. These broad categories were determined in part by the nature of the street. Thus, on Wisconsin Ave., streetcar loading platforms were obvious interferences and were specifically included. On the alternate, however, this was replaced by a medial friction event. In addition to being based on the actual nature of the study routes, these events were also predicted upon certain friction concepts of traffic flow. As may be seen, Table 1 is a compromise between the general case of four frictions and the more specific individual conflicts that occur in traffic.

TABLE 1

OBSERVED TRAFFIC EVENTS

Code Number	Description
1	Parking maneuvers
2	Marginal pedestrians
3	In-stream moving
4	Transit loading platforms
5	Pedestrians in street
6	Turning vehicles
7	Merging and crossing vehicles
8	Traffic signals

For the conduct of the experiment, a regular government vehicle with automatic transmission was used. Study teams consisted of a driver, an observer, and a data recorder. The observer served as the team leader during the experiment. It was the task of the observer to specify when an event occurred and which of the eight traffic events caused a change in vehicle operation. These were reported to the third man who was seated in the rear seat of the vehicle. He in turn coded this information on the GSR recorder. Thus, the observer had no knowledge of the driver's responses.

Members of the study team were all in the junior engineer program of the Bureau of Public Roads. All were between the ages of 21 and 30 and had at least two years of driving experience. The drivers were instructed to travel the route by floating with the traffic wherever possible. With these instructions, the general pattern of driving was quite consistent among the test drivers. Although there were some differences noted among them these were generally quite minor and ordinarily very subtle.

To begin a run, electrodes were placed on the first and third fingers of the left hand of the subject driver. Although a variety of electrode placements were tried, these two fingers gave the most sensitive GSR, and were mechanically the simplest to place. In addition, this placement allowed the drivers to handle their vehicles normally. After placement, a normal resting level for skin resistance was determined. The recorder used contained a feedback circuit for balancing out drift in the base level. Thus, in these experiments only deviations from an arbitrary zero level were measured.

Sensitivity level of the recorder was adjusted empirically for each driver at the beginning of the run. Usually a startle stimulus was employed and the sensitivity raised until the full scale of deflection was obtained. For all the subjects the required sensitivity range was quite narrow. Once the sensitivity level was determined, it was not changed during the run. Such procedure does not, of course, eliminate individual differences among the subjects. It does, however, help to reduce the variability within a subject from run to run.

In the experiments in which the aim was to detect differences between the two streets the runs were conducted during the offpeak hours. Five drivers and two observers were employed. The runs followed the dotted path shown in Figure 1. During this study period four complete cycles were obtained for each test subject.

For the other phase of the study each route was studied individually. Five different subjects were used on each route. Runs were made during five periods of a work day: a.m. peak; a.m. offpeak; p.m. offpeak; p.m. peak; and night. During the peak hours three complete cycles of the route were obtained while during the offpeak there were two. All subjects drove all conditions at least twice. The design was such that every driver was observed by each of the two observers an equal number of times.

In either phase of the experiments the run was conducted approximately as follows. At the beginning of the run the time was noted and the drivers floated with the traffic from one end of the route to the other. The observer reported to the recorder any changes meeting the criteria and what events caused the change. At the end of the run there was a ten minute rest during which time the base level of skin resistance was again determined. Usually there was a slight increase from beginning to end especially on the first run. After the rest period, the driver proceeded in the opposite direction to complete the full cycle.

Observers were instructed to report events as quickly as possible to the recorder in order to minimize the errors in locating occurrences in time on the GSR record. A sample record of the GSR responses is shown in Figure 2. A notation was generally placed simultaneously with or slightly preceding the GSR response. Whenever an

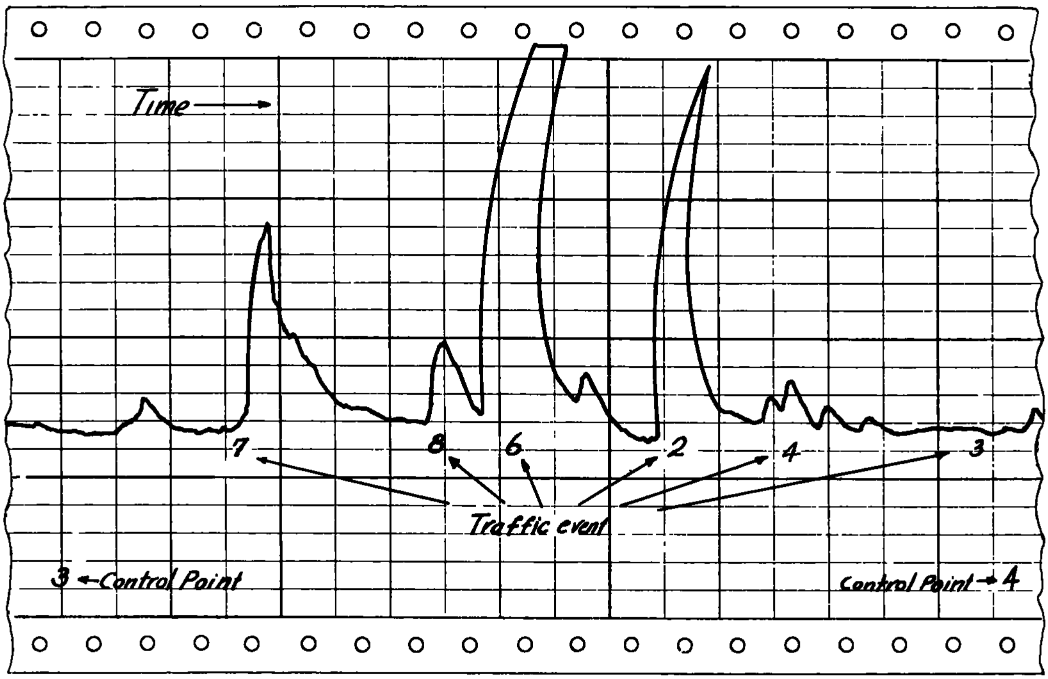

Figure 2. Sample of GSR record.

observation preceded a response by more than 5 sec, the two were considered unrelated. Similarly, an observation that followed a response by more than 1 sec was considered unrelated to the response. Both these criteria, and the latter especially, were predicated upon the assumption that the lag in the GSR response was longer than for the verbal response. In practice, uncertainty of association of observation and response occurred in no more than 5 percent of the cases.

As may be seen from Figure 2, some responses are not associated with traffic events such as the small peak before the first event (7). The GSR is sensitive to a variety of events, internal as well as external, so that this type of response is fairly common. Since only traffic related responses were of interest, these were not included for analysis. Also, the GSR does not occur every time there is a traffic event as exemplified in the case of the last event (3). These were included in the analysis. It was found that approximately 15 percent of the traffic events observed aroused no response on the part of the subject.

RESULTS

The data were tabulated for each subject for each run and each route. They were broken down by the observed events and the magnitude of GSR response associated with each event. In addition, the travel time for each trip was recorded. It was possible from these data to determine the average magnitude of GSR response for each event, and with the time measures to determine both the rate at which events occurred and the magnitude of responses that occurred in time.

The meaning of the magnitude of the GSR response needs some explanation. The recorder actually measures the GSR in units of log conductance. Basically, this unit is employed because the magnitude of change in skin resistance is more nearly linearly related to the magnitude of the inducing stimulus when resistance is measured in log conductance (6). Thus, in this study each successive division on the recorder chart represented equal increments of GSR. However, the absolute values of these divisions were not known, for these depended upon the setting of the sensitivity scale. With the method of calibration used, the values for each scale division were essentially relative to the base level. They are consequently, unitless, and may be termed "reaction units."

Table 2 gives the data for the two routes obtained from the same drivers. The data contain the frequency of occurrence of events and the average magnitude per event. All the subjects have been combined. There were considerably more traffic events occurring on Wisconsin Ave. than on the alternate route. However, the average magnitude of GSR response was approximately the same for both routes.

TABLE 2

COMPARISON OF TENSION RESPONSES ON ALTERNATE AND WISCONSIN AVENUE CONTINUOUS RUNS DURING OFFPEAK PERIODS

Item	Alternate	Wisconsin
Total events	237	445
Average magnitude	2.23	2.28
Events per minute	1.71	2.42
Magnitude response per minute	3.81	5.52

The difference in the total number of events (Table 2) in part reflects the difference in travel time for the two routes. In order better to equate the streets, a rate figure was computed and is shown as the events per minute. Here the differences between the two routes are reduced somewhat. Nevertheless, there were still 30 percent fewer responses per unit time on the alternate than on Wisconsin Ave. Thus, on Wisconsin Ave. there was a traffic event once every 24.7 sec while on the alternate there was an event every 34.9 sec. Since 85 percent of the events aroused the GSR, there was, consequently, a tension inducing event every 29.2 sec on Wisconsin Ave. and 41.4 sec. on the alternate route. Therefore, it is quite evident from these data that drivers on the alternate route faced considerably fewer interferences with driving than on Wisconsin Ave.

These results reflect only the frequency of occurrence of events and do not directly relate to the magnitude of the GSR responses. The average magnitude of response alone is inadequate since it does not reflect the differences in travel time for the two routes. One simple measure of the GSR is the total magnitude of response that occurs per unit of driving time. This measure cumulates all the GSRs independently of events and equates the routes on the basis of time. This ratio is, therefore, a statistic reflecting the behavioral response of the driver per unit time and under the assumptions of this study was considered as a measure of induced tension. This measure for the two routes is also shown in the last row of Table 2. Again, the alternate route is considerably less tension inducing than Wisconsin Ave.

The data (Table 2) were the result of pooling all the subjects. In order to test for differences among subjects as well as to determine whether there was a statistically significant difference between the two routes, the data were analyzed using the analysis of variance. Table 3 is the summary table of that analysis. Both the two routes and the four subjects differed significantly at better than the 0.01 level. It would seem reasonable to conclude that the alternate route induced significantly less tension in drivers than did Wisconsin Ave. In addition, the pooling of the different subjects ap-

TABLE 3

SUMMARY OF ANALYSIS OF VARIANCE OF MAGNITUDE OF GSR PER MINUTE FOR STUDY ROUTES

Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Routes	19.57	1	19.57	11.51[1]
Drivers	302.05	3	100.68	59.22[1]
Rtes. x drvs.	22.89	3	7.63	4.48[2]
Within	16.95	10	1.70	-
Total	361.46	17	-	-

[1]Significant at the 0.01 level.
[2]Significant at the 0.05 level.

pears to be unwarranted. This is especially relevant to the GSR data shown in Table 2 where it appears that the average magnitude of the GSR is the same for the two routes. Actually, the average magnitude shows considerable variation among the subjects and the differences between the routes varies over a range of nearly two-to-one. Thus, the averages shown are quite misleading and, consequently, the combined GSR data must be interpreted cautiously.

In addition to the study of the two routes made simultaneously, studies of each route were conducted independently. Five subjects were used on Wisconsin Ave. and five different subjects were used on the alternate route. Also there were a total of three different observers employed in these two studies. One of the three acted as observer on both routes while the other two ran either Wisconsin Ave. or the alternate route.

WISCONSIN AVENUE DATA

Tabulating the occurrence of the traffic events, there was a total of 7,800 events observed over the 2-week period. These were distributed among the eight events as given in Table 4. The most frequently occurring event was instream friction (event 3). The remainder form a small portion of the total individually. Ranking the eight events in order of average magnitude of response which each generated leads to column 5 (Table 4). In addition, a separate analysis was carried out for the subjects. Individually a rank test was applied to these rankings of the events by average GSR.

TABLE 4

FREQUENCY OF OCCURRENCE AND MAGNITUDE OF GSR RESPONSES EVOKED BY TRAFFIC EVENTS ON WISCONSIN AVE.

Event	Frequency of Event	Percent of Total	Avg. Magnitude	Rank by Avg. Magnitude
1. Parking	724	9.2	2.47	6
2. Marg. ped.	330	4.2	1.51	8
3. Moving veh.	4,682	59.7	2.49	5
4. Load. plat.	633	8.0	2.20	7
5. Instream ped.	372	4.7	2.76	4
6. Turning	400	5.1	3.34	1
7. Cross. and merg.	285	3.6	3.15	2
8. Traffic contr.	416	5.3	2.94	3
Total	7,842	99.8	2.53	-

It was found that the ordering among the subjects was statistically reliable, and was the same as that shown.

Data collected during the different run periods were combined by direction. It was found that there was considerable variation among the runs much of which depended upon changes in the composition of the traffic during those periods. Table 5 gives the

TABLE 5

EFFECTS OF TIME PERIOD AND DIRECTION ON AVERAGE MAGNITUDE OF GSR RESPONSE

Event	Northbound		Diff.	Southbound		Diff.
	Offpeak	Peak	P-OP	Offpeak	Peak	P-OP
1	2.59	2.37	-0.22	2.25	2.87	+0.62
2	1.10	1.57	+0.47	1.88	1.98	+0.10
3	2.51	2.47	-0.04	2.36	2.64	+0.38
4	2.09	1.45	-0.64	2.27	3.15	+0.88
5	2.63	3.32	+0.69	2.29	2.80	+0.51
6	3.64	2.86	-0.78	3.37	3.49	+0.12
7	2.97	3.13	+0.16	2.50	3.96	+1.46
8	3.11	3.67	+0.56	2.25	2.65	+0.40
Total	2.50	2.52	+0.02	2.36	2.77	+0.41

average magnitude of response and the changes from offpeak to peak that occurred in each direction. The positive sign indicates that the response induced by that particular event increased during the peak hours, whereas the negative sign shows that it decreased. Over-all, the average magnitude per event was the same for both the northbound and southbound directions of Wisconsin Avenue. For the northbound direction there was no difference in average magnitude between offpeak and peak runs. In general, the data obtained in the northbound direction were more stable than that obtained southbound. Consequently, the differences between peak and offpeak are most clearly seen for that data. The greatest changes during the peak hours appear to be the increase in the average tension induced by instream pedestrians (event no. 5). This is consistent with the increase in mass transit use during the peak hours and, consequently, the high density of pedestrians at loading platforms during those hours. Major decreases occurred in the turning movements out of the stream of traffic (event no. 6). This, in part, reflects a reduction in the allowable turning movements during peak hours.

The data from the southbound runs are far less clear-cut. The average tension response for all events rises from the offpeak to peak period. The greatest increase occurred in the rise in merging and crossing conflicts. Interpretation of these differences in the southbound direction can only be limited due to the wide variability of the data obtained in this direction.

The data for night runs appear to follow the pattern for the peak hours during the day. Again, the most clear-cut differences are in the northbound direction. The only major change at night appears to lie in a large increase in response to marginal pedestrians. This is consistent with the large increase in pedestrians during the night shopping hours and also restriction in marginal visibility over much of the street.

Wisconsin Avenue was divided into nine control sections of approximately equal length. The ten control points (for these nine sections) were marked on the recorder chart so that it was possible to relate the events to their location on the street. Table 6 gives the average magnitude of tension response for each section both by direction and time of day. In addition, Figures 3 and 4 show a plot of the tension response by section on the street. Generally there was considerable variability in the data within a section, and the differences among sections were on the average not too great. There was no significant order of difficulty found among the sections for the five test drivers. Thus, there was no indication that there were fixed features in any of the sections which consistently influenced driving behavior.

Figure 3 shows that the differences between peak and offpeak were quite small for all but the section between control point 3 and 4. Whereas during the offpeak hours this section gave the maximum average tension response, during the peak hours it yielded the lowest average tension response. In order to test for the significance of this difference a "t" test of matched pairs was employed. Thus, the difference between each subject's tension responses during peak and offpeak was compared. It was found that the decrease from offpeak to peak was significant at better than the 0.05 level. It seems reasonable, therefore, that a real change in traffic characteristics took place in this section. This is a section of a fairly intense commercial development and also an area where the

TABLE 6

AVERAGE MAGNITUDE OF GSR RESPONSES IN DIFFERENT SECTIONS OF WISCONSIN AVE. BY DIRECTION AND TIME PERIOD

Section	Northbound		Difference	Southbound		Difference	Difference NB-SB	
	Offpeak	Peak	OP-P	Offpeak	Peak	OP-P	Offpeak	Peak
1-2	3.04	3.18	-0.14	2.34	2.34	0.00	+0.70	+0.84
2-3	2.50	2.58	-0.08	2.36	2.99	-0.63	+0.14	-0.41
3-4	3.58	1.95	+1.63	2.47	2.86	-0.39	+1.11	-1.91
4-5	2.50	3.18	-0.68	2.18	2.78	-0.60	+0.32	+0.40
5-6	2.56	2.55	+0.01	2.37	3.15	-0.78	+0.19	-0.60
6-7	2.05	2.57	-0.52	2.71	2.89	-0.18	-0.66	-0.32
7-8	2.78	2.90	-0.12	2.82	3.07	-0.25	-0.04	-0.17
8-9	2.28	2.25	+0.03	2.66	2.76	-0.10	-0.38	-0.51
9-10	2.23	2.20	+0.03	2.48	3.06	-0.58	-0.25	-0.86

street is relatively narrow. During the offpeak hours there is a high degree of marginal activity relating to the commercial area. The additional factor of the narrowing street reduces maneuver-ability and poses a severe restriction on the driver's freedom to make lateral avoidance movements. During peak hours, parking regulations, high traffic volume, and signal progression all help to minimize turbulence in the traffic flow. Thus, in this region the driver was faced with an extensive amount of marginal friction during the offpeak hours much of which was eliminated during the peak hours.

In the southbound direction there were no clear-cut differences between either time

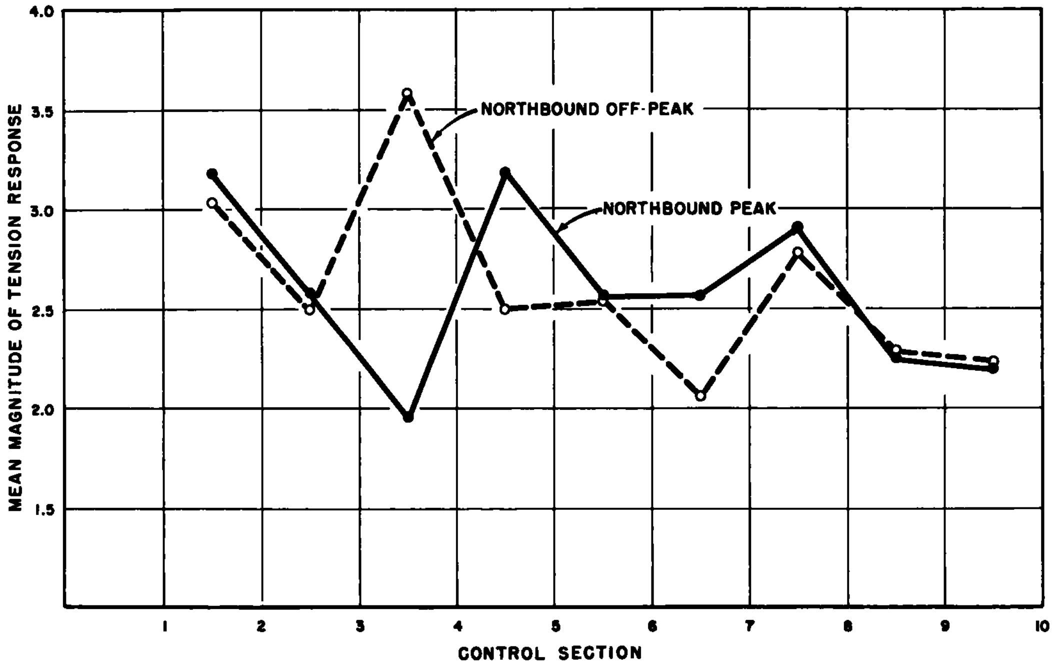

Figure 3. Average GSR by control section—northbound.

period or section. There does appear to be a peak in section lying between points 7 and 8, at least during the offpeak hours (Fig. 4). This region is a highly developed commercial area, so that there was considerable marginal activity complicated by turning movements onto and from radials entering the circle. The peak hours, besides showing a general rise in tension responses, do not appear to indicate any differences among the control sections. There is considerable variability in the data so that little can be said about these differences.

The final analysis of the Wisconsin Ave. data involved the determination of a relative frequency of events in time and the total tension response in time (Table 7). These data include all the runs for each of the subjects separated only by direction. These pooled data show that for all the subjects there are somewhat fewer events per minute northbound than southbound. This result indicates that driving northbound, the driver is faced with a traffic event every 25.0 sec while southbound he is so faced every 21.3 sec, or a tension inducing event every 29.4 sec and 25.2 sec, respectively. In terms of the over-all measure of tension, the differences between the two directions are on the whole quite small. There is little evidence to indicate that the two directions were different. The subjects also reported that there were no differences between directions.

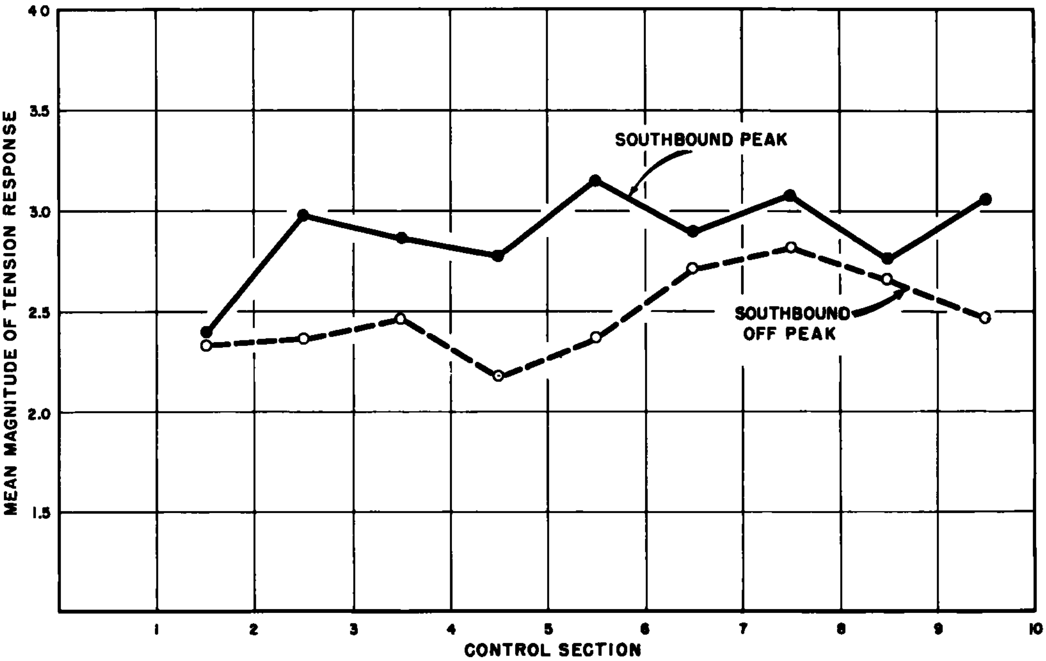

Figure 4. Average GSR by control section—southbound.

ALTERNATE ROUTE

In this phase of the study the alternate route was examined along the same dimensions as was Wisconsin Ave. A different group of driver subjects were employed and one new observer. This alternate route was a complex street itself. There was great variation in road width over the 4½ mi length, and it varied considerably in grade. Unlike Wisconsin Ave., it had no streetcars but did have bus service over part of its length. In addition, and in direct contrast, it had no commercial development. It was almost wholly residential area and the residences were, for the most part, single unit dwellings. Finally, almost all the traffic was passenger cars, again, in contrast to Wisconsin Ave. in which commercial vehicles made up a considerable portion of the traffic.

The methodology followed on the alternate route was the same as that used on Wisconsin Ave. The one change in the list of traffic events was the elimination of event No. 4 (loading platforms). Since this was irrelevant on this route, it was replaced by "opposing vehicles." This event was added because the route was two to three lanes

TABLE 7

FREQUENCY AND MAGNITUDE OF RESPONSES IN TIME

Driver	Events per Minute		Difference Northbound / Southbound	Magnitude of Response Per Minute		Northbound / Southbound
	Northbound	Southbound		Northbound	Southbound	
A	2.4	2.9	+0.5	7.30	7.60	0.96
B	2.1	2.5	+0.4	6.59	8.30	0.79
C	2.7	3.1	+0.4	6.91	6.60	1.05
D	2.6	2.7	+0.1	4.11	3.81	1.08
E	2.3	2.7	+0.4	6.90	9.40	0.73
Total	2.4	2.8	+0.4	6.29	7.23	0.87

over much of its length. Consequently, there were many possibilities for the opposing traffic stream to come into conflict with the test vehicle.

TABLE 8

FREQUENCY OF OCCURRENCE AND MAGNITUDE OF GSR RESPONSES EVOKED BY TRAFFIC EVENTS ON ALTERNATE ROUTE

Event	Frequency of Events	Percent of All Events		Avg. Magnitude	
		Alternate	Wisconsin[1]	Rank	Obs.
1. Parking	70	5.3	9.2	8	1.30
2. Marginal ped.	9	0.6	4.2	7	1.56
3. Moving veh.	863	65.6	59.7	5	1.77
4. Opposing veh.	50	3.8	8.0[2]	2	2.14
5. Instream ped.	17	1.7	4.7	6	1.71
6. Turning	70	5.3	5.1	4	1.79
7. Cross. and merg.	93	7.0	3.6	1	2.58
8. Traffic contr.	142	10.8	5.3	3	1.97
Total	1,314	100.1	99.8	-	1.84

[1]Data from Table 4.
[2]On Wisconsin Ave., Event No. 4 was loading platforms.

All the data on the alternate route were combined according to the eight different events (Table 8). More than 1,300 events were observed during the study period. As on Wisconsin Ave., the most frequently occurring traffic event was that induced by other vehicles in the traffic stream. The remainder of events accounted for a small proportion of the total individually. Table 8 gives a comparison of the distribution of events for the two routes. Since the total number of observed events for all but the moving vehicles is rather small, direct comparisons are probably unwarranted. It may be noted, however, that these moving vehicle events constituted a 6 percent greater part of the total on the alternate route than on Wisconsin Ave. Making the arbitrary assumption of homogeneity a "t" test of the differences between these two proportions was carried out. A "t" of 4.21 was obtained which was significant at the 0.01 level. This would appear to indicate that the tension inducing characteristics of the alternate route seems to include a lesser proportion of peripheral events than that found on Wisconsin Avenue. Thus, most traffic conflicts on the alternate route appear to be somewhat more directly related to instream traffic activity.

The ranking of the events according to the average magnitude of response is also shown in Table 8. The most inducing situation is the one of crossing and merging traffic (event no. 7). Event No. 4, which is medial friction, is second highest in average magnitude of response. In general, the order of intensity of tension induction for each of the events is similar to that found on Wisconsin Ave.

In order to examine the tension responses as a function of time the data were combined and are shown for the different time periods in Table 9. The a.m. offpeak runs are not included in this tabulation because they were all carried out in conjunction with runs on Wisconsin Ave.

The over-all frequency of occurrence of traffic events was 1.79 per min of approximately one every 33 sec with a minimum during the morning peak hours of 1.45 events per min or one every 41½ sec. The maximum was during the p.m. offpeak when there were 2.65 events per min or one every 23 sec. The total magnitude of tension per minute is shown in the last column of Table 9. The maximum tension response per minute appears to have occurred during the offpeak hours, being almost twice as great as for the peak hours. Also, tension responses per minute for the night runs fall intermediate between the other two time periods. It should be pointed out once again,

TABLE 9

FREQUENCY AND MAGNITUDE OF RESPONSE ON ALTERNATE ROUTE BY TIME PERIOD

Time Period	Number of Events	Average Magnitude	Events Per Minute	Magnitude of Response Per Minute
AM peak	292	1.68	1.45	2.44
PM peak	363	1.41	1.86	2.62
PM offpeak	122	1.98	2.65	5.25
Night	346	2.21	1.89	4.18
Total	1,123	1.79	1.79	3.20

however, that these differences were obtained by pooling data from subjects who were dissimilar in their tension responses. They should, consequently, be interpreted carefully.

CONCLUSIONS

As was pointed out previously, the purpose of this study was to explore the possibility of using the GSR as a means for discriminating features of traffic and streets. The first goal was to detect differences between two streets serving approximately the same traffic function. The results of this study do indicate that the GSR reliably discriminates between these two arterial routes. The distinctions among different characteristics within a route are not as clear-cut. However, the results do indicate the complexity of decisions faced by drivers on an urban street. The variety of conflicts occurring on the street are sufficiently frequent and involved to place drivers under a fairly consistent level of stress.

One finding of particular interest was the significant ordering of the different traffic events in terms of the average magnitude of GSR. The events inducing the highest average tension on both routes were the conflicts occurring with vehicles entering or leaving the traffic stream and, on the alternate route, the opposing vehicles. These are events in which the rate of change of location of the conflicting vehicles is a maximum. These are situations that require the driver to solve a complex set of differential equations in order to predict a course of action. With the human's limited accuracy in speed estimation and angular closing rate, and the limited time for such decision, these situations have a high degree of unpredictability for the driver and may reasonably be most threatening.

The two events which rank next in order are the traffic signals and instream pedestrians. Both of these may be considered as "instream uncertainty." In the present study the driver was influenced by traffic signals only when there were no other vehicles interposed between him and the signal. There was, then, a fairly high probability that the driver arrived at a signal at the point where it had just changed or was in the process of changing. This would appear to be a particularly indeterminate situation for the driver. The effect of instream pedestrians is quite similar. The driver has no way to predict the action of a pedestrian. Any conflict will arise strictly by action of the pedestrian. Both of these events probably represent a straight risk type decision operation, and the observed magnitude of tension response may well reflect the degree of uncertainty in each situation.

A third pair of events which appear to go together are the moving vehicle events and parking. These may be considered "instream interferences." In the first case the relative differences in velocity between the test vehicle and other vehicles in the stream is relatively small. Consequently there is adequate time for compensation for any changes in the characteristics of the ongoing traffic stream. Parking maneuvers were generally found to be quite conspicuous so that the test driver was able to adapt his speed or location relatively smoothly and simply. Both appear to be relatively predictable actions for which the driver can adequately compensate, and for which there is adequate time for decision making.

The last two events may be termed "fixed objects," and include marginal pedestrians and the streetcar loading platforms. For all practical cases observed, conflict between pedestrian and vehicle occurred when the pedestrian was standing or just beginning to move into the street. At this point it seems reasonable to consider this as a fixed obstacle situation. In general, it appeared in both of these situations that the driver had more or less complete control over his actions. Thus, these events may be conceived as simply choice points, and the responses were a reflection of the driver's having made a choice rather than a reflection of tension or stress.

One general implication of these results is consistent with current knowledge of the GSR. It is that the more highly unpredictable the situation the more dynamically does the driver respond. The unique thing in the present study is the fact that there appears to be a very high level of unpredictability in driving on urban streets. The data indicate that two to three times a minute an event occurs which forces the driver to take some compensatory action. Furthermore, the more complex the demands made on him by the traffic situation the greater is the tension aroused by the situation.

These results indicate that the driving environment generates a tension response in inverse relationship to the predictability of the conflicts. The significant rank ordering probably demonstrates those situations which are hardest for the driver to predict and thus to compensate for. In addition to the element of predictability may be added the complexity of the driving environment. In the only section where there was a significant difference in time period, the change in average GSR came when the complexity of the traffic situation was reduced. In addition, the differences between the two routes in terms of their percentage of marginal interferences also indicate a difference in complexity between the two routes. Thus on Wisconsin Ave. over 40 percent of all the observed events arose from interferences occurring along the margins of the street. This would indicate that the driver is faced with a highly complex field of very broad area. In such a situation the driver is forced to attend to a wide range of stimuli. He must sort, select, and then operate on this heavy load of information. With this excessive information load, his ability to select and predict is inherently restricted, one consequence of which is an increased level of stress and a greater responsiveness to events arising in the field.

Finally, the data indicate the high rate of decision making with which the driver is faced on an urban street. Where the driver must respond to a fixed object such as a streetcar loading platform, for example, the average response is relatively low. This is a situation where the driver can usually make a decision on his own terms in his own time. However, in the case of merging vehicles, the situation forces the driver to make decisions both very rapidly and with a minimum amount of information, much of which he cannot handle accurately or efficiently. Under these circumstances the driver must depend upon other drivers to make consistent responses. In complex traffic then, the individual driver is often forced to give up a certain amount of control to others in the environment. A fundamental question is: How does this delegation affect traffic operations and capacity? It would seem reasonable that the driver will compensate for this loss of control by any means that will serve to reduce his uncertainty. He can, for example, increase the headway between himself and the vehicle ahead, or he can reduce his speed. These, as well as other devices, can reduce the capacity of the street, and cause turbulence in traffic flow.

As was pointed out, the essential aim of this study was exploratory in nature. The purpose was to examine the utility of the GSR as a measure of driver behavior. These preliminary results do indicate that the GSR is promising. There are, however, many questions relating to the GSR which have not been covered in this study. One thing that should be examined far more intensively is the reliability of the response (6). It is well-known, for example, that there is a rather consistent adaptation of the GSR (8, pp. 150-152) so that the same stimulus intensity may not arouse the same magnitude of GSR on repetition. This is in part compensated by the calibration procedure used in the present experiments, and the fact that no event occurred twice in the same way.

Nevertheless, the changes occurring during a run were not examined in detail. In addition, some very simple assumptions have been made about the relation of the responses to the situation that aroused the GSR. The problem is essentially one of determining what the GSR means in a traffic situation. It is an oversimplification to assume, as was done in this study, that the GSR is aroused only by the occurrence of a traffic event. The GSR is sensitive to a wide variety of behavioral responses (9) whose relationships may be only indirectly related to the traffic event. There is little doubt, for example, that the GSR accompanies preparatory muscular activity or muscular response itself (8, pp. 157-158). Although this does not eliminate the relationship between the GSR and the traffic event, it does indicate that the relationship between the two may be quite indirect.

Another problem is the statistical nature of the GSR. In the present study the magnitude of response was a positively skewed distribution. The range of conductance was from zero to some maximum value. Such distributions pose some difficult problems of statistical analysis. Thus, in this study, the use of the arithmetic mean and the usual statistical tests of inference are in question. It may be seen, therefore, that there are many questions relating to the statistical nature of the data which were not answered in the present study.

There are, in addition, certain methodological problems of specifying and interpreting the traffic events. For the purposes of this study all the traffic events were treated as discrete. It is obvious, however, that conflicts in traffic are not discrete but develop continuously in time. Thus, the schedule of observation arbitrarily collapses what is a complex and continuous behavioral response to a single point in time. There is no way of knowing from the present study whether the observed GSR response occurred at the approach to a conflict, the conflict itself, or the point in time where a decision was made. It is conceivable that any or all of these processes could evoke a GSR.

Not only did the observation program eliminate temporal differences, it also eliminated intensity differences within each event class. It was assumed that all occurrences of any event represented the same stimulus intensity. In essence, this procedure eliminates within stimulus class variability. It is quite apparent that the affective intensity of an event may be quite variable depending upon a variety of temporal and spatial factors in the environment as well as perceptual and emotional factors in the driver. It should be obvious, therefore, that the present situation grossly oversimplifies the nature of the traffic interferences and simply places them into one of eight qualitative categories none of which have any measure of intensity attached to them. Thus, precision of stimulus measurement was sacrificed to obtain reliability of observation.

Within the limitations outlined, this study indicates that the two streets studied do differ in the rate and magnitude of galvanic skin response aroused in driving. The results, in general, indicate that the GSR may be a promising means for using driver behavior for discriminating between different kinds of streets and the interferences on them. There are, however, several statistical and methodological problems inherent in the use of the GSR which restrict its operational utility at the present time.

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