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An Evaluation of the Effects of High Visual Taskload on the Separate Behaviors Involved in Complex Monitoring Performance

Richard I. Thackray
R. Mark Touchstone

Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City , OK 73125

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16. Abstract

Operational monitoring situations, in contrast to typical laboratory vigilance tasks, generally involve more than just stimulus detection and recognition. They frequently involve complex multidimensional discriminations, interpretations of significance, decisions as to appropriate action, implementaion of actions, and evaluation of consequences. A simulated air traffic control (ATC) task was developed to study the effects of prolonged monitoring on a number of such behaviors embedded in the context of the task. All subjects performed the task under relatively high visual taskload conditions for a single 120-min session. Two types of critical events requiring different levels of information processing for detection were employed. One type of event consisted of a readily detectible loss of altitude information in an alphanumeric data block; a second type of event involved the detection of two aircraft at the same altitude on the same flight path. This latter event required continuous, successive comparisons of data blocks in order to be detected. Following detection, a decision was made as to whether or not the situation might result in a potential conflict (collision). Measures derived from the implementation of each type of decision enabled acquisition of data on short-term memory, decision time and decision errors, procedural errors, and speed of motor movement. The results revealed that time to detect aircraft at the same altitude increased significantly over the monitoring period as did omission errors for this type of event. Detection time for the more readily detectible alphanumeric changes involving loss of altitude information showed no evidence of impairment, nor was any impairment found for any of the other task behaviors that were measured. The findings are discussed with reference to previous studies suggesting that complex monitoring primarily affects attentional processes and that the rate of decline in attention appears to be related to the degree of information processing required for event detection.

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NOTICE

AN EVALUATION OF THE EFFECTS OF HIGH VISUAL TASKLOAD ON THE SEPARATE BEHAVIORS INVOLVED IN COMPLEX MONITORING PERFORMANCE

1. Introduction

It is increasingly recognized that modern operational vigilance tasks, such as those related to air traffic control, nuclear control room operation, security-surveillance systems etc., involve more than simply detecting and responding to infrequent critical events. They frequently involve complex multidimensional discriminations in which stimulus detection or identification may be followed by interpretation of significance, decisions as to appropriate action, implementation of actions, and evaluation of consequences (Craig 1984, Mackie 1984). Yet, traditional vigilance studies, for the most part, seldom look at behaviors other than those directly related to stimulus detection. This would appear to be true not only for laboratory studies using simple vigilance tasks, but for studies of complex monitoring performance as well (see Davis and Parasuraman 1982, Parasuraman 1986 for recent reviews).

In an effort to examine the effects of prolonged monitoring on behaviors other than just stimulus detection, we have developed a laboratory simulation of an air traffic control (ATC) task that incorporates many of the aspects of real-life monitoring situations. As it is currently configured, the task simulates an intermediate level of ATC automation in which the computer acts as an aid to the controller in resolving aircraft conflict situations. Although monitoring for infrequent event detection constitutes the principal task requirement, the task was developed to enable acquisition of data on short-term memory, decision making, procedural errors, and speed of motor movement.

Our intitial study with this task examined the relationship of both visual taskload and target difficulty to detection performance (Thackray and Touchstone 1985). Subjects monitored either 8 or 16 alphanumeric targets in order to detect critical events requiring different levels of information processing for detection. One type of event consisted of a readily discernible change in the contents of an alphanumeric data block; a second type of critical event involved the detection of two aircraft at the same altitude on the same flight path. This latter event required continuous, successive comparisons of data blocks in order to detect its occurrence. While the more readily detectible events showed no evidence of performance decline at either level of visual taskload, the more difficult to detect altitude events showed evidence of impairment that was significantly related to taskload; the number of such events not detected increased significantly under the higher, but not under the lower, taskload condition. Fatigue, resulting from the effort required to continuously scan and process information from a large number of targets, was offered as a possible explanation for this impairment. This explanation was supported by the finding of a significant decline in critical flicker frequency (CFF) that occurred under the 16-target, but not the 8-target condition.

Because elements of the task just described were still being developed at the time the above study was conducted, only data relating to detection efficiency (time and errors) were analyzed in that study. The present study represents an extension of this earlier one and was conducted to determine whether the apparent fatigue resulting from prolonged monitoring under high taskload conditions affects only attentional processes or whether other behaviors relevant to complex monitoring show impairment as well. Effective allocation of function in increasingly automated systems requires information on how prolonged monitoring may affect all performance aspects of such tasks, not just those related to attention.

The present study also sought to provide further information on the visual behavior of subjects during times when critical events are missed. Findings obtained in several of our previous studies suggest that critical events (e.g., altitude changes) are either missed (Thackray and Touchstone 1985) or are responded to with excessively long detection times (Thackray and Touchstone 1980) in spite of the fact that subjects appear to be scanning the display throughout the session. In the current study, videotaped recordings of eye movement activity and facial orientation were obtained in order to assess visual behavior of subjects during those times when missed events occurred.

2. Methods

2.1 Subjects. Forty-eight men and women, all paid university students, volunteered to participate in the study. Subjects ranged in age from 18 to 29 years, had 20/20 uncorrected vision, were nonsmokers, and had no prior experience with the task used or previous ATC training. None were currently taking any prescription medication on a regular basis.

2.2 Apparatus and Task Design. The basic experimental equipment consisted of a Digital Equipment Corporation (DEC) VS11 19-in (49-cm) graphics display, keyboard, and joystick, all of which were interfaced with a VAX 11/730 computer (DEC). The computer was used both to generate input to the display and to process subject responses. The VS11 was incorporated into a console designed to closely resemble an ATC radar unit. Two diagonal, nonintersecting flight paths were located on the display, along which aircraft targets could move in either direction. A given aircraft's location was displayed as a small "blip" on the flight path, and an adjacent alphanumeric data block identified the aircraft and gave its altitude and groundspeed. Aircraft were updated in position and any change in alphanumerics every 6 sec. Figure 1 shows a typical target pattern as displayed to the subject, with the total console-display configuration shown in Figure 2.

The subject's task was to continually monitor the display for one of two types of change in the alphanumeric data blocks. The duration of each type of change (referred to as a critical event) was 90 sec; if a subject failed to detect a critical event within this 90-sec period, the data block containing the change reverted to its previous state.

The first type of critical event was readily detectable and consisted of three X's in place of the three altitude numbers in a given data block. Subjects were told that this replacement of an altitude value signified that a transponder malfunction had occurred resulting in a loss of altitude information. Upon detection of such an event, subjects were told to press a designated button on the console, move a joystick-controlled

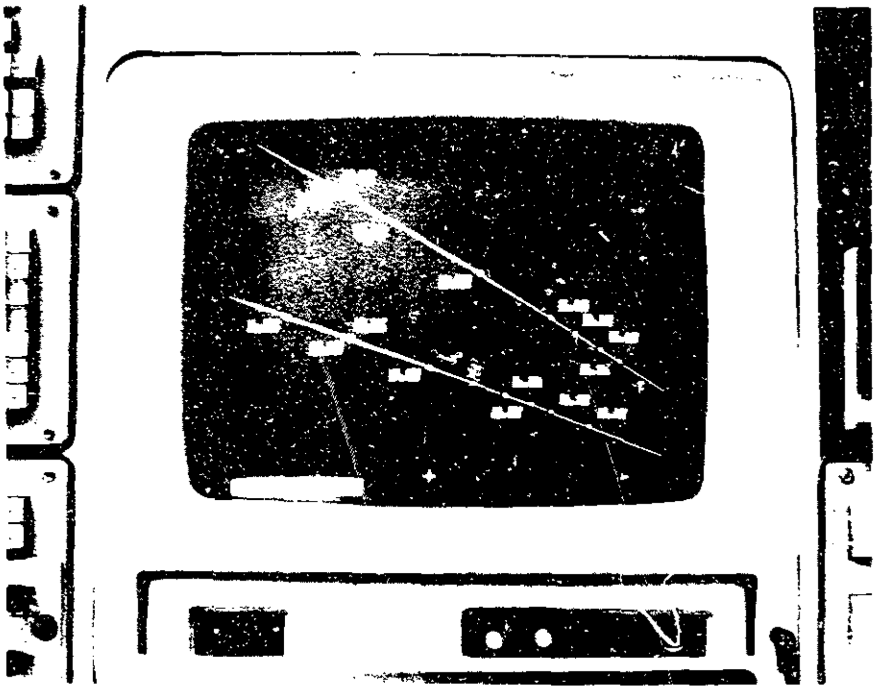

FIGURE 1. A TYPICAL TARGET CONFIGURATION AS DISPLAYED TO THE SUBJECT.

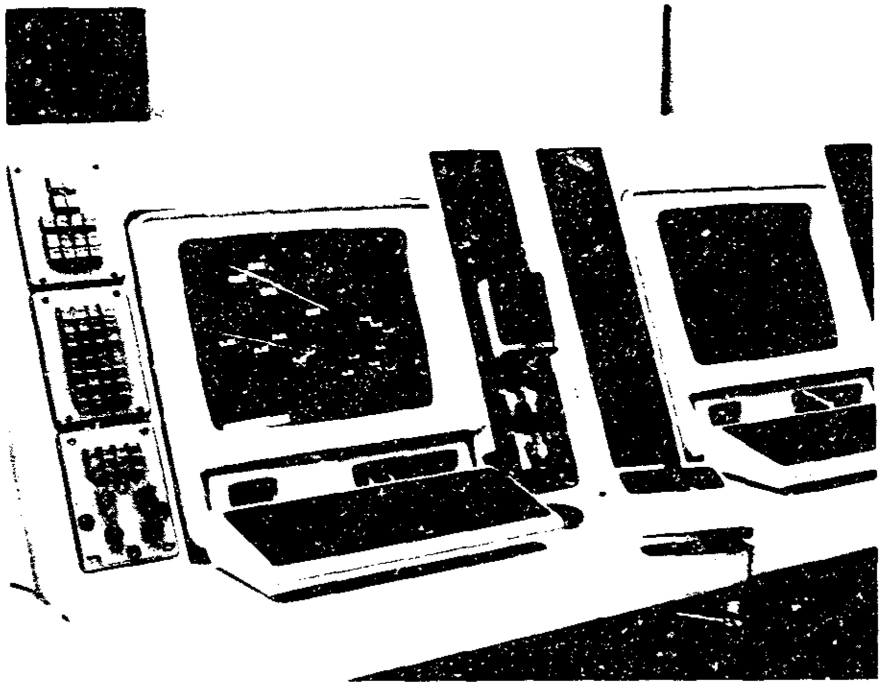

FIGURE 2. THE SIMULATED ATC WORK STATION. ONLY THE CONSOLE ON THE LEFT WAS USED IN THIS STUDY.

cursor over the data block containing the critical event, and to press another button on the joystick control unit. This last response "corrected" the malfunction by replacing the three X's with the previous altitude value. The second type of critical event was more difficult to detect, since it was not immediately apparent. This event was the occurrence of two aircraft at the same altitude on the same flight path. As soon as such an event was noted, subjects pressed a second console button. It was next determined whether the two aircraft were moving towards each other, away from each other, or in the same direction. On the basis of this determination, subjects then pressed either a "Conflict" button (indicating that the aircraft were moving towards each other) or a "No Conflict" button (indicating that the aircraft were either moving away from each other or were moving in the same direction). In order to prevent overlapping data blocks, all aircraft in this study were assigned a constant speed of 450 knots. Thus, only targets moving towards each other would constitute a potential conflict situation. Following a "conflict" decision, the cursor was positioned over one of the two conflicting aircraft, and the joystick control button was pressed. This caused the computer to assign a new altitude value to one of the two conflicting aircraft and display this value, along with the aircraft's identification in a box at the lower left of the screen. Subjects then verified that the computer-assigned altitude did not result in a conflict with some other aircraft on the flight path. If no new conflict was created, a keyboard entry was made that assigned the new altitude value to one of the two previously conflicting aircraft. (Although subjects were led to believe that a computer-assigned altitude might occassionally result in a conflict with some other aircraft, in actuality this never occurred.)

Whenever a "no conflict" response was made, no further action ensued, since no change in altitude was required. Subjects were told that the altitude of one of the two nonconflicting aircraft would eventually change to some other value (this change always occurred 60 sec after the no conflict response was made) and that they had to remember that they had responded to this particular pair of aircraft. If they failed to remember and responded a second time, a memory error was recorded.

The number of targets on each flight path was kept equal at all times; as one left the screen, another appeared. Nine critical events occurred in each 30-min period, with no more than one event present at any given time. Of these nine events, three were XXX's, three were conflicting altitude changes, and three were nonconflicting changes. These events were arranged in a quasi-random order with the restriction that each of the three types of events had to occur at least once in both the first and second 15 min of each 30-min period. Subjects were given no information regarding the frequency of events or their order of occurrence. The times between events (interstimulus intervals) ranged from 126 to 302 sec with a mean of 200 sec.

2.3 Video Recording Methodology.

A miniature Sony CCD TV camera was mounted in the lower left corner of the console at an approximate 45 degree angle to the subject's face. The output of this camera was combined, by means of a special effects generator, with the output of a second camera located to the rear of the subject that was used to record the contents of the simulated radar display. The combined outputs of both cameras were displayed on a video monitor. A small indicator light, not visible to the subject, was located above the console and was momentarily illuminated each time a critical event occurred. Continuous videotape recordings enabled subsequent playback and analysis of the subject's visual behavior during times when critical events were not detected.

2.4 Procedure

On arrival, subjects were played a tape recording that stated that this experiment was part of a series of studies designed to investigate the role of the controller in increasingly automated ATC systems. They were told that the task was designed to simulate an intermediate level of ATC automation in which computer aids are used to assist the controller. They were then given task instructions and separate practice in responding to each kind of critical event.

In order to add a greater element of realism to the task, a tape recording of background noises recorded in actual air traffic control radar rooms was played continuously during the 2-hour task session. Sound level of this noise at the subject's head location was 62 dBA. It was not expected that this would have any effect on performance, since an earlier study using a previous version of this monitoring task failed to find any significant performance effects of this noise at a considerably higher (80 dBA) level (Thackray 1982). At the completion of the 2-hour task period, subjects were given a thorough debriefing concerning the purposes of the experiment.

3. Results

3.1 Target Detection Time and Errors of Omission.

As described earlier, subjects monitored the display for the occurrence of either one of two types of events. The first type of event, signifying an altitude malfuction, consisted of an XXX that replaced the three-digit altitude value in an alphanumeric data block; the second type of event, constituting a potential conflict or no conflict situation, could only be detected through continuous comparisons of each target's altitude with the altitude values of all other targets on a given flight path.

Figure 3 shows mean detection times across 30-min periods for both types of event. Separate repeated measures analyses of variance (ANOVAS) applied to these data revealed no significant change across the 2-hour session in detection time for altitude malfuction events ($F(3/141)=1.68$, $p>.05$), but a significant increase in time to detect possible conflict/no conflict situations ($F(3/141)=15.47$, $p<.001$).

With regard to errors of omission, the more readily detectable malfuction events were never missed by any of the subjects. For aircraft at the same altitude, however, 71% of all subjects missed at least one of these occurrences during the two-hour session. Since the actual proportion of events missed relative to events presented was rather small, it was decided to compare omission rate during the first and second hours of task performance rather than during separate 30-min periods. Combining across subjects and events revealed that 21 of the conflict/no conflict events were missed during the first hour and 77 during the second, yielding miss rates of 4% and 13% respectively. A Wilcoxon comparison of the first and second hours revealed the increase in miss rate to be significant ($p<.05$).

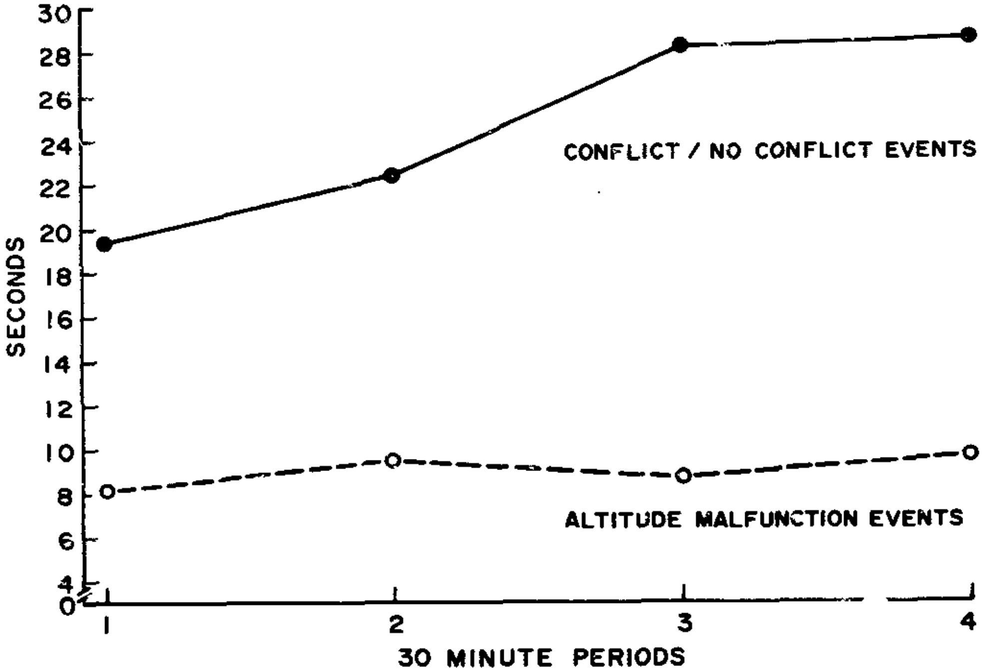

FIGURE 3. MEAN DETECTION TIMES ACROSS 30-MIN PERIODS FOR BOTH LEVELS OF EVENT DIFFICULTY.

3.2 Decision Time and Decision Errors.

Following a subject's response to the detection of two aircraft at the same altitude, a decision was made as to whether the situation represented a potential conflict or a no conflict situation. The time from detection response to decision response was obtained for each altitude event for each subject with means displayed in Table 1. Also shown in Table 1 are data for a second measure of decision time. This measure consisted of the

TABLE 1. MEAN TIMES (IN SEC) FOR SEVERAL MEASURES OF DECISION BEHAVIOR DURING THE TWO-HOUR SESSION.

	Thirty-minute Periods			
Measure	1	2	3	4
Conf/No Conf Decision Time	6.29	5.77	6.12	6.11
Time to Accept Alt Resolution	4.36	3.79	3.95	3.87

time between a subject's interrogation of the computer for its suggested resolution to a conflict and acceptance of this resolution. Separate ANOVAs performed on the two sets of data shown in Table 1 revealed no evidence of any increase or decrease in conflict/no conflict decison time across the 2-hour session (F(3/141<1.00) nor any evidence of a significant change in acceptance time for computer-generated altitude resolutions (F(3/141=2.29, p>.05).

Decision errors were recorded whenever a conflict decision was made to a no conflict situation or a no conflict decision to a conflict situation. If the incorrect decision was then followed by a sequence of behaviors appropriate to the decision made, this would suggest an incorrect interpretation of the altitude event; if the incorrect decision was followed by a sequence of behaviors that would have been appropriate to the opposite decision, one could infer that the subject had made a careless error in not pressing the button intended. Only 3 errors of the latter type were documented, suggesting that carelessness was not a significant factor in incorrect decisions. With respect to the former type of error, 14 were made during the first hour and 8 during the second, yielding error rates of 2% and 1% respectively. The Wilcoxon comparison of first and second hours was nonsignificant (p>.05).

3.3 Motor Movement Time.

In order to obtain an indication of possible change in the speed of motor activity with time on the task, measures were obtained that reflected the time taken by subjects to move the joystick-controlled cursor from the bottom of the screen and locate it over the data block containing a critical event. Two similar, but separate measures of such behavior were obtained; those associated with correcting malfunction events and those associated with resolving altitude conflicts. Mean times for each measure are shown in Table 2. Separate ANOVAs yielded no evidence of a significant change in time to complete either of these two movement sequences during the 2-hour session (F(3/141) <1.00 in both cases).

TABLE 2. MEAN CURSOR MOVEMENT TIMES (IN SEC) ASSOCIATED WITH RESOLVING MALFUNCTION EVENTS AND ALTITUDE CONFLICTS.

	Thirty-minute Periods			
Measure	1	2	3	4
Movement Times for Malfunction Events	6.86	7.22	6.47	6.45
Movement Times for Altitude Conflict Events	6.60	6.59	7.25	6.66

3.4 Memory Errors.

Whenever a no conflict decision response was made to two aircraft at the same altitude on the same flight path, the altitudes of these two aircraft remained the same for a 60-sec period following the decision response. During this time period, if a subject failed to remember having previously responded to these two aircraft and made a second detection and decision response, a memory error was recorded. The frequency with which such errors occurred was found to be quite small. During the first hour of the session, 4% of the no conflict situations were responded to twice, while during the second hour, the error rate declined to 3%. A Wilcoxon test revealed this decrease to be nonsignificant ($p>.05$).

3.5 Procedural Errors.

As described previously, detection responses to both malfunction and altitude conflict events were always followed by a sequence of behaviors that served to resolve the particular event. Whenever any element of these behavioral sequences was performed out of order, was omitted, or an incorrect element added to the sequence, a procedural error was recorded. Such errors, like the memory errors above, occurred quite infrequently, with an error rate of only 2% during the first hour and 4% during the second. A Wilcoxon test performed on these data revealed the increase in errors from the first to the second hour to be nonsignificant ($p>.05$).

3.6 Videotape Analysis of Omission Errors.

Videotaped recordings of each subject's visual behavior during the session were examined, specifically with regard to visual activity during times when altitude events were not detected. Thus, for each missed conflict/no conflict event, visual activity was examined over the 90-sec period that the event was present on the screen. Because of problems with the video recorder, and because the subject's seating position at times prevented a complete analysis of facial orientation and visual activity over the entire 90-sec period, not all missed events could be analyzed. Of the 98 events missed by the subjects, there were 40 events for which visual activity data was available during all of the 90-sec scoring period. As indicated earlier, the intent of this analysis was not to provide precise information on fixation times, fixation points, or scanning patterns, but rather simply to gain information on general visual activity during times when subjects failed to detect aircraft targets at the same altitude. From preliminary viewing of the tapes, it was determined that any portion of the scoring period could be categorized in one of three ways: (1) Eyes open, head oriented toward screen, continuous scanning; (2) Eyes closed; (3) Eyes diverted from screen.

The above categories, while admittedly rather qualitative, served the purpose for which they were intended. This was to ascertain the extent to which the increase in frequency of missed events that occurred during monitoring could be attributed to subjects failing to detect these events simply because their eyes were either closed or diverted away from the display. Analyses of the tapes revealed that 97% of the scorable missed events occurred during periods in which subjects had their eyes open and were actively scanning the display. One event was missed because a subject's eyes were diverted from the display, but no missed events could be attributed to a subject's eyes being closed during the time the event was present.

4. Discussion

Detection times for the alphanumeric change used to indicate an altitude malfunction showed no evidence of any increase over the 2-hour session. Mean detection time averaged 9.2 sec, and these events were never missed by subjects. The time required to detect aircraft at the same altitude, however, increased significantly over the session, from an average of 19.6 sec during the first half hour to 28.8 sec during the final half-hour period. In addition to the increase in detection time, the frequency with which such events completely escaped detection by subjects also increased significantly. Four percent were missed during the first hour and 13% during the second. Taken together, these findings are consistent with those obtained previously using this task under comparable taskload conditions (Thackray and Touchstone 1985).

Although the ability to detect aircraft at the same altitude showed clear evidence of impairment over the 2-hour session, the processes contributing to this impairment are not immediately apparent. Clearly, the ability to detect such events involves more than just attention; memory and scanning would also appear to be important components. Yet with regard to the role of memory as a contributer to this decline, it should be noted that none of the other functions or subtask elements involving memory that were measured in the present study showed any evidence of decline during monitoring. Thus, neither failures to remember having responded to a particular no conflict altitude event nor failures to remember correct procedural sequences increased in frequency during the session. In like manner, although only a gross assessment of scanning activity was possible from the videotaped recordings of visual activity, there were no obvious indications that scanning was not taking place during times when behavioral evidence (missed events) might suggest inattentiveness. Further, the fact that detection times for the readily perceivable malfunction events showed no change across the session would also suggest that decreased scanning activity per se would not appear to be responsible for the decline in ability to detect aircraft at the same altitude. One is left to conclude, then, that the decrement associated with these events would appear to be specific to attention. A similar conclusion was also reached by Johnston <u>et al</u>. (1966) in an earlier study of complex monitoring. Performance decrement under high taskload conditions was found to result primarily from an increase in lapses of attention, the magnitude of which did not appear to be uniquely affected by differences in memory requirements of the task conditions employed.

Memory was not the only aspect of performance that failed to change during monitoring. There was also no evidence of change in measures of decision time, decision errors, or motor movement time. These findings are difficult to evaluate because, as noted earlier, studies of complex monitoring seldom report on behaviors apart from those directly related to stimulus detection. However, a few comparisons can be made. In an early study by Adams <u>et al</u>. (1961), an air traffic surveillance task was used to study the effect of prolonged monitoring on decision making, in addition to the usual measures of target detection. Half of the subjects made only a simple detection response to an alphanumeric symbol change while the remaining half were required, following detection, to make a four-choice evaluation indicating the nature and location of the change that had occurred. Over a 3-hour monitoring session, performance declined in the simple detection condition, but showed no evidence of decline in the condition in which decisions were required. These findings suggest that the decision requirements, rather than adding to performance decrement, appeared to have prevented it.

With regard to motor movement time, a subsequent study by Adams et al. (1962) again used an air traffic surveillance task to examine the effect of nine consecutive daily monitoring sessions, each 3 hours long, on detection time and on the movement time required to complete the detection response. This latter measure consisted of the time between the initial detection response and response to a second button on a panel 16 inches away. Although movement time did slow significantly within each session, the actual magnitude of this slowing was remarkably small, amounting to approximately 50 msec.

The findings of the present study that performance decline under high (16-target) taskload conditions was confined to attentional behavior, and within that realm only to the more difficult task of detecting two aircraft at the same altitude, would appear to support conclusions reached by Davis and Parasuraman (1982) that information processing demands placed on the observer may be one of the more significant determinants of performance decline in monitoring tasks. In order to examine this possibility within the context of our previous research, a post hoc comparison was made of the present findings with those of two of our earlier studies. All studies were equivalent in terms of the number of alphanumeric targets employed, critical event rates, and task durations. The principal difference between studies was in the type of critical events used. In the earliest of these studies (Thackray et al. 1979), the critical event consisted of the replacement of an aircraft's normal altitude value with the number "999." This critical stimulus, much like the malfunction events of the present study, was a readily apparent stimulus change requiring minimal information processing for its detection. In a subsequent study (Thackray 1982), critical stimuli consisted of a change in an aircraft's displayed altitude to a value that either exceeded an upper limit or was below a lower one. Like the "999" used in the earlier study, such changes could also be detected without reference or comparison to any other information displayed on the screen. Information processing requirements in the later study, however, would seem to be greater since altitude changes became signals not because they assumed some fixed numerical value, but because they were detected as having a value that exceeded previously specified upper or lower limits.

Mean detection times obtained in these two previous studies, along with data for the conflict/no conflict altitude events of the present study are shown in Figure 4. Examination of this figure suggests that an increase in the level of information processing required for critical event detection not only increases average detection time, but appears also to influence the decrement function. An ANOVA performed on the data of the three studies supported these impressions by revealing a significant effect for processing level ($F(2/101)=120.21$, $p<.001$) and a significant level by periods interaction ($F(6/303)=4.85$, $p<.001$). Since the analyses conducted in all three of these studies found a significant main effect for periods, it is not surprising that it was also significant in this analysis as well (F(3/303)=13.35, P<.001).

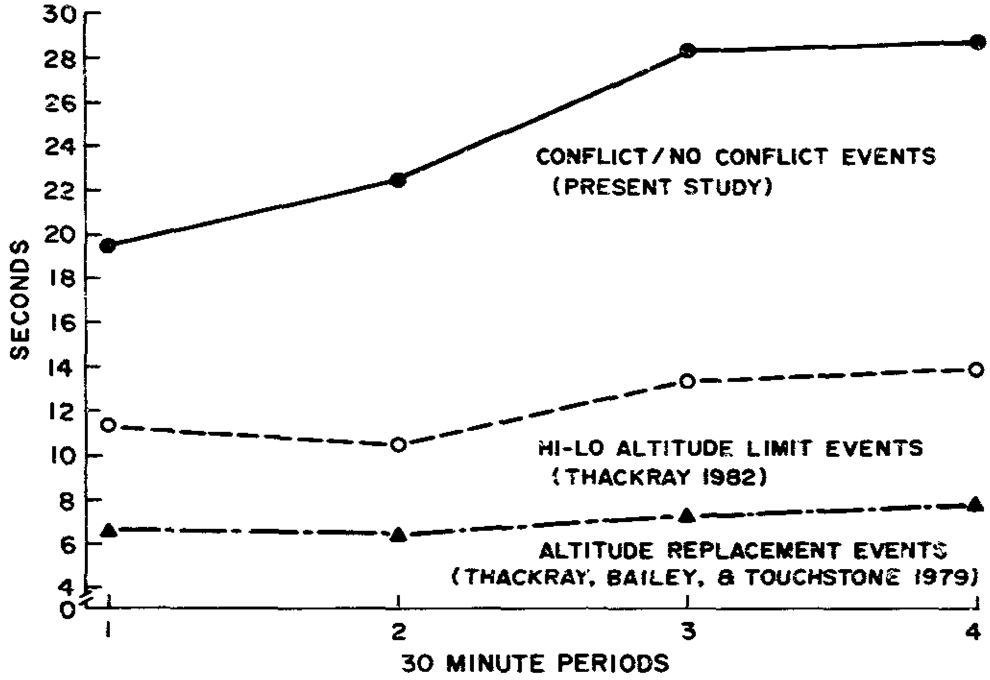

FIGURE 4. COMPARISON OF DETECTION TIMES FOR ALTITUDE EVENTS DIFFERING IN INFORMATION PROCESSING REQUIREMENTS.

In our previous study comparing monitoring performance under 8- and 16-target conditions (Thackray and Touchstone 1985), it was hypothesized that the requirement to passively monitor large numbers of targets over a prolonged period of time demands considerable effort, and that the greater decrement in performance found under the higher taskload condition was a reflection of the fatigue resulting from this effort. The results of the present study suggest that such fatigue effects are confined primarily to attentional processes; of the other behaviors that were measured (decision making, short-term memory, ability to correctly carry out procedural sequences, motor movement), none showed any increase in impairment over the 2-hour session. Further, the present study, in agreement with our earlier one (Thackray and Touchstone 1985), found that it was not detection of events that are readily apparent to the observer that showed evidence of decline under high taskload conditions. Rather, it was detection of those events that require considerable information processing in order to be "seen" by the observer that were most adversely affected by prolonged monitoring under these conditions. Data presented in Figure 4 suggest that information processing demands required for target detection may interact with visual taskload to influence the rate of attentional decline under conditions involving extensive scanning of multiple targets. Because this interpretation is based on a post hoc comparison of the findings of several different studies, additional research to examine the effect of declining attention on detection of targets differing systematically in processing requirements and presented under different levels of visual taskload is required before more definitive statements can be made. Hopefully, such research will enable us to specify more precisely the kinds of stimulus events that would benefit most from computer-aided detection, especially with the higher ratios of aircraft to controllers that are anticipated under the more automated ATC systems being contemplated (Swedish 1983).

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