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Effects of Monitoring under High and Low Taskload on Detection of Flashing and Colored Radar Targets

Richard I. Thackray, Ph.D.
R. Mark Touchstone, M.S.

Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

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16. Abstract

While midair collisions between aircraft are extremely rare occurrences, near midair incidents are more common. The present study sought to evaluate the gains in conspicuity that might be realized if flashing or color were added as redundant cues to indicate the presence of unexpected, nontracked aircraft entering controlled airspace and to examine the extent to which increased taskload and fatigue might influence the expected gains. Sixty-four subjects monitored a simulated air traffic control task over a 2-hour period for possible conflict situations (their primary task) under either high or low primary taskload conditions. They also monitored for occasional intrusions by light aircraft identifiable on the basis of target shape alone or with color and/or flashing added as redundant cues. Flashing as a redundant cue was found to be superior to color in all aspects tested; unlike color, detection of flashing targets was unaffected by screen location and by changes in primary taskload. Flashing was also least affected by monitoring fatigue. It was concluded that the superiority of flashing over color in attracting attention to objects in a display must be weighed against its possible potential for distraction. A practical means of accomplishing this in operational situations is through the use of touch sensitive displays to both acknowledge/confirm target location and to deactivate flashing.

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EFFECTS OF MONITORING UNDER HIGH AND LOW TASKLOAD ON DETECTION OF FLASHING AND COLORED RADAR TARGETS

On August 31, 1986, an Aeromexico DC-9 collided with a single engine Piper Cherokee Archer aircraft over Cerritos, California resulting in a total loss of 82 lives. According to the National Transportation Safety Board (NTSB) report, the Aeromexico flight was within the Los Angeles Terminal Control Area (TCA) and under radar control at the time, while the Cherokee, proceeding under visual flight rules (VFR) conditions, was not in radio contact with any air traffic control (ATC) facility. The accident occurred in clear weather with 14 mile visibility. The controller providing service to the Aeromexico flight stated that he did not observe the Cherokee's radar return on his display and therefore did not provide any traffic advisory to the Aeromexico flight regarding the VFR aircraft in its vicinity prior to the collision (NTSB, 1987).

While fortunately such midair collisions are extremely rare occurrences, "near midair" incidents are more common. In a review of near midair collision (NMAC) incidents occurring between the period 1983 to 1986, a recent FAA Office of Aviation Safety Report (FAA, 1987) revealed that pilot reported NMAC incidents increased from 475 in 1983 to 840 in 1986, a gain of 77 percent. Such an increase cannot be attributed simply to increased air traffic, which increased by only 7 percent over those years. The largest number of reports were associated with instrument flight rules (IFR) operators conflicting with VFR traffic during VFR flight conditions below 12,500 feet. The typical NMAC event was found to occur most frequently under good visibility conditions, during daylight hours (late morning to early afternoon), and in the vicinity of towered airports and/or within the radar coverage of the approach/departure environment. It should be noted that this set of circumstances is precisely the set that characterized the Cerritos collision.

There are many ways in which the likelihood of such near misses and mid-air collisions in air traffic control TCA's might be reduced. Following the Cerritos crash, the FAA completed a study of the TCA concept leading to 40 recommendations for improvement. These included, among others, such recommendations as specialized training to improve controller scanning techniques, improved radar equipment to minimize the possibility that a target may, at times, not be detected or displayed by the system, more rigid enforcement of regulations governing unauthorized intrusions of VFR aircraft into a TCA, and a requirement that all aircraft entering a TCA be equipped with altitude encoding (Mode C) transponders. (Without altitude reporting transponders, aircraft, such as the one involved in the Cerritos accident, typically appear simply as symbols -- dots, slashes or triangles -- on the radar screen; with a Mode C transponder, altitude is displayed adjacent to the symbol.) The Mode C requirement has been implemented and is now a requirement for 138 of the nation's busiest airports. That is, for an aircraft to operate within these TCA's, it must have a Mode C transponder. While this recent requirement will provide the controller with useful altitude information on nontracked targets, there is no assurance that such a requirement will completely eliminate further accidental or intentional intrusions of aircraft not equipped with Mode C transponders into controlled airspace. Indeed, there is the danger that the lowered expectancy of such aircraft being present in controlled airspace may reduce the controller's ability to detect these targets.

One obvious method of increasing the likelihood of such targets being detected would be to add, as a redundant cue, either flashing or a contrasting color to the displayed symbols. Both flashing and colored indicator lights are often used in visual displays for signaling purposes. However, although studies have been conducted to evaluate parameters related to the conspicuity of each type of signal (see Conners 1975, Gerathewohl 1957, and Markowitz 1971, for representative studies of flash rate and Kopala 1979, Luder and Barber 1984, Macdonald and Cole 1988, and Reynolds, White, and Hilgendorf 1972 for representative studies of color), little or no research has been conducted in which the relative effectiveness of flashing and colored signals has been compared within a single study. Although not actually employing color, Nesthus (1984) did report a study of this type in which visual search times were obtained to target symbols that appeared as either high contrast, as flashing, or as static (neither high contrast nor flashing) symbols against a background of nontarget symbols. He hypothesized that, relative to search times for static symbols, search times for the flashing target condition would be shortest,followed by search times for the high contrast condition. Surprisingly, high contrast targets were detected significantly faster than flashing targets. The author concluded that the superiority of contrast over flashing was because high contrast signals could be discriminated from background stimuli almost immediately through automatic preattentive processes. Flashing signals, however, because of the 1 Hertz (Hz), 50 percent duty cycle employed, required at least .5 second (s) before they could be seen as a flashing signal against a steady background.

The present study differed from the Nesthus study, as well as most other studies of signal conspicuity, in that a continuous monitoring task, rather than a discrete trials approach, was employed. Subjects performed a simulated ATC monitoring task under either high or low primary taskload conditions. A principal requirement of the primary task was to detect possible conflict situations between "tracked" targets; the secondary task involved the detection of small, triangular targets representing nontracked, non Mode C aircraft that had entered the subject's controlled airspace without authorization. Secondary targets were presented infrequently, at different screen locations, and in the presence of similar-sized green circles representing radar clutter. Depending on the condition to which subjects were assigned, secondary targets could appear as (i) nonflashing triangles of a noncontrasting (green) color, (ii) nonflashing triangles of a contrasting (red) color, (iii) flashing green triangles, or (iv) flashing red triangles. The study was designed to address and provide answers to the following questions:

1. What are the relative gains in conspicuity that might be realized if flashing or color were added as redundant cues to indicate the presence of unexpected, nontracked aircraft targets?
2. What are the effects, if any, of prolonged monitoring and increased primary taskload on the relative gains in conspicuity that are achieved through the use of flashing and color?

In addition to performance measures, subjective measures of attentiveness, tiredness, strain, boredom, irritation, effort, and difficulty were also obtained.

METHOD

Subjects

Sixty-four men and women, all paid university students, were assigned to eight equal-size experimental groups (high or low primary taskload and one of four triangle signal conditions). Subjects ranged in age from 18 to 29 years, and none had prior experience with the task used or previous ATC training. None were currently taking any prescription medication on a regular basis. All had normal color vision (as determined from the Ishihara test) and 20/30 or better visual acuity at 26.23 inches as determined from a Titmus II vision tester. This distance corresponded closely to the distance that a subject would normally be viewing the visual display. The Titmus II Peripheral Fields Test was also administered, with no subject failing to detect any of the lights positioned 0 to 85 degrees in both left and right horizontal visual fields.

Apparatus and Task Description

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 rectangle on the flight path, and an adjacent alphanumeric data block identified the aircraft and gave its altitude and groundspeed. Aircraft targets were updated every 6 s to reflect their new positions and any change in the alphanumerics. There were 8 aircraft on each flight path at all times; as one left the screen, another appeared.

In addition to the primary (alphanumeric) targets, the display also contained stationary "clutter" in the form of 4-mm diameter green dots. The triangular targets representing nontracked aircraft were similar in size to the dots and could appear in any one of eight different locations; four of the locations were near the extreme corners of the display and four were more centrally located. Figure 1 shows all of the possible triangle locations as well as the clutter and a typical pattern of alphanumeric targets.

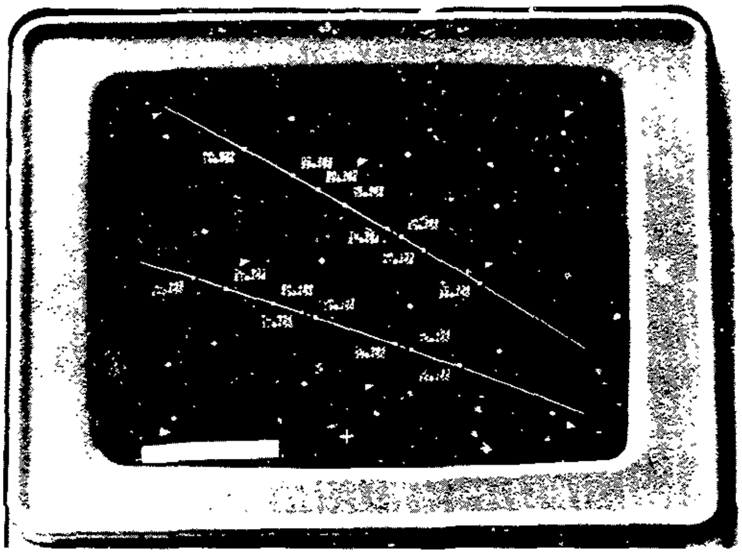

Figure 1. Subject's display showing clutter, all triangle locations, and a typical pattern of alphanumeric targets.

The primary task consisted of monitoring for two types of critical events. The first type was readily detectable and consisted of the appearance of three X's (designated an altitude malfunction event) in place of the three altitude numbers in a given data block. Subjects were told that the three X's signified that a malfunction had occurred in an aircraft's altitude transponder. Upon detection of such an event, subjects pressed a designated console button and performed a joystick/keyboard response to correct the malfunction.

The second type of critical event was considerably more difficult to detect because it was not immediately apparent: two aircraft at the same altitude on the same flight path. Any time such an event was detected, the subject was instructed to press an appropriate console button. If the event was not detected within a predetermined time limit, a "conflict alert" occurred signifying a possible conflict situation. (The two aircraft targets at the same altitude commenced flashing at a 1 Hz/s rate in conjunction with a 600 Hz/s, 65 dbA tone that pulsed at a 2 per s rate.) Any time a possible conflict was detected, either by the subject or following a "conflict alert" alarm, a decision response occurred. This was followed by a set of subsequent behaviors that differed depending on whether or not the event was determined to be a conflict situation. These aspects of the task, which have been described elsewhere (Thackray and Touchstone, 1989), are not relevant to the present study and will not be discussed here.

As previously indicated, the subject's secondary task was the detection of triangular targets representing nontracked, unidentified aircraft (designated as VFR intruders) that had entered the subject's controlled airspace. These targets were presented under the four possible color/flash conditions described earlier. For the flashing conditions, a flash rate of 4 Hz was used with a 125 ms on, 125 ms off duty cycle. Whenever one of these types of targets was detected, a console button was pressed and the target would disappear shortly thereafter. A target would also disappear if not detected within a 90-s timeout period.

Nine primary task and two secondary task critical events occurred during each 30 min of task performance, with no more than one event present at any given time. Time of occurrence of each type of event was fixed. Location of each successive secondary task target, however, was randomly assigned without replacement for each subject. Thus, although interstimulus intervals were fixed for triangular targets, the order of locations differed for each subject. Subjects were given no information regarding the frequency of events or their order of occurrence.

Color and Luminance Measurement and Specification

All color and luminance measurements were made using a Photo Research Spectrascan with the recording head of the instrument located 22 cm from the face of the visual display. The 22 cm distance corresponded to the average distance of a subject's eyes from the display. To approximate real-life radar viewing conditions, no attempt was made to restrict head movements, although task requirements to use the keyboard and panel buttons kept head locations of subjects at a reasonably constant distance from the screen. The particular red and green colors used were selected from the available DEC VS11 colors and were chosen to be as close as possible to the CIE (Wyszecki and Stiles, 1982) coordinates (red X=.650, Y=.336; green X=.329, Y=.600) specified for the FAA's Advanced Automation Sector Suites (FAA, 1985). While it was not possible to achieve a perfect match of the red/green luminances with the VS-11 display, luminances of the colors selected were reasonably close. Color and luminance values are shown in Table 1.

TABLE 1
Color and Luminance Values of Display Elements

Display Elements	**Hue**	**CIE Coordinates X**	**Y**	**Luminance (in foot-lamberts)**
Alphanumerics	Green	.233	.628	4.94
Clutter	Green	.233	.628	4.94
Triangle	Green	.233	.628	4.94
Triangle	Red	.615	.342	6.72

Video Recording Methodology

The outputs of separate Sony Charge Coupled Device (CCD) cameras, used to monitor both the subject's facial orientation and the visual display, were combined by means of a special effects generator and displayed on a video monitor. A small indicator light, not visible to the subject, was located above the console and was illuminated each time a secondary target (triangle) was displayed on the screen. Continuous videotape recordings enabled subsequent playback and analysis of the subject's visual behavior during times when secondary targets were presented. Indirect lighting was used in the subject's room, and the level of illumination at the display was 23 lux.

Procedure

Upon arriving at the laboratory, subjects were given general information about the task and tested for color vision and visual acuity. Subjects then received detailed task information describing each kind of critical event along with the appropriate responses to each. Short practice sessions followed the description of each type of event. A final combined session provided practice on all primary and secondary task events and also familiarized subjects with the conflict alert alarm. (For the secondary task, subjects received practice only on the particular triangle condition to which they had been assigned.)

Following the practice sessions, subjects completed a nine-point subjective rating scale to describe their present feelings of attentiveness, tiredness, strain, boredom, and irritation. The final set of task instructions explained that the conflict alert alarm was essentially the same as that used in contemporary ATC systems to warn controllers of possible conflict situations, and that in this particular experiment the alarm would go off whenever the computer determined that they had failed to detect a possible conflict in the minimal allowable time. Subjects were told that completing the experiment without the alarm occurring more than once would earn them a $16 bonus. Each time the alarm occurred after that, however, would halve the remaining bonus until, with 5 or more alarms, no bonus would remain. It was emphasized that, while the bonus was dependent only on the speed with which they were able to detect possible conflict situations between controlled aircraft, it was important that they continued to maintain constant scanning for VFR intruders and for altitude malfunction events. Subjects assigned to the high taskload condition had only 26 s to detect a possible conflict situation before the alarm would occur; subjects in the low taskload condition had 90 s to detect possible conflicts before the alarm was triggered. (The 26 s value corresponded to the mean detection time, as obtained from several of our previous studies, for this type of 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-h task session. Sound level of this noise at the subject's head location was 62 dbA.

At the completion of the 2-h task period, subjects were administered a second version of the rating scale that contained additional items relating to perceived task difficulty and the amount of effort required to maintain task concentration. This was followed by a thorough debriefing concerning the purposes of the experiment.

RESULTS

Detection Times for Secondary Targets

Initial examination of the response data for the four secondary target conditions revealed that subjects failed to detect nonflashing/noncolored targets most frequently, with nonflashing/colored targets showing the next highest failure rate. (For purposes of this paper, "noncolor" refers to targets having the same color as the green background clutter, while "color" refers to the red targets.) Further, in both cases, poorest detection appeared to occur under the high primary taskload condition. Table 2 shows miss rates (targets not detected within the 90-s stimulus duration period) for the various conditions.

Because missed events occurred so infrequently, it seemed desirable to combine them in some way with measures of detection latency in order to arrive at a composite measure that would more adequately reflect the totality of detection performance. Assuming that subjects were engaged in monitoring the display during times when events were missed, it is to be expected that each event would eventually have been detected within some period of time in excess of the 90-s stimulus duration period. In order to verify this assumption, videotape recordings of visual behavior during the session were examined, specifically with regard to visual activity during times when a triangle target was not detected. This analysis revealed that all missed events occurred during periods in which subjects had their eyes open and were actively scanning the display. Each missed event, then, was arbitrarily assigned a value of 90 s and averaged in with detection latencies in order to yield a single overall measure of detection performance. The values thus obtained under conditions of high and low primary taskload are shown in Figure 2. Only two triangle events occurred during each half-hour period; therefore, to provide more stable measures of detection performance, the data were plotted, and subsequent analyses conducted on the combined data for first and second performance hours.

TABLE 2

Percentage of Secondary Targets Missed Under the Various Task Conditions.

Primary Task Condition	Secondary Task Condition	Total Missed Across all Ss	Percent of Total Presented
High Taskload	Nonflashing/noncolored	9	14
	Nonflashing/colored	3	5
	Flashing/noncolored	0	0
	Flashing/colored	0	0
Low Taskload	Nonflashing/noncolored	2	3
	Nonflashing/colored	1	2
	Flashing/noncolored	1	2
	Flashing/colored	0	0

A four-way repeated measures analysis of variance (ANOVA) was used to analyze the data shown in Figure 2. Between-group factors were Primary Taskload (High, Low), Flash (Flashing, Nonflashing), and Color (Colored, Noncolored), with Period (First Hour, Second Hour) as the within-group factor. Because of recording problems, data for 3 of the 64 subjects tested were incomplete and these subjects were not included in the analysis. The ANOVA revealed significant effects for Flash ($F(1/53)=23.41$, $p<.001$), Color ($F(1/53)=3.85$, $p=.05$), and Periods ($F(1/53)=18.40$, $p<.001$). In addition to these main effects, there were significant interaction effects for Primary Taskload by Flash ($F(1/53)=4.81$, $p<.03$) and Flash by Period ($F(1/53)=5.44$, $p<.02$). No other effects were significant ($p>.05$).

Examination of Figure 2 clearly reveals the significant period effect to be the result of a general increase in detection time across the session for virtually all conditions. Interpretation of the significant effect of flash is also quite apparent: Under both high and low taskload, and for both colored and noncolored stimuli, shortest detection times were associated with flashing conditions. Likewise with color, Figure 2 reveals that under both flashing and nonflashing conditions and within each taskload condition, colored stimuli were invariably detected sooner than noncolored stimuli.

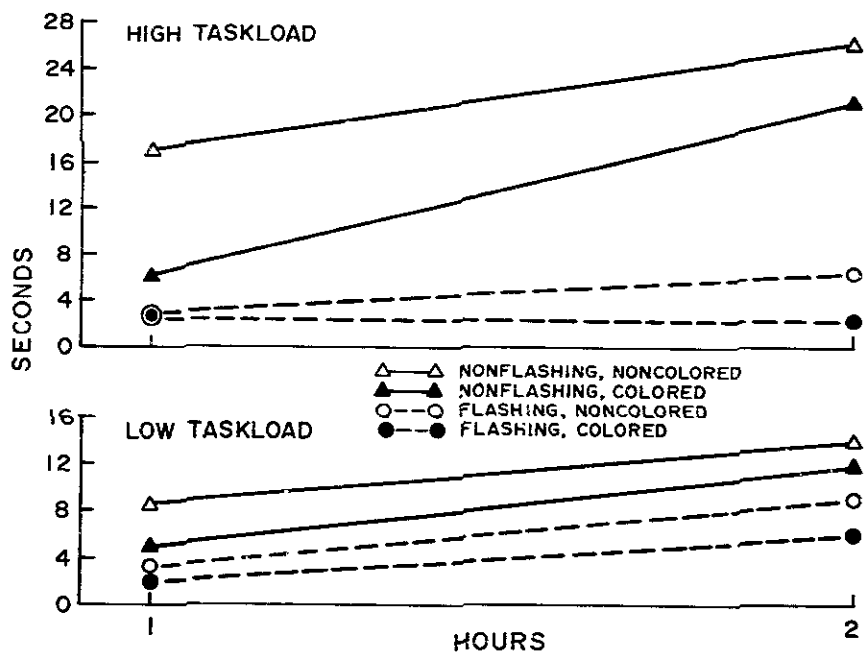

Figure 2. Mean detection times during first and second hours for each secondary task condition under high and low primary taskloads.

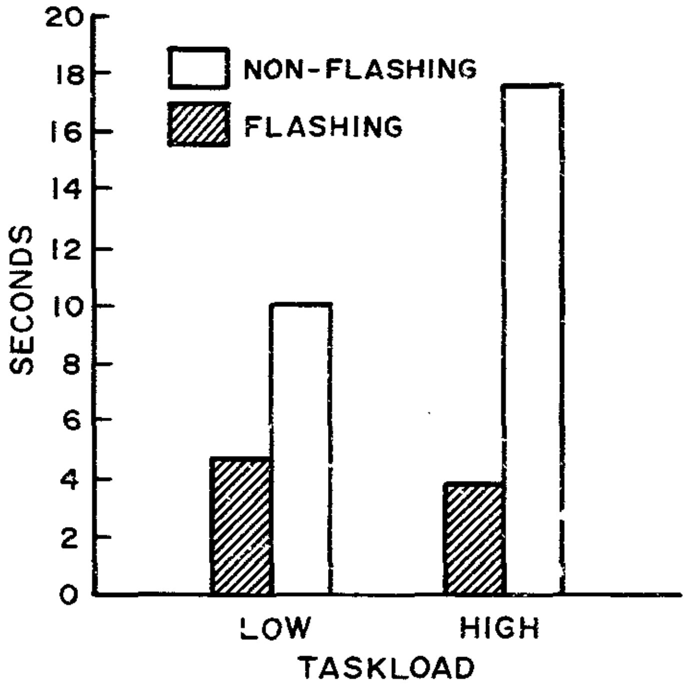

Figure 3. Mean detection time for nonflashing and flashing secondary task targets under high and low primary taskload conditions.

In order to clarify the taskload by flash interaction, the data were plotted in the form of a bar graph and are shown in Figure 3. Although detection time for nonflashing targets is shown to exceed that of flashing targets under both taskload conditions, detection of nonflashing targets appears to be influenced far more by an increase in taskload than detection of flashing targets, which actually shows a slight decrease in detection time with increased taskload. Tests of simple effects of the interaction revealed detection time for nonflashing targets to be significantly greater than detection time for flashing targets under the high taskload condition ($F(1/53)=30.6$, $p<.001$); under low taskload, detection time for flashing and nonflashing targets did not differ ($F(1/53)<1.00$).

With regard to the significant flash by period interaction, it is evident from Figure 2 that detection times for nonflashing stimuli, whether colored or not, increase more from the first to the second hour than do detection times for flashing targets. Although the figure suggests this to be almost entirely restricted to the high taskload condition, the taskload by flash by periods interaction failed to reach significance ($F(1/53)=2.56$, $p>.05$).

Location Effects

It will be recalled that half of the secondary targets were presented at outer locations of the display and half at inner locations. To examine possible relationships of flashing, color, and taskload to detection of targets in central and peripheral locations, a second ANOVA was conducted that was essentially the same as the previous one, except that "location" (inner, outer) replaced "period" as the within-group factor. Since only within-groups effects are pertinent, only these will be discussed. The main effect of location was found to be significant ($F(1/53)=21.35$, $p<.001$), with detection time for outer locations (Mn=12.93 s) exceeding detection time for inner ones (Mn=5.10 s). Such "edge effects" have been reported by others for both visual search (Baker, Morris, and Steedman, 1960; Enoch, 1959) and radar monitoring tasks (Baker, 1958), so this was an expected finding. The only other significant effect was the flash by location interaction shown graphically in Figure 4.

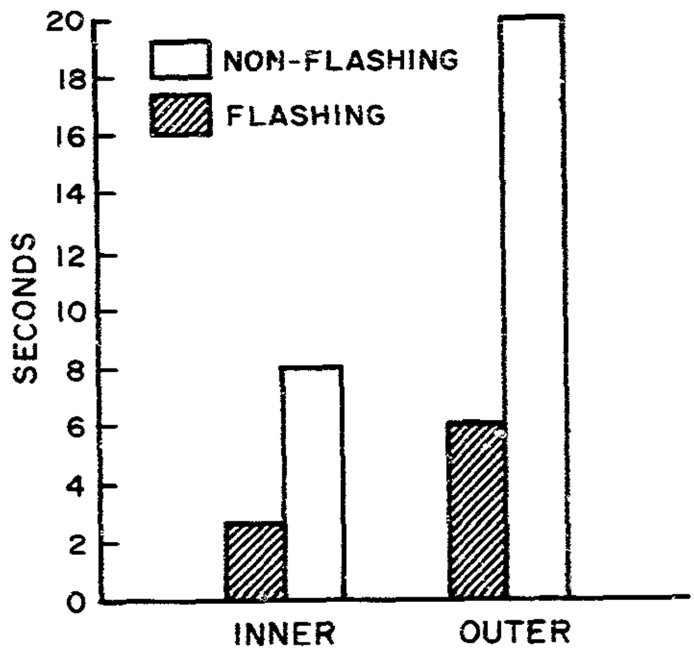

Figure 4. Mean detection time for nonflashing and flashing targets presented at inner and outer display locations.

Tests of the simple effects of the interaction revealed no difference between in- - and outer locations when stimuli were flashing ($F(1/62)=2.29$, $p>.05$), but a significant . -cation effect when flashing was not employed ($F(1/62)=26.85$, $p<.001$).

Primary Task Performance

With a visual taskload of 16 primary targets, we have shown previously that time to detect altitude malfunction events (three X's) in a data block takes approximately 8-10 s, with no increase in this time over 2 h of monitoring (Thackray and Touchstone, 1989). Consequently, detection time for this type of event serves as a useful estimate of general scanning activity during a monitoring session.

Mean time to detect altitude malfunction events for subjects in the high and low taskload conditions is shown in Figure 5. A repeated measures ANOVA revealed no significant change across the 2-h session in detection time for these events ($F(3/183)=1.21$, $p>.05$), no difference between conditions ($F(1/61)<1.00$), and no significant interaction ($F(3/183)<1.00$).

Determination of the effects of primary taskload manipulation on time to detect possible conflict situations (designated conflict/no conflict events) was somewhat more difficult because distributions of detection times under the high taskload condition were truncated at 26 s (the allowable detection time before the "conflict alert" alarm occurred). The approach adopted was to determine for each 30-min period the frequency of detection times equal to or greater than 26 s. For the high taskload condition, this consisted simply of counting the number of alarms produced by each subject during successive 30-min periods; for the low taskload condition, all detection times equal to or exceeding 26 s during these periods were counted. Mean frequencies of occurrence are shown in Figure 5. A repeated measures ANOVA of these data revealed a significant main effect for periods ($F(1/61)=59.58$, $p<.001$), but no difference between taskload conditions ($F(1/61)<1.00$) and no significant interaction of taskload by periods ($F(1/61)=1.03$, $p>.05$).

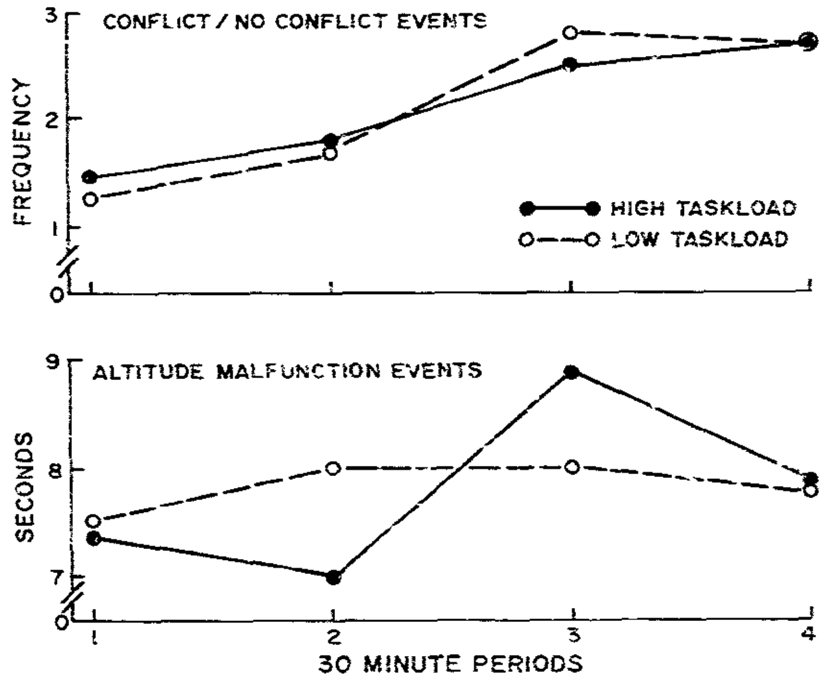

Figure 5. Mean detection times across 30-min periods for altitude malfunction events under both taskload conditions. Also shown in this figure are the frequencies with which detection times for conflict/no conflict events equaled or exceeded 26 s under the two taskload conditions.

Subjective Data

Although manipulation of primary taskload exerted no significant effect on measures of primary task performance, this was not the case with most of the subjective measures that were obtained. These data are shown in Table 3.

As indicated in the table, both groups experienced a significant decline in attentiveness, accompanied by significant increases in tiredness, boredom, irritation, and effort from beginning to end of the monitoring session. However, in addition to these main effects, there were significant interactions of period with (a) attentiveness ($F(1/62)=6.83$, $p<.01$), (b) boredom ($F(1/62)=3.91$, $p=.05$), (c) irritation ($F(1/62)=5.71$, $p<.01$), (d) effort ($F(1/62)=4.34$, $p<.05$), and (e) difficulty ($F(1/62)=6.78$, $p<.01$). Interpretation of these interactions is clearly revealed by examining the data of Table 3. Relative to low taskload, high taskload was associated with a greater decrease in attentiveness along with a greater increase in boredom, irritation, effort, and difficulty.

TABLE 3

Mean Rating Scale Values for High and Low Taskload Con .tions. Also Shown are Combined Values Across Conditions.*

		Measurement Periods			
Variable	**Taskload**	**Pre Task**	**Post Task**	**F****	**p**
Attentiveness	High	7.6	4.3		
	Low	7.7	5.9		
	Combined	7.6	5.1	71.93	<.001
Tiredness	High	5.0	6.5		
	Low	4.5	5.9		
	Combined	4.7	6.2	37.27	<.001
Strain	High	4.6	5.4		
	Low	4.6	4.5		
	Combined	4.6	4.9	1.74	NS
Boredom	High	2.7	6.2		
	Low	2.8	5.2		
	Combined	2.7	5.7	130.91	<.001
Irritation	High	1.3	3.0		
	Low	1.3	2.0		
	Combined	1.3	2.5	43.04	<.001
Effort***	High	3.4	6.8		
	Low	3.8	5.8		
	Combined	3.6	6.3	67.17	<.001
Difficulty***	High	3.2	4.9		
	Low	3.0	2.8		
	Combined	3.1	3.8	4.71	<.05

* Higher numerical values indicate higher levels of the variable, with 5 representing the midpoint or middle value.
** Only the F values for the Periods effects are shown here; between-groups and interaction effects are discussed in the text.
*** Measures for these variables were obtained at the end of the session and reflect perceived effort and difficulty as experienced at the beginning and end of the task period.

DISCUSSION

An effective warning or alerting signal should literally capture attention by "popping out" as an automatic preattentive segregation of figure from background. (Treisman, 1982). One's attention can then be focused on those aspects of the signal that may require further information processing. This study compared the use of color and flashing as redundant cues to aid in the detection of small, triangular targets signifying unexpected and unidentified aircraft that had intruded into controlled airspace. As expected, addition of either color or flashing as redundant cues significantly reduced detection time relative to detection on the basis of shape alone. When shape served as the only cue, mean detection time was 17.96 s. With the addition of color, detection time decreased to a mean of 10.37 s, a gain of 42 percent over shape alone. This gain compares quite favorably with Christ's findings that the use of color (regardless of whether it is a completely or partially redundant cue) will reduce search time for objects differing in shape by at least 34 percent (Christ, 1975, p. 561). Flashing, however, proved to be considerably more effective than color in reducing detection time. When added to shape, flashing further reduced detection time to a mean of 5.29 s, a gain of 71 percent over shape alone. An additional, but much smaller, increment resulted from combining color with flash. Mean detection time with this combination was 3.20 s, or a gain of 82 percent.

While it should be of little surprise that previous studies have generally found flashing signals to be superior to steady ones in capturing attention (Conners 1975), the gains reported are not as high as one might expect. Gerathewohl (1957), for example, compared detection times to a steady light with times to detect lights flashing at 1 to 4 Hz under differing conditions of brightness contrast. Detection time was related to both flash rate and contrast. Maximum gain (49 percent) was achieved using the highest flash rate and lowest contrast; the same flash rate under high contrast conditions yielded a gain of only 26 percent. Conners (1975), in a study designed to investigate characteristics of aircraft signal lights that would enhance a pilot's ability to "see and avoid" other aircraft, compared detection of point source steady lights with lights of differing frequency and brightness presented against a star background. Although detection times to the flashing conditions (1 to 4 Hz) were numerically superior to those obtained to steady lights, the differences reached significance only at the medium and low intensity levels. Using data reported in this study, maximum gains under medium and low intensity levels were computed to be 25 and 37 percent respectively.

It is evident, then, that the gain in conspicuity that resulted from the use of flashing events in the present study is greater than that reported by others. This might be attributed in part to differences between studies in experimental conditions and procedures employed; for example, assigning a value of 90 s to missed signals to obtain a single measure of detection efficiency. With regard to this latter procedure, however, even with these 90-s missed signal values eliminated from the latency distributions, the resulting gain over shape alone was still found to be 61 percent.

Parasuraman (1986), in a recent review of monitoring research, asks the question "Does the effectiveness of a warning device signaling the failure of a component in a semi-automated system (or the failure of the warning system itself) vary with the operator's level of vigilance?" The findings of the present study would suggest the answer to this question to be a qualified "yes." While all of the triangle conditions became less effective in attracting attention as monitoring progressed, this decline in effectiveness was found to be significantly less for those conditions in which flashing was employed. The fact that color failed to show a similar interaction with time on task was somewhat surprising, although it should be noted that virtually no research has actually examined the effects of color on the performance of vigilance or monitoring tasks. The one study of this sort of which the authors are aware employed a meter monitoring task in which the meter hands were colored red, while numbers, frames, and background were colored blue, green and yellow respectively (Pfendler and Widdel, 1986). A comparison of monitoring performance using the colored display with performance under achromatic conditions revealed a progressive, significant increase in detection time under achromatic conditions, but not when color was employed. The intent of this particular study, however, differed somewhat from that of the present one, since it dealt with the effectiveness of color in sustaining arousal, not with the relative effectiveness of color as an alerting or warning signal during prolonged monitoring.

Numerous studies have shown that increasing the attentional demands of a primary or central task tends to impair performance on secondary tasks (Bahrick, Fitts and Rankin, 1952; Bursill, 1958; Esterbrook, 1959; Leibowitz and Appelle, 1969; Webster and Haslerud, 1964, Williams, 1982, 1985). Consequently, we anticipated that increasing the attentional demands of the primary task used in the present study would have a similar adverse effect on secondary task performance. What was not known was the extent to which adding flashing or color as redundant secondary task cues might mitigate this expected impairment. Varying the time available for conflict detection, coupled with loss of a portion of the financial incentive each time the conflict alert occurred, proved to be an effective means of manipulating task demand; the condition in which subjects had only 26 s available before the conflict alert occurred was rated as being more difficult and with greater effort requirements than the condition in which 90 s was available for detection of possible conflicts. The expected adverse effect of high primary taskload on secondary task performance, however, was found to apply only to nonflashing targets; these took significantly longer to detect under high than under low taskload conditions. Flashing targets were detected with equal rapidity under either taskload condition. Color was of no apparent benefit in offsetting the apparent reduction in the functional field of view that resulted from an increase in taskload.

Not only were detection times of flashing targets unaffected by taskload conditions, they were also unaffected by the location on the display in which these targets appeared. Nonflashing targets, on the other hand, were detected significantly more slowly when presented in peripheral locations than when they appeared in the more central locations. Thus, the "edge effect" reported by others for both visual search (Baker, Morris, and Steedman, 1960; Enoch, 1959) and radar monitoring tasks (Baker, 1958), was found to apply only to nonflashing targets.

Although the principal reason for manipulating primary taskload was to examine its effect on secondary task performance, some mention of the effects of this manipulation on the primary task itself is in order. The lack of any performance decrement associated with the readily perceivable altitude malfunction events, coupled with evidence of a significant decline in detection efficiency for conflict/no conflict events, is consistent with our previous findings using essentially the same visual task, albeit without the secondary or VFR targets (Thackray and Touchstone, 1989). Evidence presented in this earlier study led us to hypothesize that monitoring under relatively high visual taskloads requires considerable effort, and that the fatigue resulting from this effort adversely affects detection efficiency for critical events requiring considerable information processing for detection, but has little effect on target changes that are readily perceivable (e.g., altitude malfunction events).

On the basis of our previous research, we would have expected that VFR intruder events, which are similar in information processing requirements to altitude malfunction events, likewise to show no increase in detection time over the monitoring session. That these events did show an increase suggests that our earlier hypothesis requires some modification. Possibly, fatigue resulting from the effort required to sustain attention during prolonged monitoring acts to focus one's diminishing or narrowing attention on those task aspects to which highest priority has been assigned. This could account for the finding that VFR intruders, as secondary task events, showed a significant decline in detection efficiency over time, while altitude malfunction events, embedded as they were within the primary task of searching for possible conflicts, showed no increase in detection time.

CONCLUSIONS AND RECOMMENDATIONS

It was not the intent of this study to address the technical problems that undoubtedly would be associated with adding color or flashing to selected types of radar targets in contemporary ATC systems. Rather, the purpose was simply to evaluate the extent to which the conspicuity of unexpected, nontracked aircraft radar targets might be enhanced if it were feasible to add color or flashing as redundant cues to such targets, and how such gains might be affected by prolonged monitoring and increased taskload. With this in mind, the findings clearly suggest that if one wishes to increase the conspicuity of unexpected, unidentified aircraft entering a controlled airspace in a manner that is minimally influenced by changes in primary taskload, by location of the target on the radar screen, or by the fatigue associated with prolonged monitoring, one should employ flashing, rather than color, as a redundant cue to attract attention. Flashing is such a compelling cue, however, that its alerting qualities must be weighed against its potential for distraction. In terms of practical application in ATC displays, it is recommended that flashing be used much as it was in the present study, i.e. as a means of directing initial attention to an unexpected, unnoticed target. Once this is achieved, the controller's response to the event, preferably through use of a touch sensitive display, would serve both to deactivate the flashing and to confirm that the controller had located and acknowledged the target.

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