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THE EFFECT OF MONITOR TYPE AND DISPLAY ORIENTATION ON THE CLASSIFICATION OF TARGETS ON A SIMULATED DYNAMIC PASSIVE SONAR DISPLAY

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ABSTRACT

With current sonar technology the operator must handle large quantities of data. The primary medium for displaying these data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the processing of sonar information from visual displays. The current study examined the impact of two display characteristics on the classification of targets on a Frequency-Time-Intensity (FTI) display. The first was type of monitor - multichrome or monochrome. Many systems use a monochrome monitor because its resolution to addressability ratio is usually superior to that of a multichrome display at an equivalent addressability. The second was orientation of the signals relative to the orientation of the CRT raster. Currently, the signals on an FTI display are perpendicular to the CRT raster. The study examined the benefit of having target lines on an FTI display fall along the scan lines of the CRT. There were no significant differences in classification performance as a function of monitor type or display orientation. However, trends in the data supported the use of a FTI display format in which targets lines fall along the scan lines of the CRT.

EXECUTIVE SUMMARY

With current sonar technology the operator must handle large quantities of data. The primary medium for displaying these data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the processing of sonar information from a visual display. Thus, DCIEM was tasked to investigate the impact of two display characteristics on the processing of information on a frequency-time-intensity (FTI) display. The first of these was type of monitor - multichrome (multiple phosphors or guns) versus monochrome (single phosphor). Current sonar systems in the Canadian Forces use a single phosphor monitor because its resolution is believed to be superior to a multichrome monitor. However, there is considerable pressure to switch to a multichrome monitor for consistency with other computer-based systems and to take advantage of the benefits associated with colour coding. The second factor investigated was the orientation of the signal lines on an FTI display relative to the orientation of the raster of the CRT. For consistency with paper FTI displays, frequency is plotted along the x axis and time along the y axis on a CRT. One consequence of this decision is that the signals are perpendicular to the scan lines of a CRT. It would seem useful to capitalize on the inherent line structure of the CRT when presenting images, such as an FTI display, that contain line patterns that are predominantly in one direction.

An initial set of studies examined the impact of these two factors on the detectability of signal lines on a FTI display. Detection performance was similar on the two types of monitors, but there was a small but significant improvement in detectability when the FTI display was modified so that the signal lines fell along the scan lines of the CRT. The current study examined the impact of these two factors on the classification of targets on a FTI display. Factors such as line visibility, display clutter, and monitor resolution may impact on operator fatigue which may in turn affect an operator's cognitive performance. Subjects were trained to classify a set of targets. During testing, targets were presented in random order, over time, on a simulated dynamic FTI display. Thus, new targets were added to the bottom of the display at regular intervals, moved slowly up the display, and disappeared off the top as they would in an operational system. Consequently, the display became increasingly cluttered over the test period of one hour.

In the monitor comparison study, subjects completed the classification task on both types of monitors. No significant differences in performance were found. In the second study, subjects were trained and then tested on either an FTI display in the standard configuration or an FTI display that had been rotated 90 degrees so that time fell along the x axis and frequency along the y axis. Again, there were no significant differences in classification performance on the two types of displays. However, trends in the data supported the use of a rotated FTI display format in which target lines fall along the scan lines of the CRT.

It was recommended that the advantages of using a multichrome monitor for displaying passive sonar data be investigated and that field trials be conducted on the impact of rotating a FTI display so that signal lines fall along the scan lines of the CRT.

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INTRODUCTION

Background

Improvements in signal processing algorithms and computing power have resulted in a considerable increase in the amount of information that can be extracted from sonar sensors. Different sectors of the ocean can be monitored separately and a wide range of frequency resolutions, update rates, and temporal resolutions can be made available to the operator. The most common format for presenting passive sonar information visually is the frequency-time-intensity (FTI) display. The FTI display shows the output of 'x' narrowband filters over 'y' previous time periods. The average energy in one of the x frequency bands (or bins) over one of the y time periods is shown by brightness (on an emissive display) or darkness on a paper display. The energy in all frequency bins for a single time bin appears as a single, variable intensity, line. Targets appear as sets of lines against a noisy background.

The primary medium for presenting passive sonar data on FTI displays is the electronic display. It provides considerable flexibility in terms of how the information can be displayed at any point in time. The wide array of electronic displays available allow the system designer the opportunity to select the most suitable one for the task. On the other hand, this flexibility and choice means that the system designer must have a good understanding of how display characteristics can impact on the detection and classification of sonar targets to design an effective system.

To assist in this process, DCIEM was tasked(1) to investigate the impact of two display characteristics on the processing of information on a passive sonar display. The first of these was type of monitor - multichrome (multiple phosphors or guns) versus monochrome (single phosphor). The second factor investigated was the orientation of the signals relative to the orientation of the raster on the CRT.

Currently, passive sonar systems in the CF use monochrome monitors. The amount of information presented on an FTI display is usually a function of CRT addressability. Addressability is a function of the display controller and refers to the number of specific points or x,y coordinates on the screen that can be selected. Whether each of those points is visible depends on the resolution of the screen. Resolution is usually defined as the width of a spot or pixel on the CRT when its luminance falls to 50% of maximum. Ideally the ratio of addressability to resolution should be one(2). As addressability exceeds resolution, pixels start to overlap and contrast between adjacent pixels of different intensity decreases. As well, the user's ability to discriminate line pairs (two lines separated by a single line of pixels) decreases.

With shadow-mask CRTs (the most commonly used multichrome CRT), resolution is limited by the pitch of the shadow mask (distance in millimetres between vertically adjacent mask-hole centres). Usually, a minimum line width of 1.1 to 1.2 times the mask pitch is adequate(2). In order for resolution and addressability to be similar, addressability must be reduced, relative to an equivalent monochrome monitor, which reduces the amount of information that can be presented on the multichrome screen.

To date, the addressability of monitors used on passive sonar systems has been based on the resolution of monochrome CRTs. If a similar addressability is used on a shadow mask monitor, contrast and the visibility of line pairs may be degraded.

The second factor to be investigated was orientation of the FTI display. For consistency with paper displays, frequency is plotted along the x axis and time along the y axis. One consequence of this decision is that the signals are perpendicular to the scan lines of a CRT. In a raster scanned CRT (the type used most consistently for sonar displays), the electron beam scans horizontally across the field, is deflected back at the end of the line, and scans across the next portion of the screen. It would seem useful to make use of this inherent line structure in the CRT when presenting images that contain line patterns that are predominantly in one direction. There are two possible ways of presenting the FTI display so that signals fall along the scan lines of the CRT. The simplest is to display frequency along the y axis and time along the x axis. However, this could necessitate considerable retraining of the sonar operators. Although operators are trained to base their classifications on an analysis of the signal lines on the display, successful classification usually involves matching the pattern on the screen with an internal template that has been built up as a result of extensive experience with similar patterns(3). Changing the orientation of the FTI display could reduce the effectiveness of this pattern matching process in the short term. The second method would be to rotate the monitor so that the scan lines are vertical. Signals would fall along the scan lines when the the data are presented in the standard format on this rotated monitor.

A previous study(4) under this tasking examined the impact of these factors on the detection of signals on a simulated static FTI display. In the first experiment in that study, which compared detection on a monochrome and multichrome monitor, performance was identical on the two monitors. The second experiment compared detection when the FTI displays were presented in the standard format, when the time and frequency axes were reverse, and when the monitor was rotated so that the axes appeared in the standard format, but the time axis was parallel to the scan lines. The data showed that there was some advantage to having signal lines fall along the scan lines of the CRT. Primarily, moderately detectable lines were detected more consistently. This suggests that the visibility of lines was being improved. The largest improvement in detectability was found with signal lines which were separated from higher intensity lines by a single row of pixels. In that case, detectability improved as much as 2dB. There was no difference between rotating the display and rotating the monitor. Nor did subjects in this study have any problem in moving from a display with time along the x axis to one with time along the y axis and vice versa. However, those subjects could not be considered highly trained.

Current Study

Both of the above parameters would be expected to affect detection primarily. However, there is always the possibility that classification performance could be affected. Classification of sonar targets has been shown to depend on the operator's ability to associate the current pattern with learned templates(3). Factors such as line visibility, display clutter, and display resolution may affect operator fatigue and stress levels which may in turn impact on cognitive performance. Thus, it was decided to evaluate the impact of these same parameters on classification performance. The experiments were carried out using a sonar display simulation system that had been developed to study the impact of display and task parameters on classification of passive sonar targets(5). Subject were trained to recognize a set of targets using a static FTI display that presented one target pattern at a time. Target lines extended the full length of the display. Subjects were then tested on their ability to recognize these targets on a dynamic FTI display. In the dynamic display, targets, noise lines and noise background dots were added to the display pixel by pixel, a line at a time at regular intervals. The top line of pixels was removed and the remaining lines moved up to make room for the new line of pixels added to the bottom of each FTI display. Thus, targets appeared at the bottom of the display and move up it over time gradually disappearing off the top as in an operational system. During the test sessions, subjects were required to identify targets that were added to the display at regular intervals over a sixty minute period.

Two experiments were run. The first compared performance on the monochrome and the multichrome monitors using the standard display format. The second compared the standard and display rotated format on the monochrome monitor. The classification task requires considerably more training than a detection task. To keep the experiments manageable, it was decided to run only one of the rotated conditions because the results on the two rotated modes in the previous study(4) had been similar. The display rotated condition was chosen because it allowed us to look at whether moving from one orientation to the other had a negative impact on performance.

METHOD

Subjects

A total of 15 observers, 8 males and 7 females, participated in the experiments. They ranged in age from 19 to 35 (mean = 24.3) and had normal or corrected-to-normal vision based on self-report, as well as a measure of visual acuity (Regan Chart) and a measure of contrast sensitivity (Nicolet CS2000 System). All subjects were naive to the task, but they were given a complete explanation of the study and the task before giving their consent. They were recruited from DCIEM personnel and from nearby universities and were compensated for their participation according to federal government guidelines.

Apparatus

The Sonar Display Simulation System was controlled with a Northern Micro personal computer with an 80486 processor and an ATI Graphics Ultra Pro video card. The simulation was displayed on either a 51 cm. Nanao multichrome monitor or a 53 cm. Nanao greyscale monitor.

The addressability of both monitors was set to 1024 pixels by 764 lines and the active area of the screen was equalized between the monitors such that each pixel had a nominal visual angle of 2.3 min. of arc at a viewing distance of approximately 53 cm. The x,y chromaticity coordinates were 0.348, 0.400 for the greyscale monitor and 0.333, 0.395 for the multichrome monitor[1] at a luminance of 32 cd/m^2. Interaction with the screen was carried out using a mouse and the keyboard. Subjects used the mouse to position a cursor over a line on the display and then clicked on the left button on the mouse to get a readout of the frequency of the line. The keyboard was used to record the names of targets that the subject identified on the display.

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[1] These were the chromaticity coordinates for the multichrome screen when the same DAC (Digital to Analog Conversion) values were applied to each gun.

The two monitors were characterized using a Minolta CS-100 hand-held colorimeter fixed to a tripod. The screens were characterized by measuring the output at every fourth DAC or voltage input level between 0 and 64 (the maximum DAC value). Each level was measured by displaying a block of pixels at the desired DAC value. In the case of the multichrome monitor, the measurements were made with the identical DAC values applied to all three phosphors. Luminance was plotted as a function of DAC value and a curve fitted to the data. The curves were used to select the DAC values on each display that would produce the same luminances and that would result in each successive luminance level differing from the previous by at least a factor of two. These luminance levels were checked at regular intervals throughout the experiment. If the output of the monitors started to drift, they were characterized again and new DAC values were selected that would produce the original luminances.

Stimulus configuration

A schematic of the two stimulus configurations used in the experiments is shown in Figure 1. Only the standard configuration was used on the multichrome monitor. In the standard (multichrome and monochrome) conditions, frequency was displayed along the horizontal axis, time along the vertical axis, and intensity was mapped on to the luminance of the pixels, such that the more intense the energy in a given frequency-time bin the higher the pixel luminance. In the rotated condition, the axes for frequency and time were reversed. Each of the four bands in the display spanned 620 pixels (22.5° of arc) by 112 pixels (4° of arc), with a 50 pixel separation between the bands. The dimensions of the total display were 21.6° of arc in height by 22.5° of arc in width at a distance of approximately 53 cm. The frequency range displayed was 1200 Hz, with 0-155 Hz on the top band, 150-305 Hz on the second, 300-611 Hz on the third, and 576-1200 Hz on the fourth band. There was a small frequency overlap at the ends of the bands to facilitate the detection of signals that might appear in those areas. Along each band were scale markers (not shown on the schematic) placed at 25 Hz intervals on the two lower frequency bands and at 50 Hz intervals on the two higher frequency bands.

Target and non-target lines were presented as lines one pixel wide that replaced the background noise. The cursor was also displayed as a line one pixel in width and 120 pixels in length, so that it extended four pixels either side of each band. At the bottom of the screen in the standard configuration and the left hand side of the screen in the display rotated configuration, the subject was given information about the last location interrogated with the cursor ('Frequency XX Hz'), and a prompt 'Target name' to identify the target. The alphanumerics were displayed at a luminance of approximately 4.0 cd/m^2 and the cursor was displayed at a luminance of approximately 11 cd/m^2.

Each stimulus configuration was used in two modes - static and dynamic. In both modes, the initial noise background was generated in advance and stored in an image file that the controlling software read in at the beginning of a run. In the static mode, target lines extended the full height of each FTI display. Only one target was presented at a time. After the target had been identified, a new background and target were generated. The new background was generated by randomly recombining sections of the original background image file. In the dynamic mode, the background image file was updated at regular intervals. Updating involved deleting the top (rightmost) line of pixels on each of the four bands,

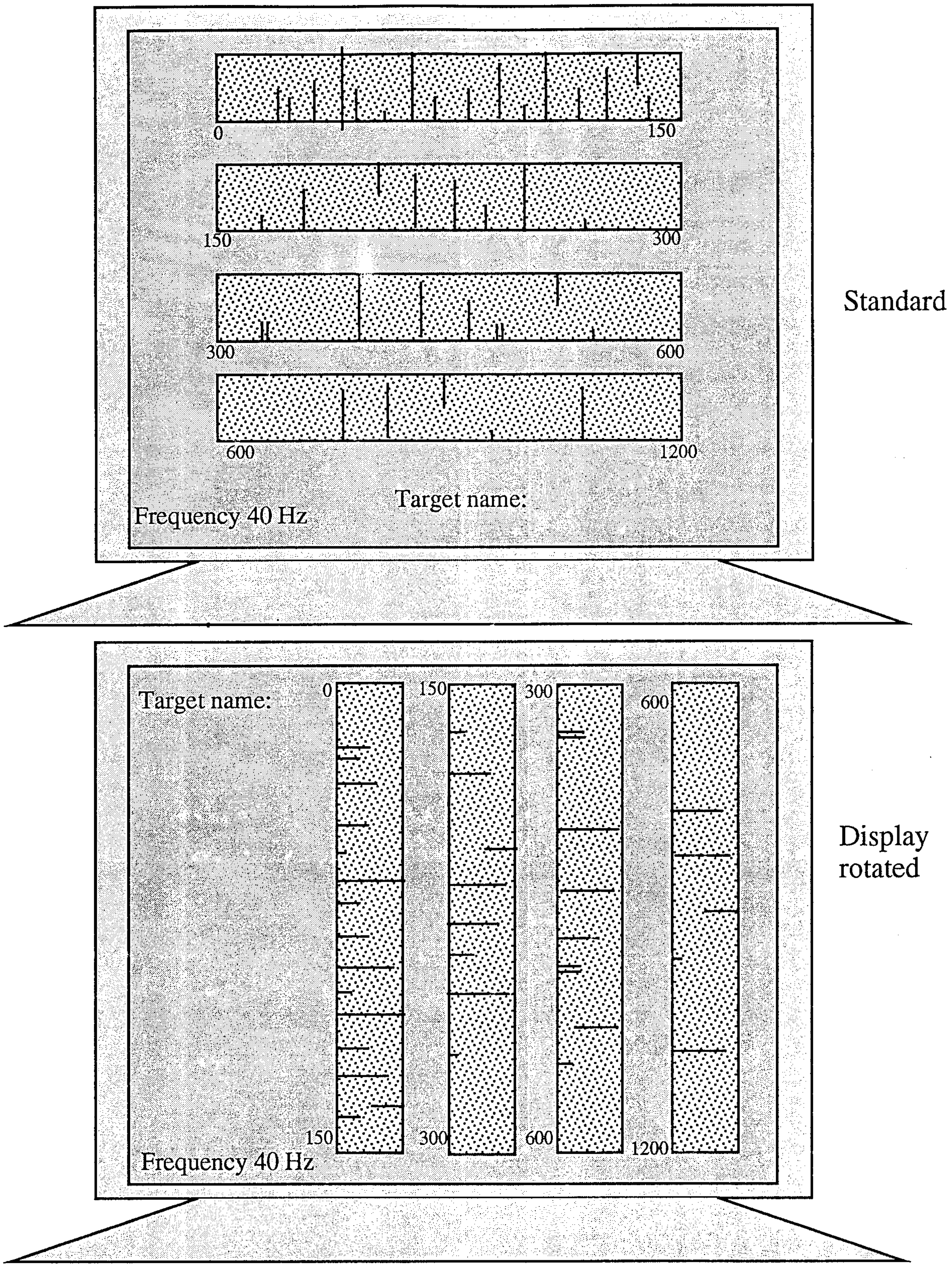

Figure 1: Schematic of the stimulus configuration for the standard format on the monochrome and multichrome monitors and the display rotated format on the monochrome monitor.

shifting the remaining lines up (right) one pixel, and adding a new line of target, noise line and noise background pixels to the bottom (left) of each band. Thus, signal lines appeared initially at the bottom (left) of a frequency band and increased in length until they reached their maximum duration. They then slowly disappeared off the top (right) of the band.

Each pixel on the display was mapped onto one of eight different luminance levels (Table 1). This corresponded to quantizing the intensity of the incoming sound into eight levels. Previous research(6, 7) has shown that detection of lines on an FTI display is not improved by using more than eight quantization levels. The sets of luminances for the two monitors were nominally the same with each luminance level being approximately $2\sqrt{2}$ times the next lower level[2]. However, as shown in Table 1, there was some variation in the actual luminances that were achieved. This was due in part to day to day variation and in part to the fact that only 64 DAC levels were available.

Table 1: Pixel luminances of the monochrome and multichrome monitors.

Monitor	Luminance (cd/m^2)							
	1	2	3	4	5	6	7	8
Monochrome	<0.01	0.05	0.18	0.5	1.6	4.4	11.6	32.2
Multichrome	<0.01	0.08	0.18	0.6	1.5	4.8	11.4	33.2

The probability that a specific luminance level was assigned to a specific pixel was determined by the following equation for the binomial rule (Equation 1). In this equation, p is the mean of the distribution (0-1), i is the specified level (1-8), N is one less than the number of levels being used (in this case 7), and $r = i - 1$. To create a Gaussian noise background, p was set equal to 0.5.

$$P(i) = \frac{N!}{r!(N-r)!} \times p^r (1-p)^{N-r} \qquad (1)$$

The mean luminance of the noise background and the signals were calculated using equation 2(7). In this equation, p_i is the probability that the luminance level L_i will be assigned to a pixel. Using equation 2, it was calculated that the average luminance of the background was approximately 2.25 cd/m^2 for each monitor.

$$\bar{L} = \sum_{i=1}^{i=N} p_i L_i \qquad (2)$$

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[2] The one exception to this was the luminance of the lowest level pixel which was always set to DAC value 0 or the background level of the monitor.

Stimuli

The set of targets that the subjects were required to identify is shown in Table 2. Some of the targets could be identified on the basis of unique characteristics while others were easily confused. Each target was composed of a base frequency and three 'harmonics' which were multiples of the base frequency. Four targets (E to H) had one or two doublets and eight targets (Q to Y) had one component (F3) that was unstable (appeared as a zigzag line). Each target could be displayed in four different configurations by shifting the base frequency upwards by 0, 2, 5, or 10 Hz which resulted in four different versions of each target for a total of 96 unique patterns. When the base frequency was shifted, harmonics maintained the same multiplicative relationship to the base frequency as in the unshifted condition. Thus, targets were required to be classified both on the basis of absolute line frequencies as well as on the relationships between line components.

Table 2: List of target names along with their associated response key, unshifted frequency components, and special characteristics.

Target Name	Key	Base	F1	F2	F3	Comments
Avenger	A	20	40	80	120	
Beagle	B	35	70	140	210	
Crusader	C	80	160	320	480	
Defiant	D	120	240	480	720	
Explorer	E	80	160	320/322	480	doublet
Freedom	F	80	160	318/320	480	doublet
Goliath	G	80	160	318/320	480/482	doublets
Horatio	H	80	160	320/322	478/480	doublets
Islander	I	20	60	120	180	
Jersey	J	35	105	210	315	
Klondike	K	80	240	480	720	
Leviathan	L	120	360	720	1080	
Messenger	M	20	100	140	180	
Nautilus	N	35	175	245	315	
Ontario	O	80	400	560	720	
Petrel	P	120	600	840	1080	
Questor	Q	20	40	80	120	unstable
Reliant	R	35	70	140	210	unstable
Scotia	S	80	160	320	480	unstable
Triumph	T	120	240	480	720	unstable
Ulysses	U	20	60	120	180	unstable
Victory	V	35	105	210	315	unstable
Wayfarer	W	80	240	480	720	unstable
Yeoman	Y	120	360	720	1080	unstable

Targets in the dynamic mode also varied in terms of their total duration (84, 112 or 140 updates), onset decay envelope, and maximum signal strength. Onset/decay envelope was defined in terms of the number of updates before maximum signal strength was reached. Approximately 1/4 of the targets reached maximum strength in 0 to 5 updates. The remainder took between 30 and 50 updates depending on target duration. The display was updated every 10 seconds and each target pixel passed through 112 updates (the length in pixels of the time dimension). Thus, some portion of each target was on the screen between 32 and 42 minutes. Targets of different intensities were generated using the binomial rule (equation 1) with p values greater than 0.5. As the p value increases from 0.5 to 1, the distribution of luminances will be skewed increasingly towards the higher levels and hence a set of pixels (a target line) will be increasingly discriminable from a background noise with a p of 0.5. Table 3 shows the p values used for the targets along with their corresponding signal strengths in dB and average display luminance. Since the p values represent the cumulative probability of the normal distribution, the signal strength for each p value in dB is $20 \times \log 10$ of the z value that corresponds to that probability. The maximum p value of all the targets was always 0.76 or greater. This was higher than the minimum p value necessary to detect a signal line 100% of the time on these displays when a target line extended through all time bins. Only the highest p value was used in the static training sessions. All of these parameters were designed to add complexity and realism to the classification task.

Table 3: Probability distribution, strength and mean luminance of signals used in training and test sessions.

Probability (p)	0.66	0.68	0.72	0.76	0.80	0.84
Signal Level (dB)	-7.7	-6.6	-4.7	-3.0	-1.5	0.0
Mean luminance (cd/m^2)	5.8	6.5	8.1	10.2	12.5	15.3

An additional set of frequencies was generated in order to add 'noise' to the display in the form of lines which might be confused with target component frequencies. Noise lines had similar intensity/time profiles to target lines.

Task

The subject's task was to determine whether members of the target set in Table 2 were present or not. Once the subject recognized a target, he/she typed in the first letter of the target name. At that point, the subject was prompted to enter the four frequencies on which the decision had been made. No other actions could be taken until four frequencies had been marked. For example, if the display contained lines at 20, 40, 80, and 120, and if all the lines were stable, it was likely that the target Avenger was being presented. The task would be to recognize this pattern of frequencies as the target Avenger, to type the 'A' key on the keyboard, and then to record the target frequencies by positioning the cursor over each line (20, 40, 80, and 120) in turn and clicking on the left mouse button.

The subjects were provided with several tools to assist them in analysing the patterns of lines on the display. They could interrogate lines of interest by placing the cursor over a line and clicking on the left mouse button. This produced a readout of the frequency of that line in the bottom left (upper left on the display rotated screen) corner of the display. They were also provided with a copy of Table 2 on a document holder beside the screen, a notebook to record information such as target characteristics or what targets had already been identified, and a calculator to calculate the offsets of targets whose base frequency had been shifted.

Conditions

Two experiments were carried out. The first compared classification performance on the monochrome and multichrome monitors in a within subject design. Six subjects completed both conditions. Three started on the multichrome display and three on the monochrome.

The second experiment compared performance on the standard and display rotated formats on the monochrome monitor in a between subject design. A different set of six subjects ran in each condition. However, the subjects that ran in the display rotated conditions did a second set of runs on the standard rotation to determine if there was any effect on classification of going from one orientation to the other. Three of the subjects in the standard format condition did a second set of runs under the display rotated condition. The remaining three did their second set of runs as part of the monochrome/multichrome experiment.

Procedure

Before giving informed consent, participants read a protocol that provided some background on the purpose of the study, an explanation of the task, the experimental conditions, and the risks. Once consent had been given, subjects were administered a visual acuity test, using a Regan chart at a distance of 6.1 m, and a contrast sensitivity test, using a two alternative forced choice task controlled by a Nicolet Optronics CS2000 Contrast Sensitivity System. Subjects were seated at a distance of 2.56 m for the contrast sensitivity test. Since the experimental task involved the recognition of narrow lines in a noisy background, we wanted to be certain that subjects had normal contrast sensitivity as well as normal or corrected to normal visual acuity.

Subjects participated in a minimum of eight sessions - four training sessions followed by four test sessions. Each session was carried out on a separate day. As much as possible, the sessions were separated by no more than two days. The first two training sessions were carried out in the static mode and the last two were carried out in the dynamic mode. All testing was carried out in the dynamic mode. The sessions lasted between one and two hours depending on the length of time subjects took to carry out the static training runs which were self-paced. At the beginning of each set of training sessions, the task was demonstrated to the subjects and they were given a chance to practice it.

The monochrome and multichrome monitors were in separate rooms. Both rooms had the same setup. The monitors were placed on stands so that their centres were approximately 43 cm. above the table tops. During the runs, subjects were seated in an adjustable chair at a distance of approximately 53 cm. from the screen in a dimly lit room. Other than the screen itself, the only illumination was from an incandescent pot light located above the monitor. The light was adjusted so that approximately 0.5 lx fell on the screen and 3 lx on the keyboard[3]. The task was carried out under low ambient illumination to ensure good

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[3] All ambient lighting conditions were measured with a Hagner Universal Photometer in the illumination mode.

contrast on the screen.

Training. There were four training sessions - 2 on the static task and 2 on the dynamic task. Subjects completed all of their static training on the same monitor. On the second day of dynamic training, subjects in the monochrome/multichrome comparison ran on the alternate monitor for their condition. The first 2 training sessions were designed to familiarize subjects with the software, the display, the task, and the stimuli. During these training runs, subjects learned what the target patterns looked like on the display, how to classify targets, and how to input information into the system. For all the static training runs, immediate feedback was given: after each answer was entered, it was identified as correct or incorrect. In addition to the words 'correct' or 'incorrect' appearing on the screen, incorrect answers were accompanied by a beep to alert the subject that an error had been made.

Each training session consisted of 2 runs. In the static mode, each run was made up of 48 trials. On each trial, the subject was presented with the pattern for one of the 24 targets at one of the four possible offsets. After the subject identified the target and entered the four frequencies that his/her decision had been based on, a new background was displayed and a new target was presented. After 48 trials had been completed, the message 'Session Over. Trial Limit Reached' appeared. The subjects were encouraged to take a break between runs to prevent fatigue.

The subjects completed four runs in the static mode. During each pair of runs, subjects received one example of each of the 96 possible patterns in a different random order. The two pairs of runs differed in that no noise lines were presented during the first two runs and three noise lines were presented on each trial in the second set of runs. The noise lines were randomly selected from a finite population on each trial.

The static training was followed by two training sessions on the dynamic task. This was the subject's first exposure to the real task. Each training run lasted 30 minutes. Targets were added at a rate of 30 per hour or one every two minutes. An additional noise line was added once every 4 minutes. The display was updated once every ten seconds. At the beginning of a run the display did not contain any targets. At the end of the 30 minute period, the message 'Session over. Time limit reached' appeared on the screen.

Each subject was given the same set of four stimulus files (scenarios). Stimulus files were constructed by randomly selecting targets, without replacement, from the population of 96 patterns and then randomly assigning a duration, onset-decay pattern, and maximum signal strength to each target.

Test sessions. There were four test days. Subjects in the monochrome/multichrome condition completed two runs on one monitor followed by two runs on the other monitor. Nine subjects in the standard/display rotated experiment completed two runs on the orientation they had been trained on followed by two runs on the alternate orientation. The same set of stimulus files were used by each subject under each condition. Test stimulus files were constructed in the same way as the dynamic mode training files and the procedure was identical to that of the dynamic training sessions However, the runs were 60 minutes long and targets were added at the rate of 40 per hour (one every 1.5 minutes) and noise lines were added at the rate of one every four minutes. Subjects completed one 60 minute run in each session. There was no break during a run.

RESULTS

Dependent measures

Several measures of performance were collected. The basic measure was percentage of correct classifications. As well, response times, overall errors/false alarms per run[4], number of frequency interrogations per correct response, and percentage of times subjects entered the correct frequencies were examined. Correct classifications, response times, and frequency interrogations were assessed over time as well.

Training results

The purpose of the static runs was to teach the subjects to recognize the different target patterns. On average, subjects classified approximately 94% of the targets correctly on the first two runs. In the second pair of runs, with three noise lines present, the percentage of correct classifications dropped to 89%. Subjects varied considerably in the time they took to analyse the patterns. Average response time per trial ranged from 15 seconds to 95 seconds.

The dynamic training runs were designed to give the subjects experience with the real task. Each subject completed four 30 minute runs during which 15 targets were initiated. Performance was much poorer in the dynamic condition. Even at the end of four runs, only about 37 percent of the targets were classified on average in a thirty minute period. Average response time was around 10 minutes. Thus, subjects probably only dealt with the first 10 of the 15 targets initiated during the 30 minute period. Performance did improve marginally from day 1 to day 2 but only on the first run. Average percent correct was 37% on the second run on both days.

Test results

Average performance for each condition in the two experiments is shown in Table 4. 'Standard 2' shows the results for the display rotated group when they ran on the standard format. Similarly, 'Display rotated 2' shows the performance on the display rotated format of the subjects in the standard format condition. Since half of this latter group completed their second set of runs on the multichrome monitor, the 'Display rotated 2' data are based on an N of 3. Two of those subjects completed only one run on the second format because of equipment problems. Thus the results must be treated with caution.

Monochrome versus multichrome

As can be seen in Table 4, performance on the two type of monitors, monochrome and multichrome, was very similar. None of the measures of performance were significantly different on the two monitors. The picture was similar when performance was examined across the duration of the run (Figure 2). Number of classifications per ten minute interval increased over the first 30 minutes and then levelled off at about 3 target per ten minute interval. Response times increased across each 60 minute run from 200 seconds up to almost 900 seconds. The results for the individual subjects were consistent with average

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[4] Errors and false alarms could have been analysed separately, but there were so few occurrences of each that it was not worthwhile.

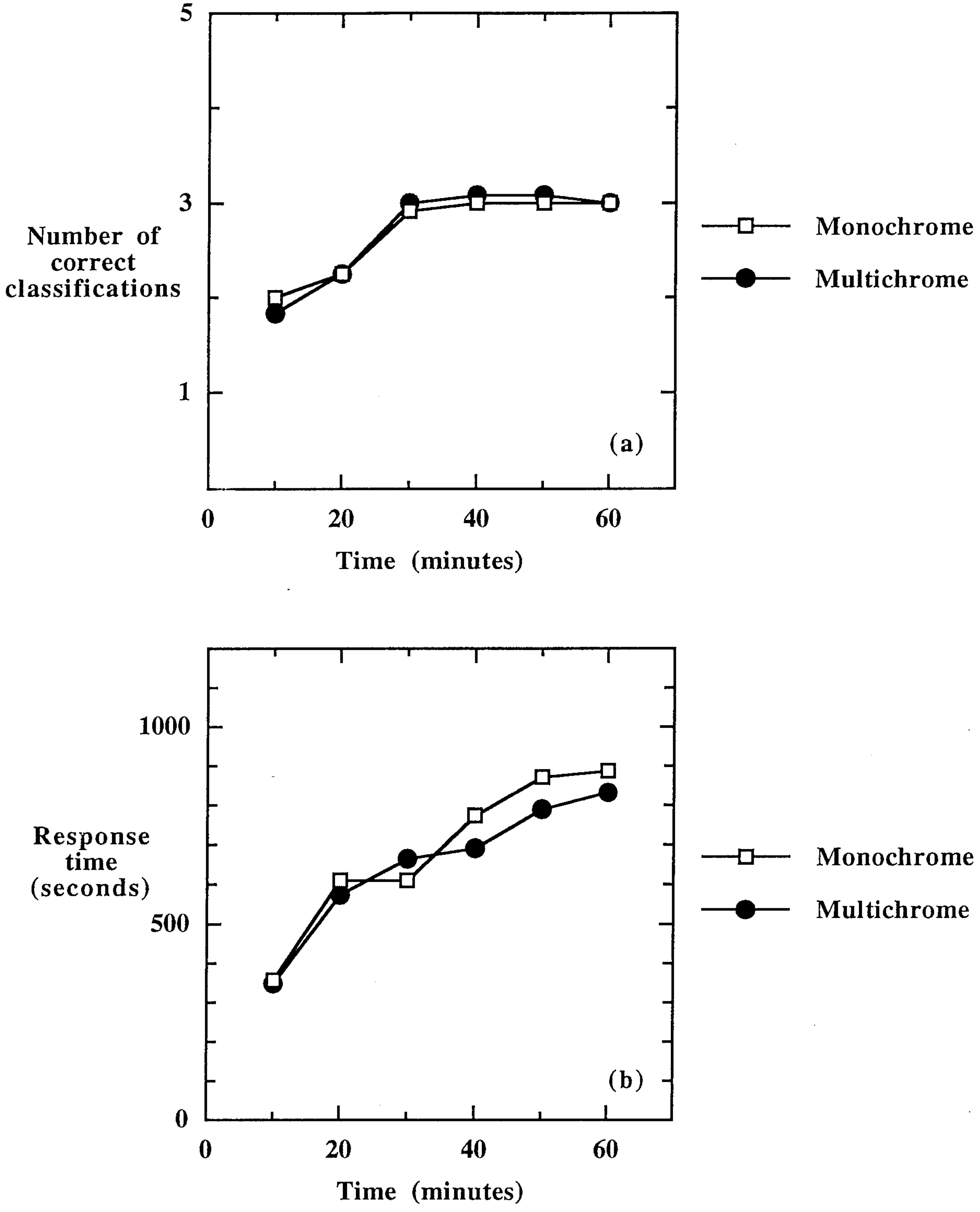

Figure 2: Average number of classifications (a) and response time (b) in each successive 10 minute interval on the monochrome and multichrome monitors.

performance although there were large individual differences (Figure 4a).

Table 4: Performance measures for each condition averaged across runs.

Performance Measures	Conditions					
	Mono-chrome	Multi-chrome	Standard 1	Standard 2	Display rotated 1	Display rotated 2
Classifications (%)	39.5	40.2	40.7	47.4	47.3	53.0
False alarms/errors	1.9	2.3	1.9	3.1	3.5	1.0
Response times (sec)	709	702	790	758	782	689
Interrogations	11.2	11.5	12.4	9.0	10.9	10.3

Standard versus display rotated format

In general, the percentage of correct classifications was slightly higher on the display rotated format than on the standard display. However, the differences were not significant. The other measures, response times, errors, and number of interrogations, were essentially identical with the small variations being due to individual differences. An examination of performance over time (Figure 3) indicates that the display rotated subjects were able to handle from 0.5 to 1 target more per ten minute interval over the hour period. Moreover, the difference between the groups increased with time on task. Response rates were similar.

To see if the small differences in performance were associated with specific target characteristics, percent correct classifications were evaluated as a function of length of onset/decay envelope, duration, maximum signal strength, and offset of the base frequency. There were no significant differences between the formats as a function of any of those characteristics. However, percentages of correct detections were about 10% higher at the two lower signal strength in the display format group and equivalent in the highest. Similarly, subjects in the display rotated group classified a higher percentage of targets with long onsets (Table 5).

Table 5: Percent correct classifications as a function of onset/decay envelope and signal strength.

Condition	Onset/decay		Signal strength		
	short	long	-3.0	-1.5	0
Standard	47.5	35.5	34.2	49.2	37.5
Display rotated	51.6	45.2	43.8	60.9	39.2

Since subjects completed runs on both formats, it is possible to look at the effect of switching display orientation on classification performance. Figure 4 shows the percentage of correct classifications for each subject on each of the four test runs. The results for the monochrome/multichrome subjects are included as well to show the effect of practice. As can be seen, those subjects did the same or showed a slight improvement across the four

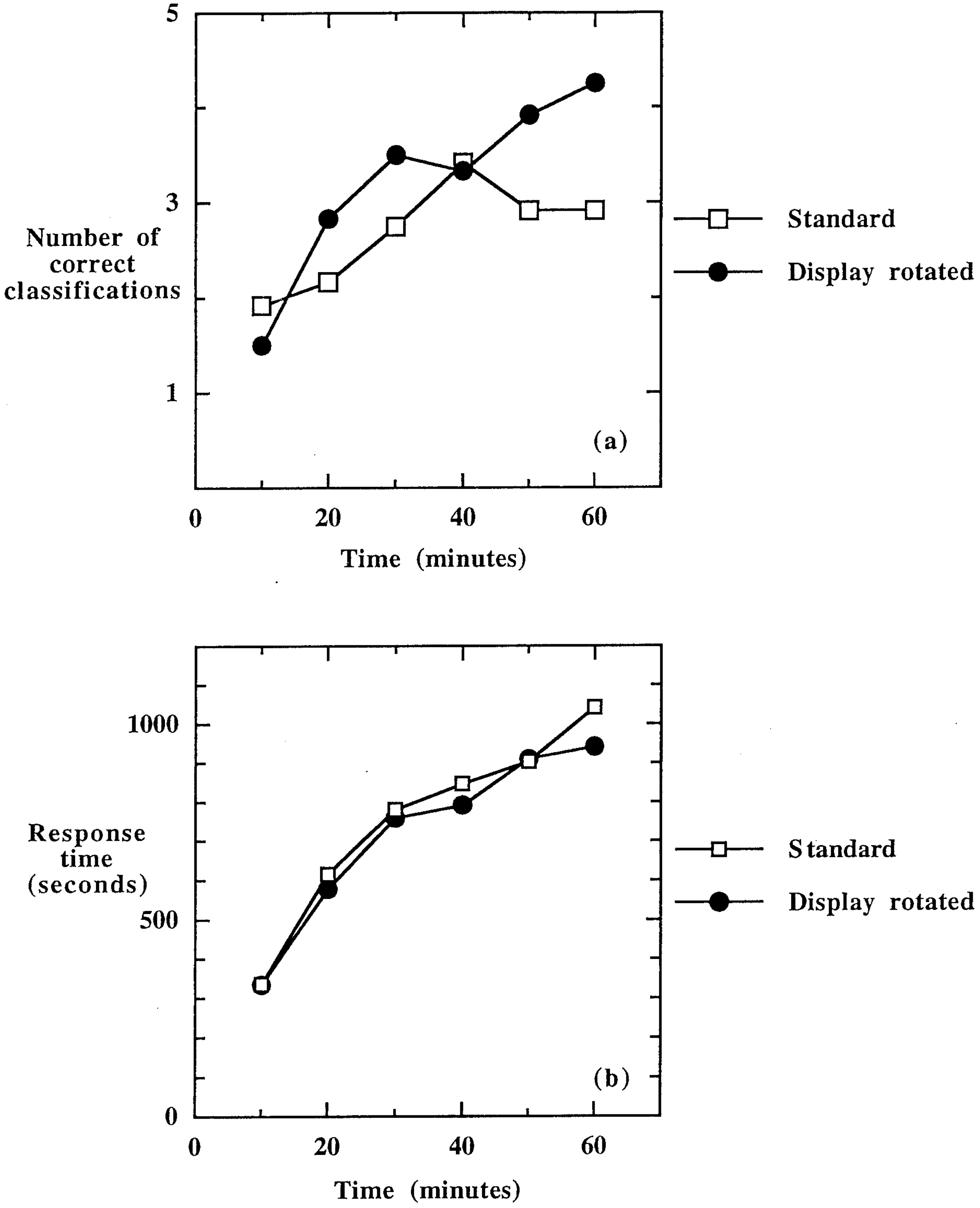

Figure 3: Average number of classifications (a) and response time (b) in each successive 10 minute interval for the standard and the display rotated format.

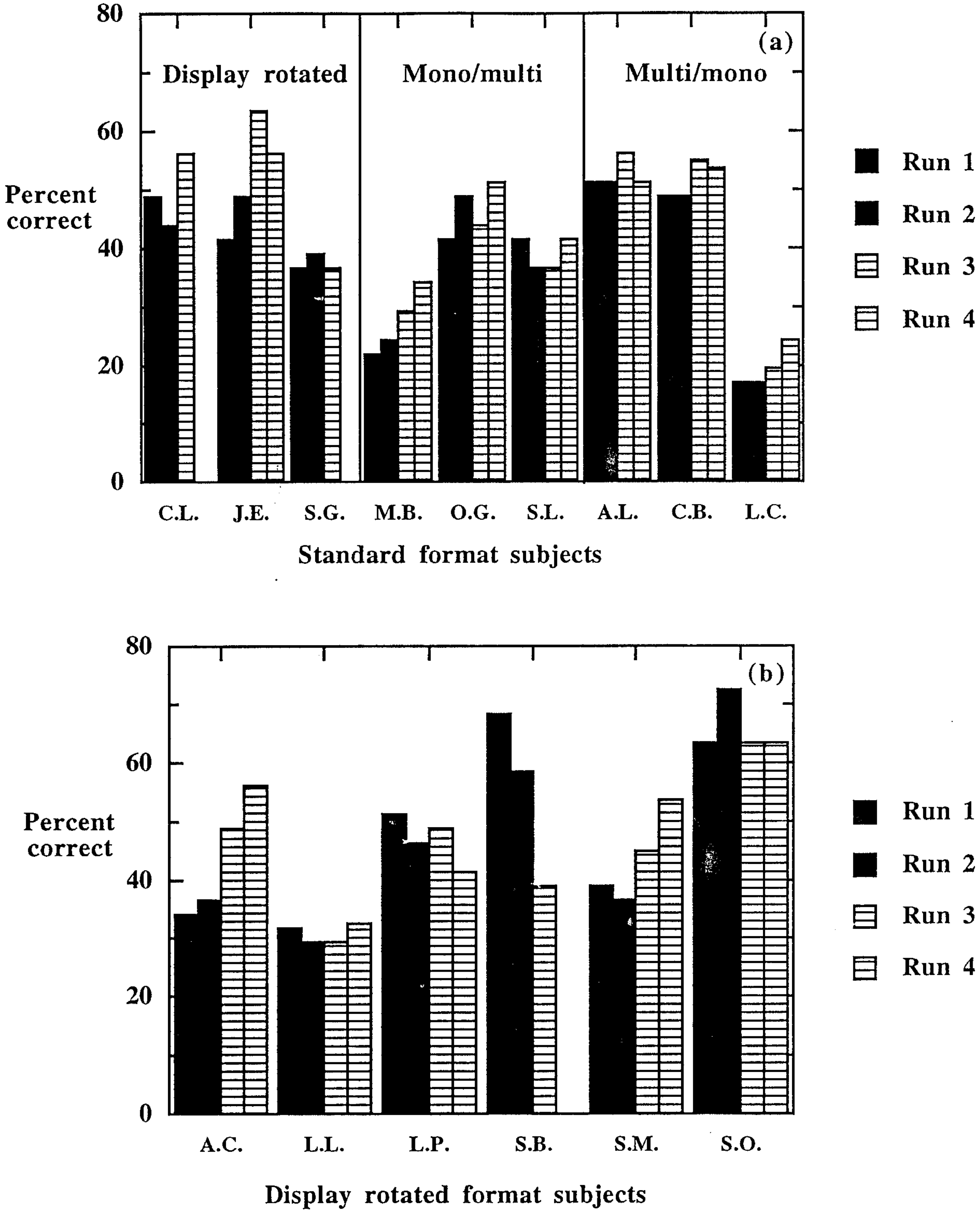

Figure 4: Percent correct classifications for each subject on each run. Subjects in (a) used the standard format on their first two runs and subjects in (b) the display rotated format.

runs. Of the three subjects in the standard group that did their second set of runs in the display rotated format, the two best subjects (CL and JE) did better on the display rotated format. Of the six subjects that moved from the display rotated to the standard format, two improved (AC and SM), two remained the same (LL and LP) and two did poorer (SB and SO). Thus, there appears to be no consistent pattern of results for that group. However, the two subjects that had improved performance on their second two runs were averaging less than 40% correct on their initial runs. Thus, it is possible that their improvement was due to learning. As well, the subjects whose performance declined in going from the display rotated to the standard format had the best performance overall.

DISCUSSION

The purpose of these experiments was to examine the effect of monitor type and display orientation on the classification of targets on a simulated sonar display. The experiment on monitor type compared the classification of targets on a multichrome monitor with that on a greyscale monochrome monitor. Performance was almost identical on all measures examined. This finding supports the results of the previous study that measured detection performance and provides added support for the conclusion that either type of monitor could be used for presenting sonar data. Although it was not expected that a multichrome monitor would seriously impair classification performance, there was some concern that performance might be degraded preferentially over time. However, as Figure 2 indicates, number of correct classification and response times were similar across a run of 60 minutes on both monitors.

The experiment on display orientation compared the classification of targets when the FTI display was configured so that signals fell either along the scan lines of a greyscale monochrome CRT or perpendicular to them. As with the first experiment, there were no significant differences in performance on any of the measures examined. Thus, at the very least one can conclude that classification performance is not degraded by using a format in which target lines fall along the scan lines of the CRT. However, trends in the data suggest that the modified display format might actually enhance classification of targets. Overall, the percentage of correct classifications was 7% higher with the display rotated format (Table 4). Most of this difference could be attributed to the display rotated subjects being able to classify a larger percentage of targets at the lower signal strengths or with long onset/decay envelopes (Table 5) or that occurred later in the run when the display was most cluttered and subjects potentially most fatigued (Figure 3). These differences are consistent with the hypothesis that the visibility of target lines is enhanced when they fall along the scan lines of the CRT.

Finally, it was the subjects that did best on the task that did relatively better on the display rotated format (Figure 4). The task used in this study is not easy. Members of the target set, while discriminable, frequently have lines in common. After about ten minutes, there are a large number of lines on the screen. The subject must keep track of which targets have been identified and which lines have not been accounted for. Based on these data and previous studies using this simulation(5), subjects vary considerably in their ability to do this task. The best subjects tend to develop strategies for improving their classification rate.

They look for specific patterns rather than analysing on a line by line basis. The complexity of the task may have overwhelmed any benefit due to the display format for the poorer subjects.

Limitations of the study

The advantage of modifying the FTI display format so that target lines fall along the scan lines of the CRT has been tested on a monochrome monitor only. The same advantage may not be found with a multichrome monitor because of the shadow mask. If the decision is made to go to a multichrome monitor, a further evaluation will be required to determine if the same advantage can be shown on a multichrome monitor.

Both of the experiments used subjects that had no experience with classifying targets on an FTI display. In total, they had about 6 hours experience on the one display format before shifting to the alternate FTI display format. It is unlikely that they had internalized any templates for the targets that they were trying to identify. Given their response times, most of the targets were probably identified by finding the frequencies of the lines as they appeared on the screen and comparing the frequencies of similar height with the frequencies of the various targets in Table 2. Thus, it is not surprising that there is little evidence of difficulty in switching from one format to another.

The results might be different if real operators used the rotated format FTI display under operational conditions. They have had extensive experience with the standard format. Analysis of the classification process indicates that initial classification is based on pattern recognition(3) rather than analysis. Rotating the format may impair this pattern matching process. This problem could be overcome by rotating the monitor and retaining the standard format. The previous study that examined the detectability of lines that fell along the scan lines of the CRT found no difference in performance when the FTI display was rotated and when the monitor was rotated. However, rotating the monitor would necessitate a complete redesign of the layout of information on the display. Thus, it would probably be best to assess the performance of real operators on the different display formats before making a final decision about the best method for modifying the FTI display so that signal lines fall along the scan lines.

CONCLUSIONS

Two experiments were carried out to examine the classification of targets on an FTI display on a monochrome and multichrome monitor and with the FTI display rotated 90° so that the target lines fell along the scan lines of the CRT. There were no differences in classification of targets on the two types of monitors. Based on the results of this study and related studies, use of multichrome displays should not adversely affect the detection and classification of signals on FTI displays. The decision to include multichrome monitors should be made on other issues such as usefulness, compatibility with other equipment, stability, and reliability. This study did not address any of those issues. In the second experiment, classification of targets was slightly better on the display rotated format, but the differences were not significant. The lack of significance could have been due in part to the complexity of the classification task. it was recommended that serious consideration be given to modifying the human machine interface for passive sonar displays so that signal lines fall along the CRT scan lines. Prior to a final decision being made, a study should be carried out to determine if a similar advantage is found with multichrome displays and to evaluate the relative cost of rotating the monitor and the FTI display.

RECOMMENDATIONS

1) The advantage of using multichrome monitors for displaying passive sonar data should be investigated.

2) Field trials should be conducted to investigate the impact of rotating the FTI display, so that signal lines fall along the scan lines of the CRT, on classification performance of sonar operators.

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With current sonar technology the operator must handle large quantities of data. The primary medium for displaying these data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the processing of sonar information from visual displays. The current study examined the impact of two display characteristics on the classification of targets on a Frequency-Time-Intensity (FTI) display. The first was type of monitor - multichrome or monochrome. Many systems use a monochrome monitor because its resolution to addressability ratio is usually superior to that of a multichrome display at an equivalent addressability. The second was orientation of the signals relative to the orientation of the CRT raster. Currently, the signals on an FTI display are perpendicular to the CRT raster. The study examined the benefit of having target lines on an FTI display fall along the scan lines of the CRT. There were no significant differences in classification performance as a function of monitor type or display orientation. However, trends in the data supported the use of a FTI display format in which targets lines fall along the scan lines of the CRT.

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