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An Experimental Study of Destination Entry with an Example Automobile Navigation System

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ABSTRACT

An over-the-road study of driver destination entry using an example in-dash GPS-based navigation system was accomplished in traffic on urban surface streets and freeways. The evaluation used typical drivers, and a vehicle instrumented to record driver control inputs, vehicle response motions including lateral lane position, and driver eye glances and fixations. The primary task was to follow the routes in a safe manner, while moving with traffic and maintaining speed and lateral lane position. As a secondary task, the drivers entered the successive destinations while driving, using a touch screen, and at their own pace. They were told there was no hurry, nor was there a need to enter the destination quickly. Results are shown for number of keystrokes, total fixation times, number of fixations on the device, fixation duration, lane keeping performance, and subjective ratings related to ease of destination entry. Overall, the drivers were able to accomplish the destination entry tasks with acceptably short glance durations on the navigation display, and with satisfactory subjective ratings for ease of entry.

INTRODUCTION

For many years drivers have operated devices in the vehicle, such as radios, heating and air conditioning, and other auxiliary controls. These activities comprise secondary tasks, in addition to the primary task of steering the vehicle along the prescribed path at the desired speed. Historical accident data and anecdotal evidence suggests that drivers have been able to adapt to these additional attentional workloads without effecting primary task performance unduly.

More recently, new in-vehicle devices have been introduced including such things as cellular telephones, more complex entertainment systems, navigation systems, and other devices aimed at assisting the driver in the driving task. While these devices are all useful in one or more important ways, they raise the issue of possible driver distraction and whether the secondary workload can become sufficiently high that it begins to affect primary task performance. To compound matters, additional novel and innovative in-vehicle devices are expected to be introduced in the near future.

As a response to these developments, possible standards to provide guidelines for vehicle designers and operators in this regard are being discussed, a notable example being the recently proposed SAE Recommended Practice for navigation system destination entry accessibility (Ref 1). Several studies and literature reviews have been accomplished that relate to this work. A study reported by Tijerina, et al, (Ref 2) purports to be the first published data on route guidance system destination entry while driving (in their case, on a test track). While the results of several over-the-road studies involving route following have been reported, to our knowledge little or nothing has been published on destination entry under over-the-road conditions in traffic. Nevertheless, there are extensive human factors data and principles which bear on the issue, and which have been used, and are being used, in the vehicle and component design and R & D process to ensure suitable device and vehicle characteristics. In view of this activity, it was of interest to observe and measure the use by typical drivers in over-the-road conditions of an example contemporary navigation system with regards to destination entry.

EXPERIMENTAL SETUP

The driver subjects entered destinations using the touchscreen display of a navigation system while driving an instrumented vehicle on city streets and on an urban freeway. The destination entry keystrokes and associated eye movements were videotaped and later reduced to obtain keystroke timing, eye fixations, entry errors, and other data.

Ten driver subjects participated in the evaluation, as summarized in Table 1. Nine of the drivers were novice users of the navigation system and 1 subject had used it previously. The driver sample included 5 males and 5 females, 5 of whom were engineers. Their average age was 33, and their average mileage per year was 13,400.

Table 1. Driver Subject Characteristics

Occupation	Gender	Age
Engineer	M	26
Administrator	F	29
Engineer	M	29
Bookkeeper	F	30
Engineer	M	30
Clerical	F	31
Engineer	M	34
Draftsperson	M	34
Administrator	F	43
Engineer	F	44

The evaluation vehicle was a 2000 Acura 3.2 RL equipped with the Acura Navigation System. The navigation display was located relatively high in the center console of the instrument panel, above the position of the radio, as shown in Fig 1. All drivers were able to reach the display, comfortably, from their normal seating position and posture. For this study, the touchscreen was used as the entry means, and destinations could be entered entirely in this manner. However, some error-correction required the use of the CANCEL button to the left of the screen, which was pressed when it was necessary to go back one screen. The destination address was displayed on a card fixed to the steering hub.

Figure 1. Driver's View of Instrument Panel

The vehicle instrumentation consisted of video cameras and recording, and driver control and vehicle response sensors. Two small cameras were mounted on the side mirrors and angled down to view the roadway lane markers, and record lateral lane position. A mini camera was mounted on top of the dashboard, above the navigation display, pointed towards the face of the subject to record eye movements. A fourth camera was mounted between the driver and passenger seats, pointing down at the navigation unit to view driver actions and destination inputs. The camera outputs were combined by a quad splitter, a timer overlay was superimposed, and the final video image was displayed on a monitor and recorded on a VCR. Sensors were mounted in the vehicle to measure speed, steer angle, and yaw rate. The data were recorded using a digital data acquisition system in a laptop computer located in the rear seat. All equipment in the vehicle was powered from the vehicle battery using an inverter located in the trunk.

PROCEDURE FOR DESTINATION ENTRY

All destinations were entered using the "By Address, Street First" method. This meant that the full address of a destination was entered, with the street name entered first. Therefore, "Address" was selected from the first screen and "Street" from the second screen, as shown in Fig 2.

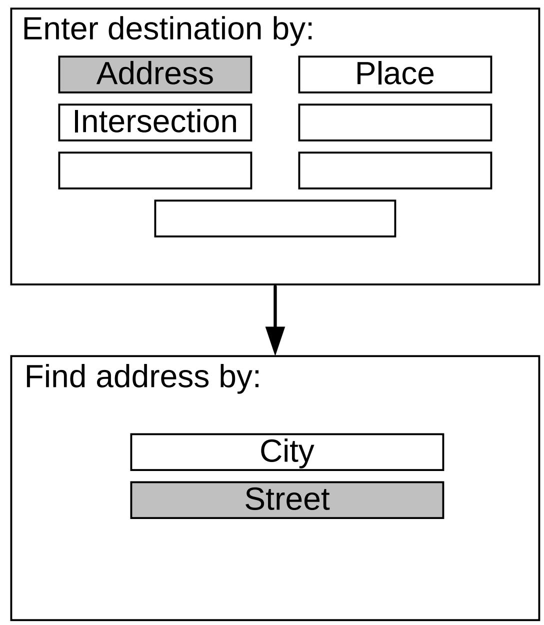

Figure 2. Destination Entry Sequence

The next step was to enter the name of the street, shown in Fig 3. This involved entering letters from an alphabetical keypad layout until the screen automatically switched to a list of streets. Then, the street was selected from the list.

Figure 4 shows the screen for entering the numerical address. The numbers are arranged in a conventional telephone configuration. Once the address was completely entered, a "Done" button was pressed.

Following numerical address entry, the city was selected from a list of possibilities, as shown in Fig 5. A maximum of 4 cities was shown on the screen.

The final step was to confirm the entry, as shown in Fig 6. This final screen showed the address entered. The driver pressed an "OK" button to confirm the entry and complete the destination entry task. The combination of a street entry, an address entry, a city selection, and a confirmation entry comprised a destination entry.

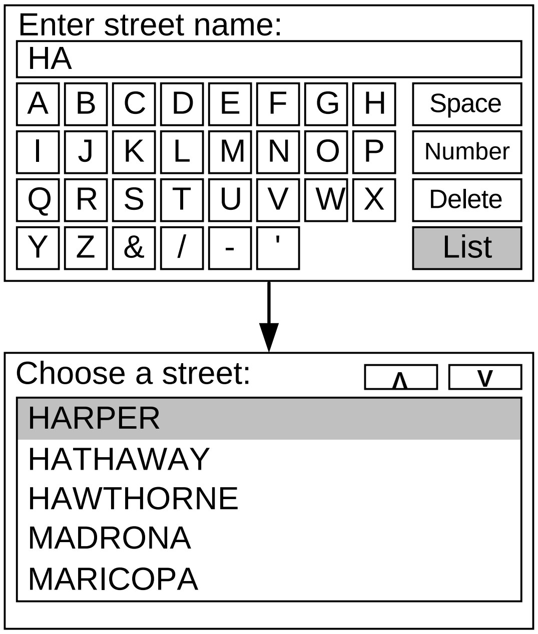

Figure 3. Example Street Entry

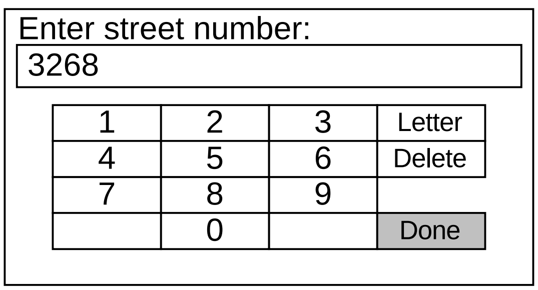

Figure 4. Example Numerical Address Entry

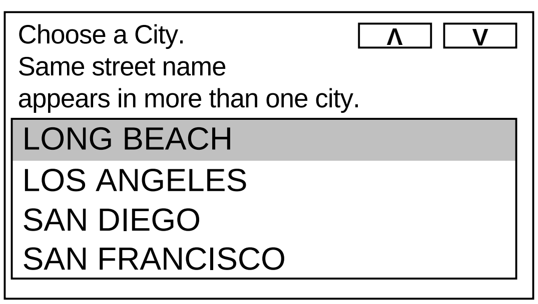

Figure 5. Example City Selection

The destinations used for the practice trials and the evaluation trials represented an average level of difficulty for the task. The entry method described above was considered to be a common and representative form with this navigation system. The street first entry method was selected as more straightforward than entering the address by city first. The street names were chosen

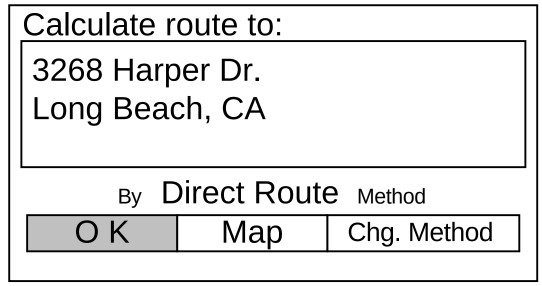

Figure 6. Example Confirmation Entry

based on the number of letters that had to be entered. They were selected such that an average of 5 letters was entered to reach the street list, with an effective range of 4 to 6 letters. The numerical addresses were chosen to be 4 digits in length, which was felt to be typical. Within a given address, a particular digit only appeared once.

For the city selection, the location of the destination city was consistent within the practice and evaluation trials. On practice trials, the destination city was always on the first screen of the list (4 per screen). On evaluation trials, the destination city was always the top entry on the list. In general, the destination cities and addresses were not on the study driving route, but were in nearby cities and locations in the greater Los Angeles area. The overall study route is shown in Fig 7. It consisted of city streets and freeways in the Torrance, California area. The 2 city streets routes (Vermont and Normandie) were 1.1 miles long, connected by streets approximately 0.5 miles long. Both streets were 2 lanes in each direction, and the subjects drove in the left lane at 35 mph (56 km/h). The urban freeway sections were 6 miles in length, and the subjects looped back to the original entry point. The freeways were 4 lanes in each direction, and subjects drove in the second lane from the right at 65 mph (105 km/h) or with traffic. The route was driven on weekdays either in the morning (9:30 - 11:30 am), or in the afternoon (1:30 - 3:30 pm). In general, the 2 sessions had similar traffic conditions. No sessions were scheduled on Friday afternoon because traffic was typically heavier at that time. The evaluations took place only in good weather and on dry roads.

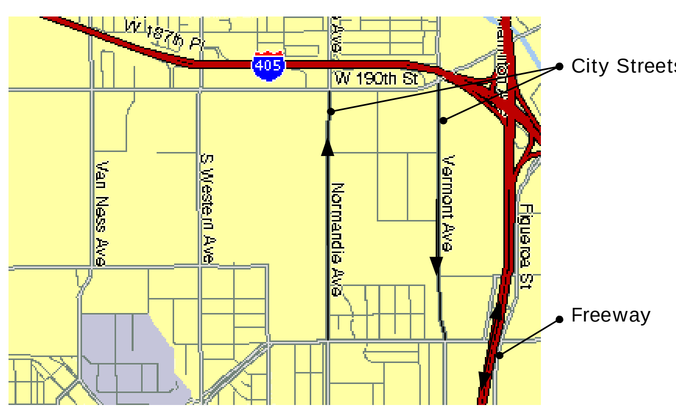

Figure 7. Study Routes

EXPERIMENTAL PROCEDURE

The subjects began by reviewing the navigation system user's manual, and receiving introductory instructions. Then subjects sat in the driver's seat and adjusted it. The experimenter in the passenger seat explained the use of the navigation system. The drivers were told that their primary task was to maintain the vehicle speed, maintain a safe following distance, and keep the vehicle in the lane. The destination entry task was described as less important, and the drivers were told that there was no hurry and that they did not have to enter the destinations quickly. As noted above, the destinations were not immediately ahead on the driving study route. If a driver did not feel comfortable or safe at any time during a destination entry sequence, that run was aborted, which rarely occurred.

The drivers first did 3 practice trials with the vehicle parked. Most subjects were generally familiar with the area. After driving the study route loop one time, subjects were given 2 practice destinations to enter while driving, one on each stretch of road. The practice trial destinations were different from the evaluation trials, but were entered in the manner described above. Subjects could ask questions during the practice trials. The same practice trials were used for each subject, and they were always shown in the same order.

After the practice trials, the subjects did 3 evaluation trials on the city streets, with one trial on a given road section. In order to eliminate possible ordering effects, 2 groups were used. Group A entered the evaluation destinations in the order 1-2-3, while Group B entered the destinations in the order 3-2-1. After completing the 3 trials on the city streets, the driver stopped the vehicle and filled out a subjective rating form. Then the subjects were directed to the freeway. They first drove the freeways to become familiar with the route. On the second loop, the subjects entered the evaluation destinations. After completing the 3 evaluation trials and exiting the freeway, they filled out another subjective rating form. Subjects were then directed back to the starting point. The entire procedure took approximately 2 hours for one subject to complete.

RESULTS

The data comprised the videos, and the driver and vehicle response and performance measures. Four images were shown on the video: the navigation system display and controls, the face and eyes of the subject, and lane position at the left and right front wheels. Data reduction from the videos for each destination entry included the start and end times for each entry step, the number of keystrokes, the number of fixations or "chunks," and the number of keystroke errors. Eye movement data consisted primarily of the individual fixation times on each of several "targets" within the driver's field of view, and the percentage of total fixation times on those targets. The following definitions adapted from Ref 3 are used with the eye movement data:

- Target - the forward road scene, the navigation system display, or other.
- Fixation time - the duration of a fixation at 1 target. It does not include the transition time to or from the target.
- Glance duration - fixation time plus the transition to the target.
- Total fixation time - the sum of the individual fixation times on 1 target for a destination entry.
- Total entry time - the elapsed time between when a driver first looks away from the road until he or she finally looks back after the last fixation for 1 destination entry.
- Transition - a change in eye fixation location from 1 target to another.
- Entry chunk - 1 or more entry keystrokes, or other entry actions, made during one fixation on the display. Attention to the navigation display was only considered to be a chunk if some entry or other action was made.
- Time off road scene - the total time between 2 successive fixations on the road scene which are separated by fixations on non road targets, including all transitions between targets.

Table 2 summarizes the average entry times on city streets and on the freeway for each destination over all subjects. The mean total entry time over all subjects was 34.2 sec, and individual averages ranged from 27 to 49 sec. There was very little overall difference between entries made on city streets and those on the freeway, differing by 0.2 sec. Six of the 10 subjects had a lower mean total entry time on city streets. On city streets, the 3 destinations had very similar average entry times. The only noticeable difference was a higher standard deviation for the destination 3 entry, and this was due to one subject having an unusually long entry time for that case. On the freeway, there was more variation between the destinations, with greater differences between mean total entry times and wider ranges for the minimum and maximum values.

Table 2. Summary of Mean Total Entry Times (sec)

Route	Entry Destination	Total Entry Time	Standard Deviation
City Streets	1	34.4	5.4
	2	34.8	5.7
	3	33.7	7.6
Urban Freeway	1	31.8	7.7
	2	36.7	7.9
	3	33.8	10.9

An analysis of variance was performed to check for statistical differences in the Table 2 entry times between the destinations, and there were no significant differences at the 95% confidence level.

An overall average of 17.3 keystrokes was necessary to enter the destinations (17.1 on city streets, 17.4 on freeway). This ranged from 15 to 25 with 15 keystrokes being the necessary minimum. All occurrences of more than 15 keystrokes were the result of errors or mispresses. As would be expected, the total entry time generally increased when the number of keystrokes increased, and this is shown in Figs 8 and 9, where each data point represents one destination entry for one driver. The figures show a linear regression fit to the data which arbitrarily assumes linear behavior for fewer than 15 keystrokes.

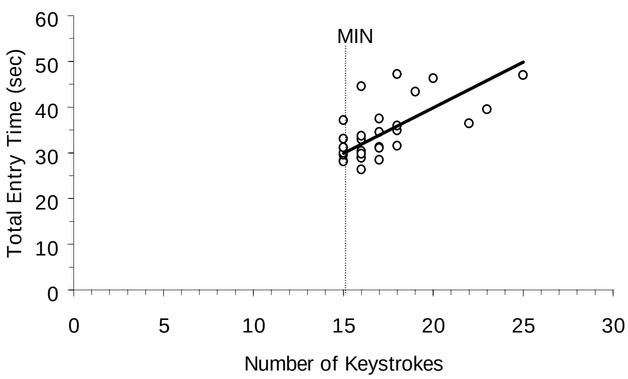

Figure 8. Total Entry Time Compared to Keystrokes on City Streets

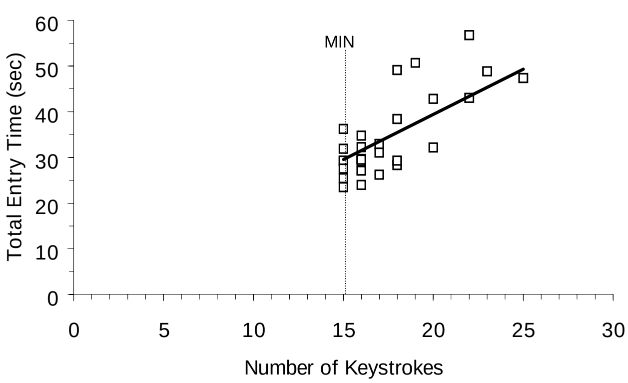

Figure 9. Total Entry Time Compared to Keystrokes on Freeway

One entry chunk involved one fixation on the display, and this consisted of 1 or more keystrokes, errors, or mispresses. Chunks were determined from the eye movements, and the number of keystrokes in a particular chunk was also recorded. Figures 10 and 11 show the total entry times as a function of the number of chunks on city streets and the freeway. Again, each data point represents one driver and one destination entry. To enter all 15 keystrokes, an overall average of 13.5 chunks was necessary (13.1 on city streets, 13.9 on the freeway), with an overall range of 10 to 21 chunks. When no errors or mispresses occurred during a trial, an overall average of 11.7 chunks was used, ranging from 10 to 13 chunks. So, drivers would sometimes accomplish more than one keystroke in a chunk.

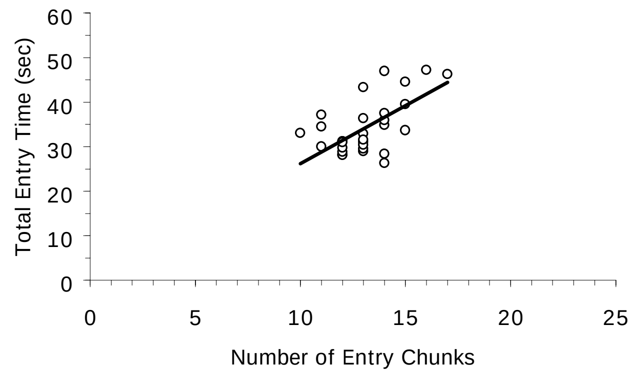

Figure 10. Total Entry Time related to Entry Chunks on City Streets

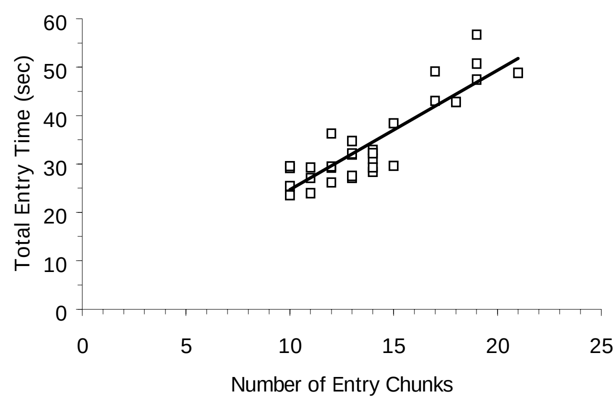

Figure 11. Total Entry Time related to Entry Chunks on Freeway Streets

The eye fixations during the destination entry trials were analyzed. There were a total of 799 individual display fixations over all trials and subjects. Table 3 and Figs 12 and 13 summarize the average total time spent by each subject with the eyes fixated on the forward road scene, the navigation display, and other for city streets. "Other" was defined as any fixation time other than the road scene or the navigation display, for example, looking at the side view mirror; plus all of the transition times between fixations. The total fixation time on all 3 parts of the visual field shown here is approximately the same as the total entry time. The difference is that the latter did not include the initial fixation time on the navigation display prior to the first keystroke, nor the remaining fixation time after the last keystroke. During the destination entry tasks on city streets, Table 3 shows that the display was fixated about 55% of the time, while the road scene and other targets were fixated about 45% of the time.

Table 3. Summary of Fixation Percentages on City Streets and Freeways

Subject ID	Fixation Percentages					
	Road Scene		Navigation Display		Other	
	City Streets	Freeway	City Streets	Freeway	City Streets	Freeway
1	23	24	53	56	24	20
2	22	20	60	59	18	21
3	24	27	54	50	22	23
4	14	17	60	64	26	19
5	22	27	63	55	15	18
6	20	24	53	43	27	33
7	16	26	69	57	15	17
8	27	29	53	50	21	21
9	19	20	55	52	26	27
10	38	37	32	33	30	31
Mean	23	25	55	52	22	23

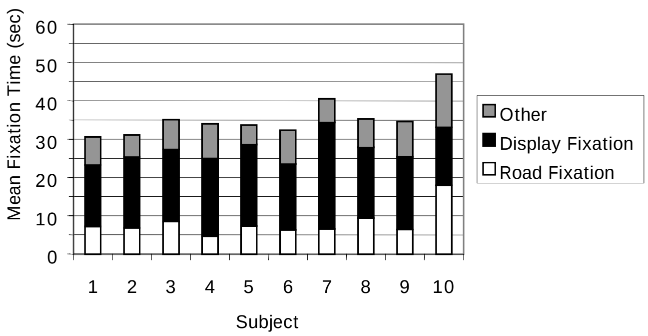

Figure 12. Total Fixation Times on City Streets (Mean of 3 Entries)

During the destination entry tasks on the freeways, Table 3 and Fig 13 show that the display was fixated about 52% of the time, while the road scene and other targets were fixated about 48% of the time. In general, the percentage of time the driver spent looking at the road scene during data entry was a little greater on the freeway than on city streets.

The number of keystrokes entered during a single display fixation was related to the duration of the fixation on the display, as shown in Figs 14 and 15. There were occasional fixations on the display that did not involve a keystroke, and those are not included in these figures. As the number of keystrokes made during a fixation increased, the display fixation time generally increased for both city streets and the freeway, as would be expected. Overall, display fixation times increased by about 0.6 sec for each additional keystroke entered, for both city streets and the freeway.

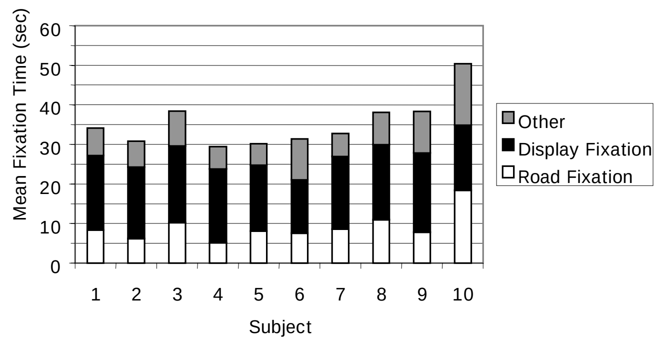

Figure 13. Total Fixation Times On Freeway (Mean Of 3 Entries)

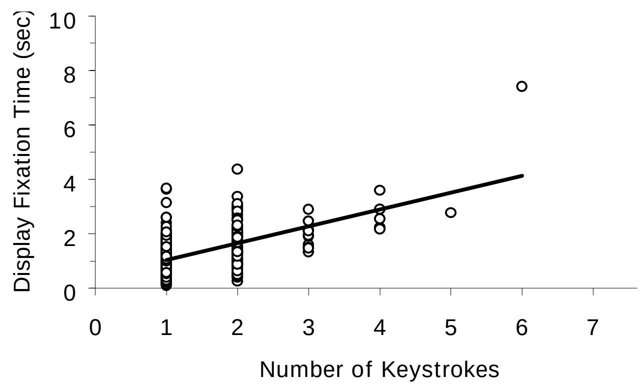

Figure 14. The Relationship of Display Fixation Times and Keystrokes on City Streets

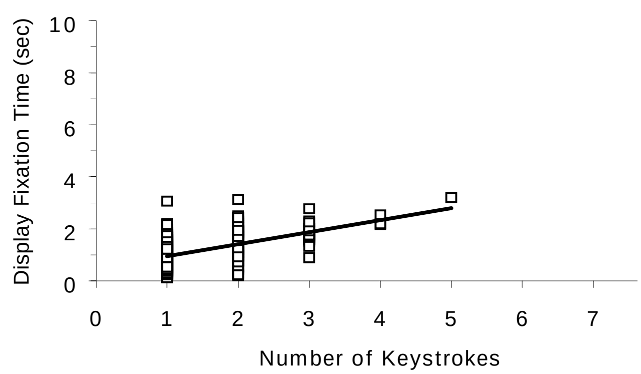

Figure 15. The Relationship of Display Fixation Times and Keystrokes on Freeways

Since most of the chunks (95%) involved either 1 or 2 keystrokes, Figs 16 and 17 show distributions of the display fixation times in those cases for city streets and freeways combined. The average display fixation time was 1.0 sec when 1 keystroke was entered in a chunk, and about 1.5 sec when 2 keystrokes were entered. Also, 94% of all the display fixations in the cases of 1 or 2 keystrokes were less than 2.0 sec. Combining the results for 1 and 2 keystrokes gives the distribution in Fig 18.

Figures 16-18 show fixation times. As defined above, the transition time to the display would need to be added to the fixation time to obtain glance duration. Glance duration is probably the measure of interest when considering possible occlusion methods for evaluating the suitability of navigation displays, such as have been discussed in connection with the Draft SAE Recommended Practice of Ref 1.

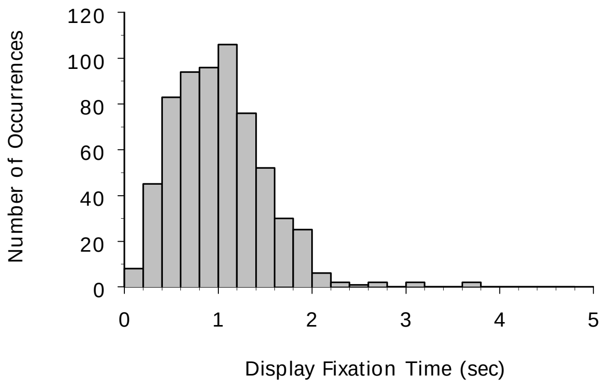

Figure 16. Display Fixation Times for 1 Keystroke Entered

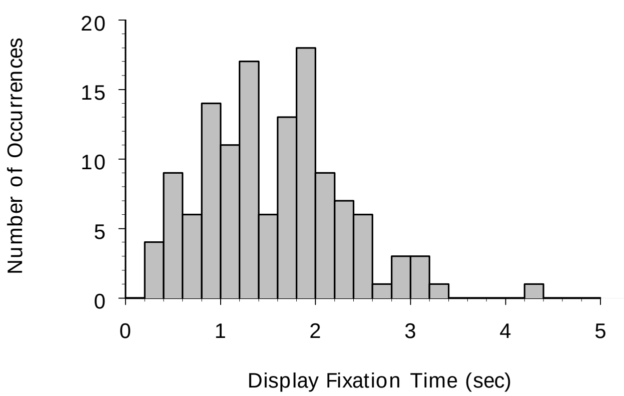

Figure 17. Display Fixation Times for 2 Keystrokes Entered

Figure 19 shows the distribution of the road scene fixation times across all of the subjects for city streets and freeways combined. During the destination entries, the road was fixated for an average of 0.47 sec each time, with 95% of the fixations being less than 1.2 sec. Figure 20 shows the distribution of transition times across all subjects for all transitions (among road scene, display, and other). They averaged 0.15 sec, with 95% of the transitions being below 0.25 sec.

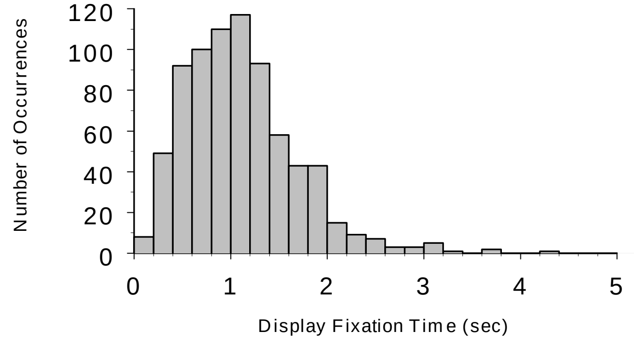

Figure 18. Display Fixation Times for 1 and 2 Keystrokes Entered

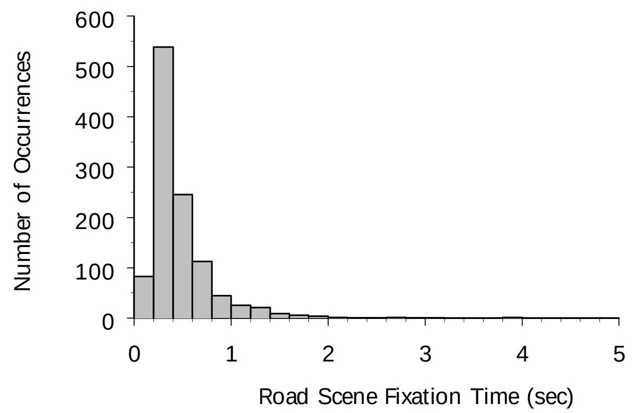

Figure 19. Distribution of Road Scene Fixation Times

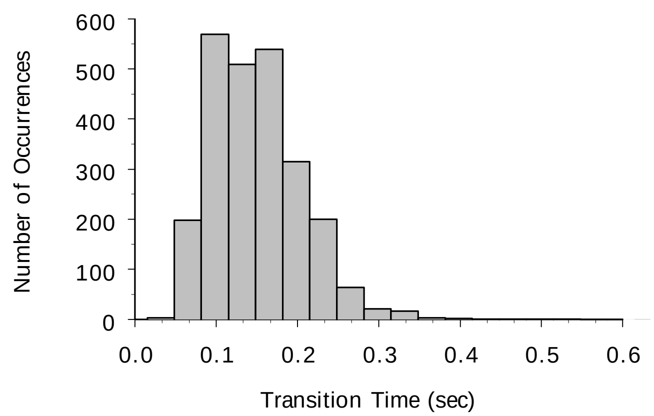

Figure 20. Distribution of All Transition Times

The total entry time for a trial was somewhat related to the average display fixation time within that trial. This relationship is shown for city streets and the freeway in Figs 21 and 22. The only fixations that were included were those where keystroke entries (including errors and mispresses) were made. An approximate inverse relationship was evident for trials on the freeway, but there was little trend for trials on city streets.

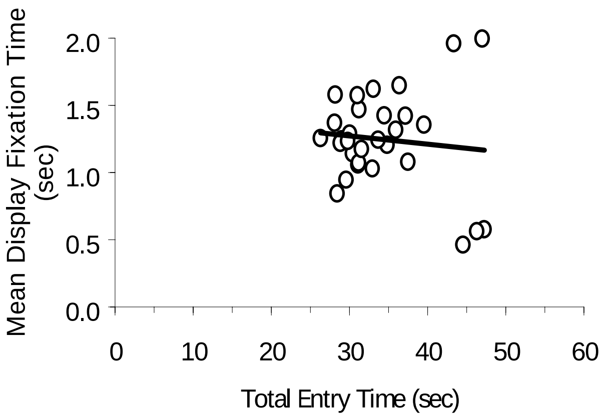

Figure 21. Mean Display Fixation Time Compared to Total Entry Time on City Streets

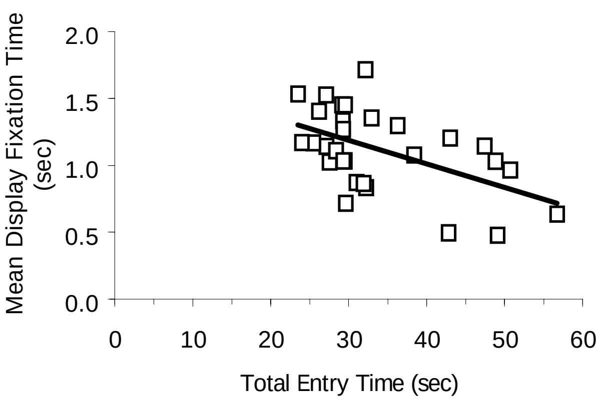

Figure 22. Mean Display Fixation Time Compared to Total Entry Time on Freeways

Table 4 summarizes the number of destination entry errors that were made by each subject. Recall that almost all the subjects were novice users. Somewhat more errors occurred on city streets than on the freeway. This may reflect a practice effect, since the city street trials always preceded the freeway trials. Slightly more errors occurred during street entry (13) than during numerical address entry (11), with only 4 errors occurring in other portions of the entry process. In most instances, the errors added 2 additional keystrokes (one to correct the error and one to re-enter correctly). However, 8 of the errors occurred without the subject being aware (such as entering an incorrect digit on address entry), and therefore did not add any additional keystrokes. Nine of the 10 subjects made at least one error within their 6 total entry efforts. The error cases added about 2 sec to the overall average entry time.

During all the destination entry trials, a total of 4 lane exceedances occurred as recorded by the video cameras, and these are summarized in Table 5. A lane exceedance was defined as the outer edge of the tire going beyond the lane edge marker stripe. These exceedances occurred while the subject was looking at the navigation display, or immediately following a fixation on the display. Two of the 4 lane exceedances occurred on city streets with the subject crossing the left lane-marker. Figure 23 shows a summary of the time off road scene that corresponded to each lane exceedance. The lane exceedances occurred more often when the time off road scene exceeded about 3 sec. By comparison, over all subjects, 1 exceedance occurred on the freeway during the combination of baseline runs (no destination entry) and the periods when no entry task was being accomplished (a total of about 10 minutes per subject or 100 minutes overall). Overall, the number of exceedances observed was trivial, and they were statistically rare events, given the total driving time.

Table 4. Summary of Destination Entry Errors

Subject ID	Number of Errors		
	City Streets	Freeway	Total
1	1	1	2
2	0	0	0
3	4	0	4
4	2	1	3
5	3	0	3
6	1	3	4
7	6	0	6
8	0	1	1
9	1	3	4
10	0	1	1
Total	18	10	28

Table 5. Total Lane Exceedances

Direction	City Streets	Freeway	Total
Left	2	0	2
Right	1	1	2
Total	3	1	4

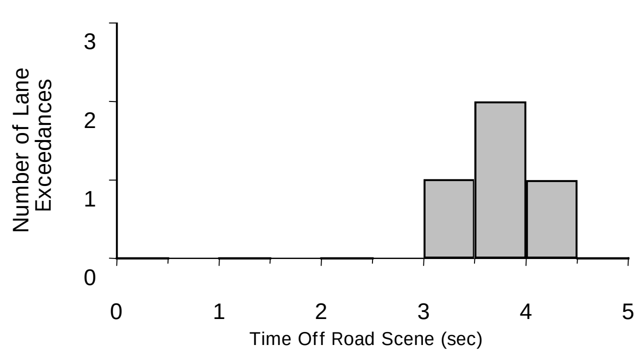

Figure 23. Lane Exceedances vs. Time off Road Scene

Vehicle speeds were recorded during the destination entry trials and baseline runs. The subjects were instructed to drive at a comfortable, constant speed without exceeding the speed limit. On city streets, the average vehicle speed was 37 mph, slightly above the speed limit of 35 mph, with an overall speed range of about ± 4 mph. The average baseline (no entry) vehicle speeds on city streets were similar. The average vehicle speed of 57 mph on the freeway was below the speed limit of 65 mph, having a range of about ± 5 mph. The baseline (no entry) vehicle speed on the freeway was higher than during the destination entry trials, by an average of about 3 mph, but the average baseline speed was also under the speed limit. The extent to which freeway traffic may have influenced the average speeds was not analyzed.

Learning effects were examined across all destination entries for both groups of subjects. Recall that the 2 groups of subjects entered the same destinations, but in opposite order. The total entry times in Fig 24 show that the mean entry time for Group B was 18% longer than for Group A with more variability between subjects in Group B. Within Group A, there was no clear learning effect either within the road type or across all entries. Group B did display a slight downward trend in entry times within each road type, however, only one subject within each road type followed this downward trend, indicating that there were no particular learning effects.

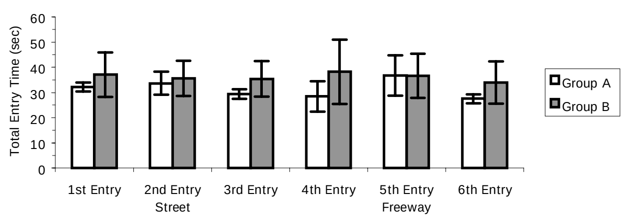

Figure 24. Assessment of Learning Effects

A 2 factor analysis of variance showed that there were no statistical differences between the subject groups or differences due to the order in which the destinations were presented. For both road types, any differences observed between the two subject groups can be attributed to differences between the subjects, but not to the order in which the destinations were entered.

Each subject completed several rating forms after the 3 trials on the city streets, and another set after the 3 trials on the freeway. Figure 25 shows the ratings for Ease of Street Name Entry. Overall, this was rated between Easy and Moderately Easy for both city streets and the freeway. The ratings on city streets had somewhat less variability across all subjects, while ratings on the freeway were more scattered. Two subjects rated the Ease of Street Name Entry higher on city streets than they did on the freeway, while one subject rated it higher on the freeway. Figure 26 shows the ratings for Ease of Address Entry, which was rated Easy for both road types. Overall, the address was considered easier to input than the street name.

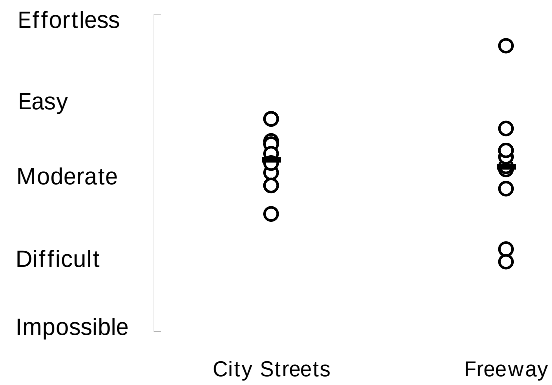

Figure 25. Ease of Street name Entry

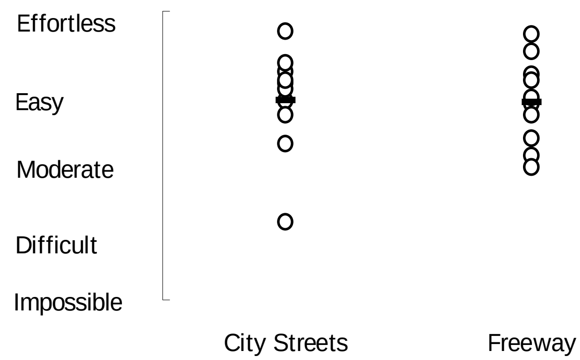

Figure 26. Ease of Address Entry

DISCUSSION

The average total entry time over all 10 subjects was about 34 sec. No individual subject had a total entry time for 1 destination of less than 25 sec on either city streets or the freeway. Examining only the street and address entry portions of the destination entry process, the average total time for 1 destination was about 23 sec, with no subjects less than 15 sec. While the several destinations had different streets and addresses, the differences due to these varying destination effects were small, and none were significant for either city streets or the freeway. Overall, the objective data and the subjective ratings indicated that the total entry times observed were acceptable to the driver subjects.

An average of 17.3 total keystrokes was made in the entry process. This compares to the minimum of 15 keystrokes needed to enter the destination. A total of 28 keystroke errors were made over the total of 60 runs.

This is quite small, considering that none of the drivers had extensive experience with this navigation system or the example vehicle.

Overall, on the average, 13.5 chunks were used to enter all 15 keystrokes of the destination entry process. This corresponds to some chunks and fixations involving more than 1 keystroke. Street entry had an average number of chunks that was greater than the minimum necessary number of keystrokes, a result of errors and mispresses while entering the street. When the errors and mispresses were removed, the average number of chunks remained close to the minimum necessary number of keystrokes, as 5 to 6 chunks were typically used for the street entry. This indicates that the majority of error-free street entries involved only one keystroke per chunk. Address entry had an average of 3.2 chunks overall, being only slightly lower when errors and mispresses were removed. For error-free address entry, the 5 necessary keystrokes were typically performed in 2 to 3 entry chunks, indicating that more than one keystroke was entered in many chunks. This was likely the result of having fewer keys to search than in street entry, and also having a more familiar key layout.

The average fixation duration involving 1 keystroke was 1.0 sec. The average fixation involving 2 keystrokes was 1.5 sec. For display fixations where 1 or 2 keystrokes were entered, 94% were below 2.0 sec. The average fixation duration overall was 1.2 sec. Correspondingly, the average number of keystrokes per fixation was 1.3 sec. Also, 95% of all transition times were below 0.25 sec. Transition time to the display can be added to the fixation time to obtain glance duration.

During the destination entry trials, the navigation display was typically fixated about half the time. Compared to city streets, more attention was given to the road scene when driving on the freeway. This was likely a result of more adjacent traffic while performing the entry tasks, higher speeds, and possibly a greater perceived risk.

Longer total entry times for 1 destination were typically associated with shorter average fixations on the display. This effect was apparent for entries made on the freeway, but less so for entries made on city streets.

A number of destination entry trials contained at least 1 error. These error trials added about 2 sec to the overall average entry time, which is small, given that average total entry times were more than 30 sec.

When a lane exceedance occurred it was most often associated with a time off the road scene greater than about 3 sec. Overall the number of lane exceedances was small, they occurred both when making destination entries and at other times, they were statistically rare events, and the lane keeping performance was deemed to be acceptable. The average vehicle speed on city streets was slightly higher than the speed limit, and the average vehicle speed on the freeway was somewhat below the speed limit. Subjects typically drove a little slower during the destination entry trials as compared to their baseline speed, but the data were not corrected for traffic and other workload variables.

The subjective ratings showed that the destination entry process was acceptably easy under actual driving conditions on both city streets and the freeway.

Recent test track results obtained by Tijerina, et al (Ref 2) provide an interesting comparison. Using an older Alpine system (similar to the Acura system used in this study except that the response time was much slower, the entry method was joystick rather than touch screen, and it did not have intelligent incremental key filtering to eliminate unnecessary alphanumeric character input) they found average trial times (to enter a POI destination) for the younger drivers of about 80 sec, and average mean glance durations over all drivers of about 2.5 sec. Note that their POI destination entry involved more driver actions (and hence glances) than the destination entries in this study (they measured an average of 33 glances to the Alpine unit for young and old drivers combined), which corresponds to the longer trial times. The mean glance duration to the road ahead was about 0.8 sec, compared to about 0.5 sec (about 0.65 sec including transition to) in this study, and the average eyes off road scene time as a fraction of the average trial time was about 0.75 (60 out of 80 sec), which is similar to the results in Table 3. So, the results of this study using a later model device under over-the-road conditions show shorter glance durations to the device, shorter total entry times, and a similar eyes off road time expressed as a fraction of the total time for 1 trial. Comparisons with their lane exceedance data may not be pertinent, because of differences in primary task instructions between the 2 studies. In Ref 4, which refers to the Ref 2 data, Tijerina suggests no single glance duration (to the device) greater than 2.5 sec as one approach to defining "what is reasonably safe."

Green presents an extensive review of driver eye glance data for a variety of driving tasks and activities in Ref 5. Overall, he concludes that the longest mean durations ranged from 1.2 to 1.85 sec, while they are predominately under 1.2 sec. He notes Rockwell's rule that "drivers are loath to go more than 2 sec without information from the road." Green concludes that the preliminary data show that "glance durations for most navigation-system-related tasks are not much longer than those for conventional tasks," and that for navigation tasks described in the literature 5 to 18 glances are required (a value which he characterizes as generally greater than would be associated with even the most difficult of existing tasks).

The results of a recent study in the Ford driving simulator (Refs 6 and 7) show average mean square glance times of about 1.4 sec^2 for the "SPELL" destination entry mode (corresponding to an average mean glance time of about 1.2 sec). The corresponding task duration (SPELL entry) was about 71 sec for the 45-55 age group, and the total glance time was about 38 sec. The eyes on the device fraction was about .54, which is similar to the values in Table 3.

The well known design guide of Zwahlen, et al (e.g., Ref 8) hypothesizes that no in-vehicle task should exceed 4 glances or require glances exceeding 2 sec. More specifically, for 15 sec runs at 40 mph on an airport runway, their data suggest that lateral lane position standard deviations reach unacceptable values after 2 to 4 sec of working with a CRT touch panel inside a vehicle. It should be noted that the 2 CRT entry tasks they used, tuning the radio and climate control, could each be accomplished in 2-4 glances or less, so they do not appear to have studied data entry conditions beyond the boundary which they hypothesized at the outset. The data from the present study show that more glances are used and rated acceptable by the driver in real world situations where there is no particular urgency to complete the destination entry task, and at the same time, most of the glances (92%) were less than 2 sec.

In the over-the-road data of Hada, et al, (ca 1994) reported by Green (Ref 5) the driver was told to look at 1 of 3 possible display locations in the vehicle "as long as you feel safe to do so." The results for glance durations are similar to the results in Fig 16 for 1 keystroke; with a log normal distribution, a median duration of .86 sec on the expressway, .79 sec on the urban street, and a 95 percentile upper bound of 2.2 sec. Their data also show that the subjects looked at the display approximately once every 3 sec on the average. Similar over-the-road results of Kimura, et al, also reported by Green (Ref 5), where the subjects "were able to gaze steadily without feeling uncomfortable," shows a 5 percentile point of 1.0 sec, a 50 percentile point of 2.0 sec, and an overall mode of 1.2 sec for glance durations. Note that the Hada data were obtained near Ann Arbor, MI, whereas the Kimura data are from Japan. Green suggests that the longer glance durations in the Kimura data are a result of the instructions to the subjects (e.g., not feeling safe vs. uncomfortable) rather than traffic or other cultural differences.

Overall, the results of this study show that drivers can make destination entries with a contemporary navigation system while operating in actual traffic conditions; with acceptable levels of secondary task loading, path performance, and subjective lack of difficulty. The glance durations and eyes off road time behavior used by the subjects were within previously suggested rules of thumb for safe operation, and total entry times of 30-40 sec were acceptable to the drivers when there was no need to enter the destination quickly. While future developments in such areas as voice activation may further simplify the driver's task or provide for the addition of other in-vehicle devices and information features, this study suggests that more conventional means of display and data entry can continue to be deployed and used until other possible techniques can be reduced to practice.

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