Time Sharing Between Compensatory Tracking And Search-and-Recognition Tasks

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This study deals with one aspect of driving behavior; i.e., the sharing of time between two types of activities that the driver is forced to accept as a part of the driving task. Steering and recognition behavior has been abstracted and explored in the laboratory by analyzing performance on a compensatory tracking task taken as an analogue of steering and on a filmed presentation of a sign search-and-recognition task. The relative effects of the interaction between tasks were explored. The main findings of the study were that (a) where time sharing was required, each type of performance was degraded; (b) increasing the number of message units appearing in the recognition task did not differentially affect simulated steering performance but did increase the time required for recognition of a key message; (c) increased speed of the simulated steering task displayed decreased recognition time of the discrete visual task; and (d) where a specific message had equal likelihood of appearing or not appearing, recognition time was greater when the key word did not appear. Results are discussed in terms of operator sampling behavior.

•CONTROL of lateral placement on the roadway is an intrinsic part of the task of driving which requires the human operator to maintain vehicular position within rather narrow bounds. In addition, the driver must search for, select, and process a variety of discrete informational indicators relevant to his ongoing and future psycho-motor and decision-making performances. These two tasks require two very different visual tasks which compete for the viewer's time and must in some way be sampled such that minimal variation in steering is achieved. How these two types of operator performance interact and the effects of their interaction on system performance are poorly understood. Yet, the efficiency and safety of the system depend on the proficiency of human processing of these concurrent informational inputs.

The experiment described here provides data relevant to the operator's sharing of time between a continuous control task, referred to as tracking, and the task of seeking out and detecting a critical aspect of a rather heterogeneous environment, referred to as search-and-recognition activity.

Previous investigators have considered each of these two aspects of operator performance, but have not examined the interaction processes. A more formal definition of both tracking and search-and-recognition behaviors, along with studies relevant to this inquiry, provides some basis for predicting the baseline conditions employed in this research.

One-Dimensional Tracking

Tracking has been assumed to be an analogue of the steering task and is therefore defined in this context (1); that is, as a paced task where an "externally driven input

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signal defines an index of desired performance and the operator activates the control system to maintain alignment of the output signal of the control system with the input signal. The discrepancy between the two signals is the error and the operator responds to null the error."

Compensatory tracking provides a signal of the error and requires only a reference and control mechanism. Such a situation is analogous to minimizing deviations from a prescribed path or roadway. Such a configuration may be displayed on the face of an oscilloscope. Use of a low frequency sinusoidal input provides a geometrically smooth input similar to roadway curvature. The information load appears to be a function of the increment magnitude that must be achieved within a relatively stable response period. As the frequency increases, the information load increases. Consequently, any time consumed in the evaluation of other portions of the environment would be expected to lead to more imperfect proficiency of guidance.

Subjects appear to be able to match input frequencies up to 3 or 4 cycles per second (cps) according to Ellson and Gray (10). McRuer and Krendel (14) give a value of about 1 cps. A specific control or display configuration may affect that motor response sufficiently to account for these differences.

In a field situation, amplitude has been shown to affect the operator's error-free performance of guidance. A study at the Ford Motor Company (13) indicated that on a test track with sine wave configurations, drivers reduced their speed to effectively track higher amplitude curves. This field study suggests that increments of angular change remain constant over a time span probably associated with the subject's response time.

Brown (7) has shown that many cases involving objects in motion may be considered to be perceived as a constant proportion of the velocity of angular change, suggesting that a single metric may suffice to predict tracking error for a particular control configuration.

Recognition Time

Recognition has been defined by Munn (15) as the ability "to differentiate between the familiar and the unfamiliar or what has been experienced and what is new." Recognition time may be defined as the delay between the onset of some information display and its overt discrimination by an observer. In the context of this research, search-and-recognition activities were measured. The distinction between simple recognition and the dynamic task discussed here is that the task is not localized. It is in motion and must be pursued at least briefly. It must indeed be searched for, pursued, recognized and finally reported by some overt act.

In the static state, discriminations of this type have been measured by obtaining measures of disjunctive reaction time. Considerable evidence supports the assumption that recognition time increases with task complexity. Classical reaction time experiments indicate that reaction time increases with the number of alternative responses (9, 16). In an unpublished study, performed at the U. S. Bureau of Public Roads, Desrosiers (8) found in a simulated situation that the mean recognition distance of a subject approaching a sign at a constant velocity varied inversely with the number of alternative messages on highway signs.

Task Sharing

Many studies have been conducted where information from separate discrete tasks is to be optimally organized and translated to control devices by the human operator (6). Most of these have involved the sharing of tasks between more than one sensory modality.

Briggs and Howell (5) have provided data on the interaction of two continuous tracking activities considering the effects of stimuli separation and speed. They have considered both peripheral and central aspects of the time-sharing process. Although more than one information source was to be attended during this study, three major differences existed between their study and the one reported here. First, both tasks required tracking perfomance which demanded forced pacing in an alternation pattern between the inputs by the operator unless he left unattended one of the two components of the time-sharing situation. Second, the spatial separation of displays was fixed for any one experimental condition, reducing search time and also the applicability of such a configuration to the situation in question; i.e., utilization of information sources which are themselves in motion, relative to the observer. Third, neither task required the discrete decoding of visual information implicit in recognition tasks. There are, however, certain requirements met by the study by Briggs and Howell which have pertinence to the situation of prime interest. These are discussed at a more appropriate point in this report. All studies reviewed indicated a generalized degradation of performance as task complexity increases.

The following statements concerning time-sharing performances formally present the major hypotheses subjected to test in this study.

1. The effect of a superimposed search task will increase the tracking error (degrade tracking performance) in proportion to the frequency and amplitude of the tracking signal (a sinusoidal function).

a. Tracking error will increase proportionally with the tracking frequency and amplitude.

b. Tracking error will increase proportionally with the number of words on the signs (complexity of the search-and-recognition task).

2. The speed and accuracy of the search-and-recognition task will be inversely proportional to the frequency and amplitude of the tracking task and to the increase in the complexity of search-and-recognition task.

a. Recognition time (measured as time from the sequence beginning) will be proportional to the frequency and amplitude of the tracking signal (a sine wave).

b. The proportion of false alarms in recognition will increase as the frequency and amplitude of the tracking signal are increased.

3. Tracking performance will be decremented equally when a specific message in the sign display is present or not present for signs bearing equal numbers of alternatives.

a. Tracking error will not be dependent on the presence of a specific message on the sign.

These hypotheses suggest monotonic changes and do not predict absolute magnitudes of error. They are intended to ascertain the relative effects of the concurrent operations that subjects were requested to perform.

Figure 1 presents the three-dimensonal matrix of conditions defining the range of variables composing the experiment. The matrix does not differentiate between experimental conditions providing the presence or absence of a specified message.

The separation of experimental and control conditions is also shown in Figure 1. Quantative predictions of tracking error are suggested by the frequency-amplitude product multiplied by a constant. No quantative predictions were made for search-and-recognition times.

The first hypothesis predicts increasing erroneous tracking performance related to an increasing frequency-amplitude product. The lower left-hand corner of the matrix reveals the lowest such product, hence predicts the smallest tracking error. The upper right-hand block displays the greatest tracking error. This trend is paralleled for each of the search-and-recognition conditions with a corresponding increase in the predicted tracking error as the number of words per sign increase.

The second hypothesis predicts a positive relationship between recognition time, as a measure of search-and-recognition performance, and the frequency-amplitude product of the tracking task. Moving from the upper right-hand corner diagonally across to the lower left-hand corner of the matrix of conditions is a prediction of increasing recognition time for signed key messages, which is related to frequency and amplitude across conditions of increased number of words per sign.

The last major hypothesis tested in the study relates to the influence of expectancy of appearance of a message of the search-and-recognition and its relation to tracking between the presence or absence of a key message.

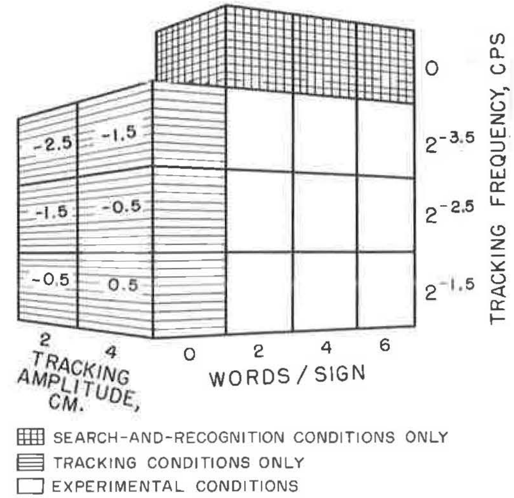

Figure 1. Matrix of experimental conditions.

METHOD

Apparatus

Figure 2 shows the general relations of the task configuration to the response devices. Each of these blocks in their interacting role is discussed in this section. In addition to the presentation and response systems, timing, measurement and recording systems for the experiment are discussed. Figure 3 shows the relative position of the displays and control devices.

Tracking Task

The subject was seated at a console containing a circular cathode ray display (CRT), 12.5 cm in diameter. The display was situated slightly below the line of sight at a 12° tilt with the vertical axis of the room. A low-intensity ambient brightness of approximately 10^{-3} mL surrounded the scope face. The brightness of the tracking signal was approximately 1 mL.

The signal was a point of light normally driven horizontally across the face of the CRT and was to be corrected by manipulation of a simple manual rotary control (a hand-crank). The control mechanism, 15 cm in diameter, had a 90-kg flywheel attached to prevent jerking of the control system. Two such cranks were located on the console so that either one could be easily operated by the subject's preferred hand. The two controls were mounted on the face of the console at a 45° angle with respect to the floor. The crank was adjustable to a height which required support for the elbow by a rubber pad. Hence, rotary control was achieved almost entirely by wrist motion.

Search-and-Recognition Task

A series of motion pictures containing scenes of a new section of the Interstate Highway near Washington was presented on a rear-projection ground glass screen. The

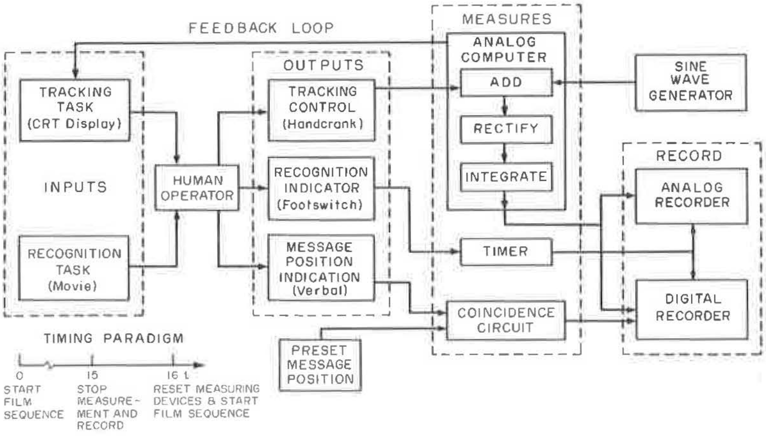

Figure 2. Block diagram of time-sharing system.

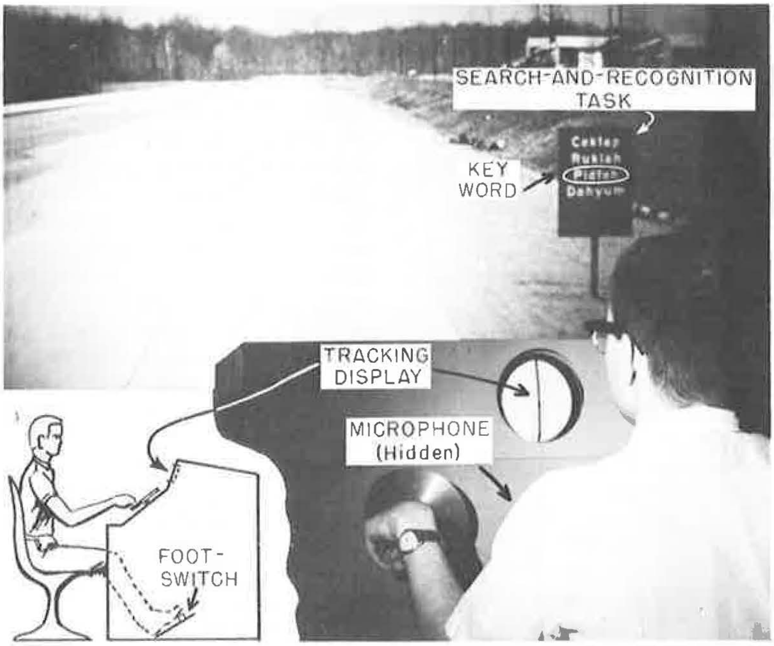

Figure 3. Subject seated at driving console performing tracking and search-and-recognition tasks.

screen was located 8 ft from the seated subject with vertical alignment to the CRT. No apparent texture masked the projected images and the angle of inclination required for a visual shift from one display to another was slight.

Displayed on the face of the screen was a sign-reading task containing messages composed of nonsense syllables having association values of 27 to 47 percent. Each message unit had six letters and the lengths of the messages and the contours of the letters composing the message units were matched.

The apparent sizes of the signs were the same as they would have been on the actual highway configuration; i.e., the visual angle subtended by the sign on the operator's eye was matched for the time from the sign that corresponded to the distance of an actual vehicle traveling at constant velocity. Each approach scene was projected at a rate of 24 frames per sec, and was 16 sec in duration including 1 sec of film displaying passing and receding from the sign position.

Before photographing the highway section, portable sign standards were erected with green backgrounds nearly reproducing the hue and saturation of the present standards used for destination signs on the Interstate Highway System. During photographic sessions, interchangeable messages were placed on the standard backgrounds and the signs were oriented so that the brightness was approximately equal for all signs. The camera was mounted near the head position of the driver, hence providing motion pictures which were used to synthesize the appearance of driving on a roadway from the driver's view.

During photography, four standards were placed 1,000 ft apart with one of 30 sign configurations randomly assigned to each location so that background environment could not be associated with a particular sign configuration during the experiment. Each sign contained a combination of 2, 4 or 6 message units with or without the presence of a key message, PIDFOH, and position of the key message was also randomly assigned to one of the available positions.

The developed pictures were duplicated so that seven complete randomized edited versions were available for the experiment. All films had the 30 scenes of the randomized standardized signs in different randomized orderings.

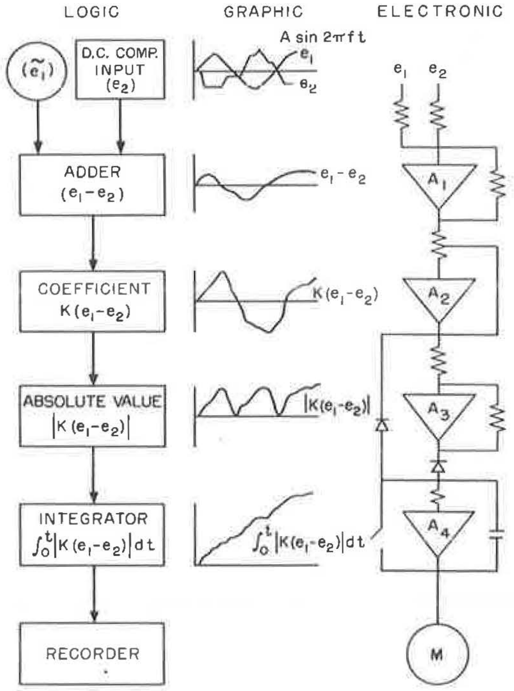

Figure 4. Method for recording tracking error, represented in three ways.

Timing

The timing system provided sampling of performance on the two time-shared tasks. The timing paradigm is shown in Figure 2. Synchronization of time was achieved by employing the film as a common time base. A small hole was cut in the corner of frames spaced in time 15 and 1 sec apart. Light from the projector source energized a photo-resistor in the upper corner of the screen. The subject seated on the other side of the ground glass screen could not see flashes of light from the projector and hence perceived a synthesis of a continuous roadway with no interruption.

The photo-resistor pulsed a "flip-flop" which alternately: (a) reset the measurement devices to a de-energized state, followed by an activated state of measurement, and (b) stopped the measurements and digitally recorded performances on each of the subject tasks.

Measurement

Measurements of rectified integrated tracking error, time from the sequence start where subjects indicated recognition associated with the sign reading task, and correctness of verbal responding to the key word on the sign reading task were recorded digitally. These measures were employed as the dependent variables for determining the tenability of the time-sharing hypotheses. Analogue records of tracking performance and a discrete indication of recognition time were also collected.

The system of measurement of cumulative tracking error is shown in Figure 4. This error measurement system is essentially the one developed by Gain and Fitts (11) for a series of tracking studies. In this system, one of the cranks was attached to a linear potentiometer which controlled a d.c. voltage. This in turn was added to a low-frequency sine wave whose algebraic sum was displayed on the cathode-ray display and in parallel course multiplied by a constant value empirically derived for minimal error of computation, rectified and integrated. An output pulse from the flip-flop actuated a double-pole, double-throw relay between the rectifier output and the integrator at the termination of each 15-sec sampled sequence. This relay in turn energized a delay sample circuit associated with a Hewlett-Packard Model 405-AR d.c.-digital voltmeter. The voltmeter in turn "issued a print command" to a Hewlett-Packard Model 560-A digital recorder. Total tracking error system measurement during any one day of running was less than 1 percent.

The sampled sequence initiation pulse from the flip-flop actuated another double-pole, double-throw relay which issued a short pulse to the clamping circuit associated with the integrator, thereby "zeroing" the unit and permitting an accurate accumulated error score to be developed.

The measure of time from the end of the sampled sequence was achieved by use of the second set of contacts on this pulsed relay. A positive going pulse of 80 v started the count of a Hewlett-Packard Model 522-B electronic timer. A stop pulse was initiated by either the subject's application of pressure on a foot switch or by the one set of relay contacts associated with the stop phase of the flip-flop.

Verbal indication of the position of the key word on the search-and-recognition display was measured for "correctness" of response by use of a coincidence circuit. For each sequence the experimenter set into a series circuit the position associated with the key word at the beginning of each trial. The verbal response was recorded by pressing the second switch in the pair of cascaded switches. If the position reported was the same as that pre-set by the experimenter, a voltage activated a binary indicator and the digital recorder printed an indication of position correctness.

Procedure

During the experimental runs, subjects were requested to simultaneously track (keep the dot on the CRT display centered on a vertical black line dividing the scope face) and to indicate when the word PIDFOH could be recognized on the motion picture display. Subjects pressed the foot switch as soon as they recognized PIDFOH, or if the key word was not recognized as present, they were also to press the switch. Immediately upon initiating the motor response to the search-and-recognition, subjects verbally gave the position of the key word by reporting the numerical position, one through six, or "zero" when PIDFOH did not appear on the sign.

Subjects were not instructed to pace the task in any particular manner, but merely to give indications of their recognition of the key word as soon as possible without guessing and to track as well as possible throughout each trial.

Prior to the experimental session, subjects had approximately 4 hr of training in tracking and search-and-recognition. The film used for the recognition control cases was also used for training. In all cases, with the exception of the last subject, training took place the day preceding the experimental session. The experimental session was divided into two 3-hr sessions. Each of the 14 trials was 8 min in duration with rest periods of approximately that length between trials.

Six subjects randomly drawn from the Bureau of Public Roads Office of Research Staff were employed. The four males and two females, from 21 to 45 years old, reported no anomalies of vision or motor impairment and all had at least several years of driving experience.

Experimental Design

A balanced five-factorial design, with randomized presentations of the stimulus conditions associated with the search-and-recognition task, was randomly presented for each tracking condition. Six subjects were employed for tracking under two amplitude and three frequency conditions under filmed conditions having signs containing 2, 4, or 6 messages with or without the presence of a key message PIDFOH. Each of these conditions was presented five times. The control conditions associated with tracking were equal in length, but the sample size was accordingly increased to 30 trials.

A latin square treatment of frequency, amplitude and subjects provided a determination of time transitions that might be associated with the experimental presentations.

Control tests of tracking performance were paired with each of the time-shared (experimental) runs. The first half of the trials provided a control case requiring tracking without the filmed presentations followed by an experimental case where subjects were required to perform both tracking and search-and-recognition activities. The latter half of the trials for each subject was a reversal; i.e., each experimental trial was followed by a control case.

Two control trials providing recognition information only were conducted during the first and second halves of the experimental session. No tracking was required.

RESULTS

Four types of analysis were conducted to ascertain the influence of constituents of the tracking task on performance on the search-and-recognition task and likewise the influence of components of the search-and-recognition task on tracking performance. These analyses included testing of the significance of the differences between means of each of the treatments described earlier; i.e., an analysis of the integrated tracking error variances and similar analysis of the recognition times between each of the conditions associated with the dynamic recognition task.

Basic to the inquiry was conduct of a test of the generalized time-sharing hypothesis which states that there is a trade-off between the two tasks such that high erroneous performance on one of the tasks is highly correlated with relatively accurate performance on the other. This hypothesis was simply tested by sampled rho-correlations of the time-shared aspects of the experimental configuration.

A third type of analysis of time-sharing behavior of the interpolated tasks was an examination of the erroneous recognitions of signs presented. Finally, control tests were conducted to ascertain: (a) possible learning confounding throughout the experimental sessions, and (b) a comparison of experimental and baseline conditions where the tracking task or search-and-recognition task was presented singly.

The tracking data and recognition time data are separately presented and finally the interactions of the two performance modes are considered together in an examination of the "trade-off" hypothesis.

Tracking Performance

A summary of the factors and their interactions interjected into the experimental situation is given in Table 1. This table does not reflect analysis of presentation of the tracking task alone, but rather those presentations where subjects were required to perform both tracking and search-and-recognition tasks concurrently. Inferences therefore drawn from these data reflect not only the effects of the attribute in question but also the influence of attributes of the search-and-recognition task. Table 1 shows that frequency, amplitude,

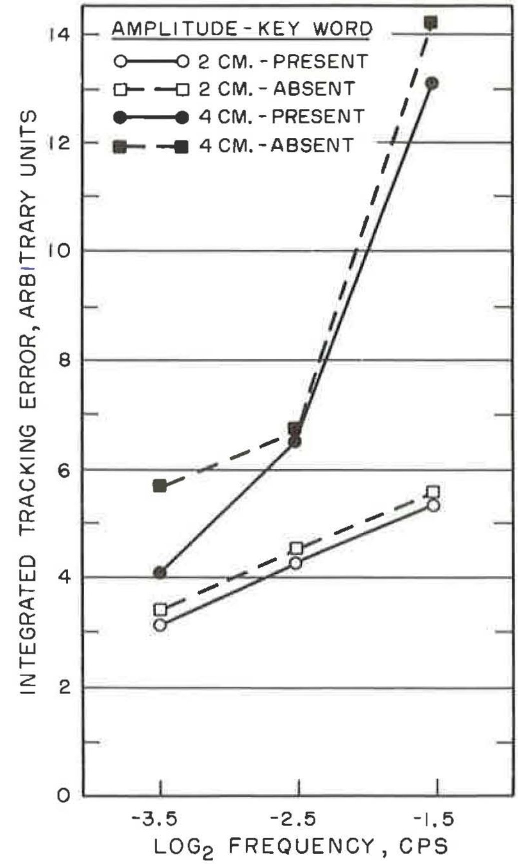

Figure 5. Relative tracking error data showing effects of frequency, amplitude and presence of search-and-recognition key word.

TABLE 1

ANALYSIS OF VARIANCE SUMMARY TABLE FOR CUMULATIVE TRACKING ERROR

Factor	Sum of Squares	DF	Mean Sum of Squares	F Ratio
Frequency	5,582.52	2	2,791.26	493.15[a]
Amplitude	4,593.27	1	4,593.27	811.53[a]
Complexity	22.58	2	11.29	1.99
Presence	59.52	1	59.52	10.52[a]
Subject	2,481.67	5	496.33	87.69[a]
FxA	2,244.01	2	1,122.00	198.23[a]
FxC	33.85	4	8.46	1.49
FxP	14.01	2	7.00	1.24
FxS	490.69	10	49.07	8.67[a]
AxC	1.06	2	0.53	0.09
AxP	12.97	1	12.97	2.29
AxS	635.52	5	127.10	22.46[a]
CxP	26.58	2	13.29	2.35
CxS	35.39	10	3.54	0.62
PxS	19.82	5	3.96	0.70
FxAxC	22.10	4	5.52	0.98
FxAxP	13.69	2	6.84	1.21
FxAxS	509.41	10	50.94	9.00[a]
FxCxP	60.59	4	15.15	2.68[a]
FxCxS	124.93	20	6.25	1.10
FxPxS	50.21	10	5.02	0.87
AxCxP	12.76	2	6.38	1.13
AxCxS	49.89	10	4.99	0.88
AxPxS	25.47	5	5.09	0.89
CxPxS	87.22	10	8.72	1.54
FxAxCxP	54.24	4	13.56	2.40
FxAxCxS	108.15	20	5.41	0.96
FxAxPxS	60.65	10	6.06	1.07
FxCxPxS	146.28	20	7.33	1.30
AxCxPxS	17.23	10	1.72	0.30
FxAxCxPxS	157.80	20	7.89	1.39
Residual	4,894.44	864	5.66	-
Total	22,676.20	1,079	-	-

[a]Significant with probability less than 0.01.

presence of the key word, and subjects have demonstrated differential effects greater than can be expected by chance one time in a hundred. Further, only the interactions involving frequency or amplitude and subjects and their respective and combined interactions display significance.

Figure 5 shows tracking error as a function of the significant variables of frequency, amplitude and presence of the key word. The data for all subjects are combined.

The differential effects of tracking error compared to the control condition (tracking without the time-shared task) are clearly demonstrated in Figure 6. This figure demonstrates the relative magnitude of differences and illustrates the presence of degradation due to the compounding of the two imposed tasks. There is a clear decrement in proficiency when the two tasks are facing subjects; in both the low and high amplitude cases. The error score in the dual task increases overall about 80 percent, whereas the differences between the key word's presence and absence are separated by only a small, but reliable amount (about 15 percent).

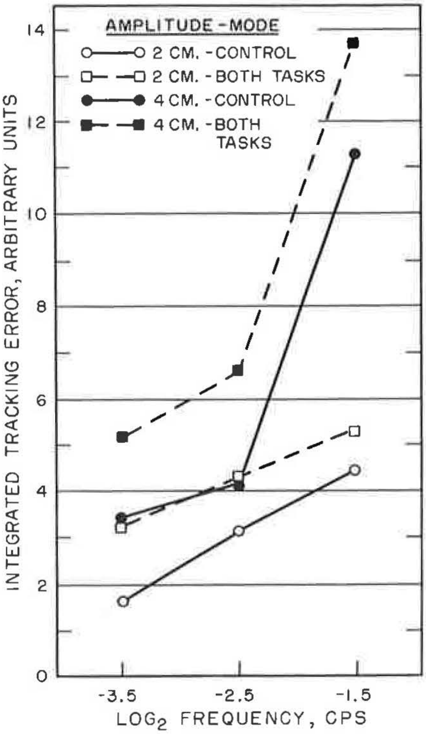

Figure 6. Relative tracking error data showing effects of sign reading task by frequency and amplitude of tracking signal.

Using the method of matched groups for all subjects, both presence and absence conditions of the key word and all sign complexities, a comparison by means of student's "t" test of the lowest frequency-amplitude condition with and without the interpolated task yields t = 3.92 which is significant at the 0.01 level. Therefore, tracking performance for the lowest average velocity condition without the secondary is superior to the comparable time-shared condition.

Search-and-Recognition Time

As observed for measures of tracking performance, subject differences for recognition time are also significant. Table 2 summarizes recognition time cases where the key message on sign was present.

Of the two components of the tracking task, frequency appears to have differentially affected performance on the dynamic recognition task. Figure 7 shows the time from the sequence beginning when subjects indicated recognition of the key message for each of the frequencies employed in the experiment. The reader is cautioned that this curve is illustrative because subject differences influence such a plot. It is shown that employment of tracking as a secondary task greatly increases the time required for recognition of the signs' key message.

The lack of subject interactions of complexity indicates that the subjects responded in essentially the same manner to different numbers of message units on the signs. The differences between two, four and six words reflect a monotonic increase in recognition time as the number of message units increase. The time increase between the two- and six-message signs is only about 4.4 percent or slightly less than ½ sec. The range of values for the time-sharing case extends from approximately ½ sec to about 2 sec beyond the recognition time for the control case where the film was shown without the displayed tracking task.

TABLE 2

ANALYSIS OF VARIANCE SUMMARY TABLE FOR RECOGNITION TIME

Factor	Sum of Squares	DF	Mean Sum of Squares	F Ratio
Frequency	9.53	2	4.76	4.81[a]
Amplitude	3.82	1	3.82	3.86
Complexity	20.61	2	10.30	10.40[a]
Subject	1,062.65	5	212.53	214.68[a]
FxA	5.84	2	2.92	2.95
FxC	2.29	4	0.57	0.58
FxS	28.22	10	2.82	2.85[a]
AxC	0.11	2	0.06	0.06
AxS	5.45	5	1.09	1.10
CxS	17.14	10	1.71	1.73
FxAxC	4.80	4	1.20	1.21
FxAxS	28.12	10	2.81	2.84[a]
FxCxS	27.48	20	1.37	1.38
AxCxS	11.13	10	1.11	1.12
FxAxCxS	28.89	20	1.44	1.45
Between treatments	1,256.08	107	-	-
Error	428.47	432	0.99	-
Total	1,684.55	539	-	-

[a]Significant with probability less than 0.01.

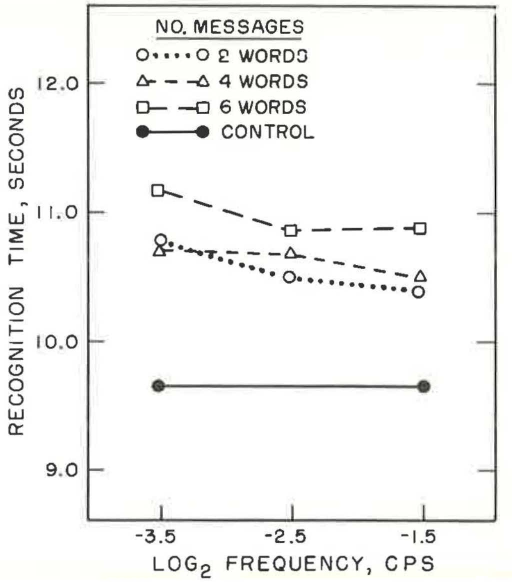

Figure 7. Recognition time data showing effects of time sharing with tracking task by frequency for different numbers of words on sign (compared with average time without tracking).

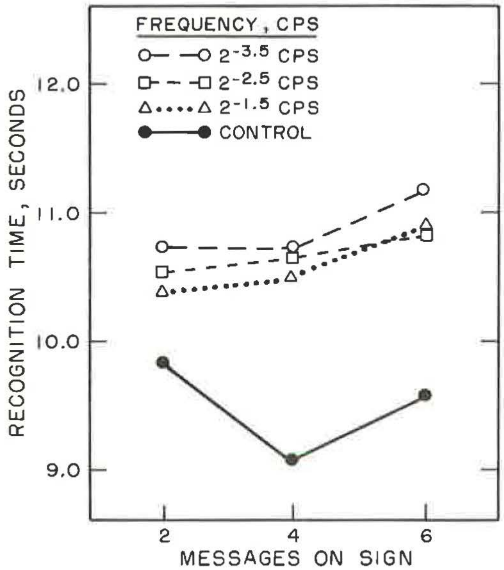

Figure 8. Recognition time data showing effects of number of messages and tracking frequency (compared with non-time-shared performance).

TABLE 3

PERCENTAGE OF ERRONEOUS RESPONSES BY SUBJECT

Subject	Error	False Alarm	Total Erroneous Response
1	0.8	1.7	1.2
2	5.8	2.5	4.2
3	2.5	0.8	1.7
4	1.7	0.8	1.2
5	0.8	0.0	0.4
6	0.8	0.8	0.8
Avg.	2.1	1.1	1.6

The control and experimental means are both shown in Figure 8. The control conditions show a dip at 4 message units per sign which does not parallel the general trend of the experimental data. The time differences are significant between 2- and 4-message units at the 0.05 level, but fail to reach significance between 4 and 6 units.

Search-and-recognition performance was tested to ascertain whether there was any change in performance over the first and second halves of the experimental sessions. Using a t-test for matched groups, the mean recognition times for each subject were compared for the 5th and 10th trials. No statistical differences at the 0.05 level were obtained.

The errors in judgment were obtained from the responses of the subjects to the position of the key word on the signs. The error scores are given both by percentage of misses and false alarms in Table 3. The table gives the error rates incurred by each of the subjects with respect to reports of erroneous position indications and reports of position when in fact the key message was not present (false alarms). These rates are sufficiently low that no test to discriminate between guessing and non-guessing was required. The total error was well below the 5 percent criterion imposed, therefore no additional analysis of the erroneous responses was conducted.

Time-Sharing Hypothesis

It was hypothesized that there should be a systematic inverse relationship between tracking error and recognition time if time sharing is determined on an individual trial basis. That is, if subjects optimize their performance on one of the two imposed tasks they would be expected to yield performances which were highly negatively correlated with each other. Randomly selected samples of performance were taken for time-sharing conditions for individual subjects. Twenty such samples were subjected to rank-order rho-correlations. Only one of the correlations reaches significance at the 0.05 level of significance. Therefore, rejection of the hypothesis that there is a significance correlation between the two time-shared performances must be made as the number of significant correlations does not exceed those expected by chance alone.

DISCUSSION

Time Sharing

The analysis of data revealed no systematic tendency on the part of operators to optimize one task to the exclusion of the other, when both tasks were simultaneously presented. Subjects were instructed to perform both tasks as well as possible and not to guess on the recognition task. Otherwise the experimental situation was relatively unstructured.

The analysis of time-shared process may, therefore, be derived from an analysis of the pattern of response and eye movements or from the magnitude and dispersion of errors of tracking and search-and-recognition performance. The latter alternative is within the domain of this study.

No effects of the number of messages, presented on the signs, on tracking performance are evidenced from the data. This would suggest that the overall time required by the dynamic recognition task was not affected differentially with regard to the number of message units. Yet the number of message units did contribute to increasing recognition time. Such a paradox either suggests that: (a) the differences in recognition, although significantly different are so small that they merely do not affect tracking performance (the variance associated with other factors is relatively large), or (b) the subject must quicken his alteration response to or from the tracking task to decrease time occupied in non-tracking activity.

Although differences in the differential error between time shared and control cases involving tracking alone are not great for each of the frequency-amplitude combinations, the trend is toward lesser differentials rather than greater ones as the tracking frequency is raised. If a constant differential between each control and experimental comparison is assumed, then it can be seen that the same increment of error is attributable to each of the frequencies.

With no difference between the integration of sine waves of differing frequencies (unless the integration time is very short) exists, the lack of visual feedback for 1 or 2 sec becomes increasingly important as the frequency is increased. Gottsdanker (12) has indicated that although essentially the same mechanisms operate in extrapolation of a course under visual and visually deprived conditions that operators manifest more variable and less accurate performance when they are visually deprived. The subject does maintain some proprioceptive feedback and is able to extrapolate the course, but this ability is decremented as frequency is increased.

Implications of Briggs and Howell's work (5) are that where there is spatial separation of tasks to be performed that a discrete sampling process must occur. Where disjunctive tasks compete for the observers' efforts, the sampling rate is paced in accord to the objective velocity of the tasks as well as some subjective criterion. A decrement in performance supposes a lack of visual error feedback, or expressed differently, a reduction of the sampling rate of the error signal on the part of the operator. If there is a rate of increase less than that expected by a condition of reduced feedback information, then the operator must increase his sampling rate with an associated effect on some other aspect of behavior. This assumption may be made only if the operator is presumed to be operating below the limits of his channel capacity.

It is therefore expected that if an equal time duration is expended on the search-and-recognition independent of the tracking task, that: (a) the analysis of variance of recognition times will show no significant differences for tracking frequency, amplitude, or interactions of those components (i.e., recognition times would not be increased or decreased due to the addition of the secondary task; but, as was seen earlier, the average recognition durations decrease as the frequency of tracking task increases); and (b) if an increment in tracking error in the time-sharing condition exists, then such an increment should increase as a function of increased frequency.

If the converse of both of these conclusions is shown, then it may be presumed that a time reduction on recognition is utilized in minimizing tracking error. The data clearly substantiate such a notion. The number of messages displayed to subjects shows no effects on tracking performance, but indeed frequency and the complex interaction of frequency-amplitude-subject are shown to have effects on recognition time at a level substantially beyond that expected by chance. A reasonable inference to be drawn is that as frequency (a component of angular change of the target) is increased, the rate of sampling of that course is increased with a consequent alteration in search-and-recognition behavior. The analogue to the field situation suggests that if the steering task may be considered in the same context as tracking, then search-and-recognition behavior will suffer with respect to sign reading complexity and actually improve as tracking velocity is increased.

The effects of the key word not appearing on the sign on tracking performance suggest that expectancy played some part in diverting the "attention" of subjects from the simulated steering activity. The significant increase in tracking error leads to the conclusion that greater periods of time were employed in attempting to find the key word in its absence. The implications to signing practice are discussed briefly in a later section.

Cues in Non-Time-Shared Recognition Trials

Noted in the comparison of control and experimental data was a decrease in recognition time associated with increased numbers of messages in the search-and-recognition where no time sharing is required. It would be predicted on the basis of Desrosiers' (8) laboratory results that an increase in recognition time would be required. Although Desrosiers found no significant differences in field tests, this lack of significance was attributed to the high variance of performance in the field situation. It is most likely that due to the use of the control film for training that disproportionate learning was associated with the four-message signs. There was no way of directly testing this hypothesis. However, close observation of these films revealed that activity was greatest in the periphery for the scenes where four-message signs appeared. Where subjects were required only to view the film (which in this case had been repeatedly shown during training), it is likely that such peripheral cues would be detected and utilized.

Spatial Separation of Information

Although care was taken to present a reasonable projection of the roadway (i.e., the rates of change of objects in the simulated view of the road were comparable to those in the field), fidelity of the films employed required much larger angles of message sizes subtended, for recognition. This, in effect, also meant that the lateral movement of objects across the viewed field was much farther from the line of regard in the laboratory situation than would be encountered in the driving world. Concurrently, the angular velocity of the signs was much higher at the time of recognition. This constraint meant that the message, when detected, was displayed from the line of regard about 10 deg; whereas in the field, previous tests under comparable speed conditions showed recognition of signs of the type employed in this study to be recognizable at about 400 ft, making the displacement of the sign at the time of recognition about 2 deg, within the foveal region of the eye. The shift of fixation in the field situation is quite small, thereby reducing the transition time between the two information sources, visual steering feedback and the messages on the signs.

Automatization

Control devices employed for repetitive inputs permit some reliable kinesthetic cues for the operator. The roadway has a wide range of cues which may be translated through the steering control, but such inputs appear to have low redundancy. In the experiment described there was high redundancy in the compensatory tracking signal; hence the error, incurred during periods when the subject directed his fixation toward the signs, was probably minimized. Bahrick and Shelly (3) found in tasks dependent on both visual and kinesthetic cues, that during prolonged trials a gradual change from extroceptive cues to proprioceptive control occurred. So indeed there may have been a reduction in the error scores under these high redundancy conditions. A balanced design reduced the influence of this factor in analysis of error scores, however.

Frequency-Amplitude Components of Tracking

It should be recognized that frequency and amplitude are, in the context of this presentation, aspects of the same phenomena, i.e., rate of angular change of the source of the tracking target stimulus. A report by Bowen and Chernikoff (4) indicates a predictive notion concerning the cumulative tracking error of subjects, by suggesting that an error estimate may be determined by the frequency-amplitude product, i.e., $E = kfa$. Tests of this relationship yielded good fits of the data. Although this relationship does not take into account the gain of the specific control utilized by subjects, there is significant indication of the "trade-off" between these two aspects of the tracking task to indicate reason why each should have pronounced differential effects and why there should exist an interaction between them.

Bowen and Chernikoff showed that equal frequency-amplitude products should yield equal tracking error. This point is not germane to the central topic of this report, but making comparisons of conditions having equal average velocities is essential to determining the applicability of the principle in the body of this research. So as not to confound the argument by possible interactions not revealed by previous analysis, matched groups for all subjects, presence, and complexity conditions were compared for the equal frequency-amplitude products included in the matrix of conditions presented.

Where $f_1 = 2^{-3.5}$ cps,
$f_2 = 2^{-2.5}$ cps,
$f_3 = 2^{-1.5}$ cps,
$a_1 = 2$cm,
$a_2 = 4$cm,

and E is the error associated with conditions dictated by the subscripts, the following hypotheses were tested by use of the t-test. The corresponding probabilities of the differences exceeding t are $H_1 : E_{f_1} a_2 = E_{f_2} a_1$, $0.3 < p < 0.4$ but $H_3 : E_{f_1 a_1} = E_{f_1 a_2}$, $p < 0.01$ and $H_2 : E_{f_2} a_2 = E_{f_3} a_1$, $0.5 < p < 0.6$ but $H_4 : E_{f_2 a_2} = E_{f_2 a_2}$, $0.05 < p < 0.10$. From the preceding, the frequency-amplitude equality concept can be considered to be valid. The differences between the equal fa products do not significantly differ, whereas cumulative error is compared for matched groups for like frequencies but different amplitudes. They do differ significantly or are near the critical level of accepted difference.

In addition to Bowen and Chernikoff's treatment of the frequency-amplitude product as a predictor of tracking error, Brown (7) has subsumed these components as those that may be translated into angular velocity, a primary stimulus to the human operator. Such a concept permits the translation of vehicle velocity and road curvature into just these terms. The stimuli employed ranged in maximum angular velocities from

0.74°/sec to 5.37°/sec. Under AASHO design standards for speeds 30-60 mph, on curves fitted to those speeds, angular velocities range from approximately 2.6°/sec for a 60-mph vehicle entering a curve whose radius is 1,330 ft with five percent superelevation, to approximately 6.7°/sec for a vehicle traveling at 30 mph on a 375-ft radius curve. Under these conditions the driver does not, in theory, need to make more than an initial correction, whereas subjects in this study were "negotiating a very crooked road indeed."

Although the differences between tracking error for equal frequency-amplitude products were not greater than could be expected by chance, there is a relative difference exhibited by the two amplitude conditions worthy of note. Inspection of the configuration confronting subjects shows at least two types of differences between the conditions: (a) pertaining to the angular velocity of control conditions, the average velocities for one condition tested differ almost 30 percent, but the maximum velocities did not differ; and (b) the maximum velocities differ by almost 10 percent, but the average differs only a few percent.

Implications for Signing

An earlier study conducted at the Institute of Transportation and Traffic Engineering at UCLA (2) revealed that as many as 15 percent of drivers made "poor selection of routes due to confusion of messages on the signs" or because "they had not seen the signs in time to make proper maneuvers." The driver is faced with a dilemma in negotiating high-speed roadways such as found in the interstate system. A wrong decision in selecting an appropriate ramp may take the driver many frustrating miles away from his desired destination. So it is especially critical to the driver who is unfamiliar with a specific course to "make the right decision." He may attempt to optimize the situation in such a manner that he has greater periods of time in which to reach a decision which is translated into reduced velocity, or he may direct his "attention" away from external visual sources such as signs; it is quite conceivable that his control performance, particularly lateral control, will be appreciably degraded.

This evidence from this study for the interaction effects of steering and search-and-recognition activities taken together with the report of ITTE suggests that the points where the driver must make decisions concerning alternative courses needs a substantial research effort. Congestion along the highway such as found at ramps does not explain the high accident records found in these areas. A report by Mullins and Keese (17) shows that more than 20 percent of accidents in freeway sections studied occurred at ramps where decision processes must be made on the basis of sighting entry into acceleration and deceleration lanes where impinging traffic and signing must be searched out, located or recognized and acted on. If recognition is to occur in comparable periods of time for decision points, then sampling of relative position on the roadway must be decreased and this is indicated not to be the case; or the angular velocity of the target (roadway) must be decreased. This may be accomplished by a decrease in speed, a factor that appears to be critically associated with accident rates (18). Where speed variability is high on high-speed roadways, there is also some evidence of a reduction in volume.

The issues that must be considered then are alternative methods of presenting information to the operator so that he is not overburdened, and ways of maintaining low variability of speed for such decision points along the highway.

A final point germane to signing practices and admittedly a general one is that where expectancy of a message unit is relatively great, an indication of the proper course should be shown on a sign, i.e., otherwise longer periods of time are presumably drawn to the sign-reading task at the cost of maintaining stable steering control.

SUMMARY AND CONCLUSIONS

Previous research on the independent aspects of tracking and search-and-recognition activities have not considered the interactions between these two tasks. Although studies of time-sharing between different sensory modalities and two-dimensional tracking have indicated generalized degradation of performances beyond certain input loads, consideration of tasks having different basic functional properties has been lacking.

The reported study did investigate the interaction processes between two such tasks and compares the alterations in performances where tracking and search-and-recognition performances are measured in a non-time-sharing role.

Analysis of individual performances revealed that the process remains essentially independent for each particular encounter with a time-shared situation, but tests of the specific hypotheses revealed a change in operator-pacing as the complexity of the activity increases. However, in all comparisons of the independent tasks and their time-shared counterparts, the presence of the second task yields a decrement in performance. The first hypothesis stated that tracking error would increase in proportion to the increase in each of the components of angular velocity (frequency and amplitude of a sinusoidal function). This hypothesis was borne out in part. Although the level of the tracking error was raised above the control tracking conditions in the presence of the search-and-recognition task, no differential increase occurred as a function of the angular velocity components. This was implied to suggest that the rate of sampling of the tracking signal was increased with its speed.

The effect of increasing the number of message units on the simulated sign-reading task had no effect on tracking performance, indicating an optimizing of time pacing where the greatest number of message units appeared in the search-and-recognition task.

The second hypothesis relating the effect of tracking frequency and amplitude on search-and-recognition speed and accuracy was not borne out. Recognition time actually decreased for the higher frequency tracking signals, but the effects of amplitude were less drastic. This further substantiated the theory that the rate of sampling is increased at higher angular velocities of the tracking signal. The false alarm rate was low for all conditions and did not differ between tracking conditions.

The final hypothesis tested in this research was that no differences would exist in tracking performance where the search-and-recognition task was with and without the inclusion of a previously learned message. This hypothesis was not borne out, as tracking was degraded where the key message was not included in the task. It is presumed that greater periods of fixation were required where the expected message did not appear, hence distracting from the visual response required for minimizing tracking error.

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