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COMPARISON OF PERFORMANCE ON A SIMULATED TARGET TRACKING TASK WITH AND WITHOUT AN AUTOMATED DETECTION CAPABILITY

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COMPARISON OF PERFORMANCE ON A SIMULATED TARGET TRACKING TASK WITH AND WITHOUT AN AUTOMATED DETECTION CAPABILITY

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EXECUTIVE SUMMARY

Automated controllers are becoming an integral part of many complex systems. One such controller is an automated detector and tracker (ADT) which aids an operator in detecting and tracking the location of targets such as ships, tanks, or aircraft. To study human use of an ADT, an Automated Detection and Tracking Simulation (ADTS) system has been implemented. The ADTS is a modification of an Automated Tracking Simulation (ATS) that has been used to study the use of an automated tracker (AT) as a function of its reliability and task difficulty. With both systems, the user's task is to detect and track the position of targets. With the ATS, the user has the option of assigning some or all targets to an automated tracker (AT) which mimics the user by trying to update the position of targets that it is responsible for. This capability has the overhead of having to assign and deassign targets every time the AT fails to update a target, but it gives the user ultimate control over the task. The ADTS, in addition to tracking existing targets, has the ability to add targets to the display.

The purpose of the current experiment was to determine if task differences between the two systems affected performance. In the ADTS, the user does not have the option of handling some targets manually. This difference makes the user more of a system monitor than an active participant, but it also reduces the number of actions required to handle ADT errors. Task differences were assessed by comparing performance on the two systems when their capabilities were identical. Performance on the ATS was compared with performance on the ADTS with the detection threshold set so that either no targets were added or no non-targets were added. The results indicated no differences in hit rate or response time across the three conditions. However, miss rate decreased significantly and false alarm rate increased significantly between the ATS condition and the second ADTS condition. The increase in false alarms was due primarily to an increase in manual false alarms and was attributed to a change in strategy. However, it was not clear if the change in strategy was due to the change in task or to the experience level of the participants. All of the participants in the ADTS task had previously completed several sessions with the ATS.

ABSTRACT

The experiment in this report compared performance on a target tracking task using an Automated Tracking Simulation (ATS) system with performance on the same task using an Automated Detection and Tracking Simulation (ADTS) system. With both systems, the user's task is to detect and track the position of targets by comparing the location and strength of new signals with the location of existing targets. With the ATS the user has the option of assigning some or all of the targets to an automated tracker (AT). The ADTS, in addition to tracking existing targets, has the ability to add targets to the display. The purpose of the current experiment was to determine if task differences between the two simulations affected performance. The results indicated no differences in hit rate or response time across the three conditions. However, miss rate decreased significantly and false alarm rate increased significantly between the ATS condition and the ADTS condition with the detection threshold set to the maximum strength for non-target signals. This difference was attributed to a change in strategy. However, it was not clear if the change in strategy was due to the change in task or the experience level of the participants. All of the participants in the ADTS task had previously completed several sessions with the ATS.

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INTRODUCTION

Background

Automated controllers and decision aids are becoming an integral part of many complex computer-based systems. They are implemented with the aim of reducing human error and workload and improving system performance. One such controller is an Automated Tracker (AT). It tracks the position of targets (other ships, submarines, etc.) by comparing the location and strength of new signals with the location of existing targets. If the position of a signal is within a certain area surrounding an existing target, the AT associates that signal with the target, updating the position of the target.

If the objectives for automated controllers are to be realized, it is important to understand how and when people use them and the impact of those decisions on overall system performance. To this end, a simulation of a generic target tracking task in a naval environment was developed. The user's task is to detect and then update the position of a series of targets over time. He or she can carry out the task manually or assign some or all of the targets to be tracked by an automated tracker. Previous experiments (McFadden, Giesbrecht, & Gula, 1997) have examined the use of the automated tracker, percentage of targets tracked, and types of errors as a function of the actual and perceived reliability of the tracker.

Many automated tracking systems include an automated detection function as well allowing the automated system to both detect and track targets. Adding an automated detector changes the nature of the task somewhat. Users can no longer choose to give control of a target to the automated tracker or to handle it manually. Their role shifts even more towards a monitor of the automated system rather than an active participant in the task. To study the impact of the inclusion of an automated detection capability, an automated detection function was added to the ATS. This modified version of the ATS is called the Automated Detection and Tracking Simulation (ADTS).

As with a real system employing an automated detection capability, the user's task on the ADTS differs from that of the ATS. With the ATS, the user had the option of assigning a target to the AT or tracking it manually. If the AT failed to update the position of a target, the user had to deassign the target (take it away from the AT), update the position of the target, and if desired, reassign it to the AT[1]. With the ADTS, there is no longer any requirement to assign and deassign targets. Both the human and the automated system can potentially add and associate any of the available signals every time new information becomes available. Thus, it is not possible to prevent the AT from trying to handle certain targets. However, the user no longer has the time cost of deassigning targets that the AT fails to update. In order to separate out the effect of adding an automated detection capability from the change in the task, it is necessary to replicate some of the conditions run on the ATS on the ADTS.

Current study

This experiment compared performance on a target tracking task using the ATS with performance on the same task using the ADTS. Identical scenarios were used on the two tasks and the automated tracker parameters were set so that the AT would be highly reliable (McFadden, Giesbrecht & Gula, 1997). With the ADTS, the detection threshold was set so that automated detector would not detect any targets or so that it would never detect any non-targets. In the first case, the capabilities of the automated system on the ADTS were identical to those of the ATS. The primary benefit would be the requirement for fewer actions to handle targets that the AT failed to track. Given the use of a relatively reliable AT in this study, it was not anticipated that this would result in much reduction in time to handle the targets. In the second case, the user did not have to worry about adding targets that were easily detected. Since manual detection of signals associated with strong targets was relatively easy, it was not expected that performance or time to handle the targets would differ substantially from that found under the ATS .

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[1] Alternately, the user could remove the target symbol, add the signal representing the target at its current location and assign it to the AT. However, this would result in the disappearance of the target track.

METHOD

Participants

Six people (three males and three females) participated in the study. Three of the participants were military personnel, while the remaining were civilian personnel and university students. They ranged in age from 21 to 43 years and all reported normal (20/20) or corrected-to-normal vision.

Apparatus

The experiment was carried out on a Power Macintosh with a 17" screen using the Automated Tracking Simulation (ATS) and the Automated Detection and Tracking Simulation (ADTS) experimental control software[2]. Both the ATS and ADTS are simulations of a target tracking task for studying human use of an automated system. Examples of the ATS and ADTS screens are shown in Figures 1 and 2. User tasks are performed through a series of tracking display (shown on the left of the figures), signal table (shown on the right), and function button (far right) selections. All selections are carried out via a mouse. Invalid selections are distinguished by a grey shade, beep, or no action following a selection.

For a detailed description of the Automated Tracking System (ATS) refer to McFadden, Giesbrecht and Gula (1997). The Automated Detection and Tracking Simulation (ADTS) is a modified version of the ATS. With the ATS, the participant has the option of giving control of specific targets to the AT (Assign) and taking away control (Deassign). Signals associated with targets under AT control appear in the AT signal table which is accessed by clicking on the small window labelled manual. With the ADTS, all signals can be handled all the time by either the human or the ADT. Thus the assign and deassign functions are no longer required and there is only a single signal table. Signals that are associated with targets are highlighted. Targets that are associated with signals are solid black and targets that are unassociated have a white **X** in them.

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[2] Both the ATS and the ADTS were developed by APG, Toronto, Ontario under contracts from the Defence and Civil Institute of Environmental Medicine.

Either the participant or the ADT can add and associate signals. Only the participant can deassociate and remove targets.

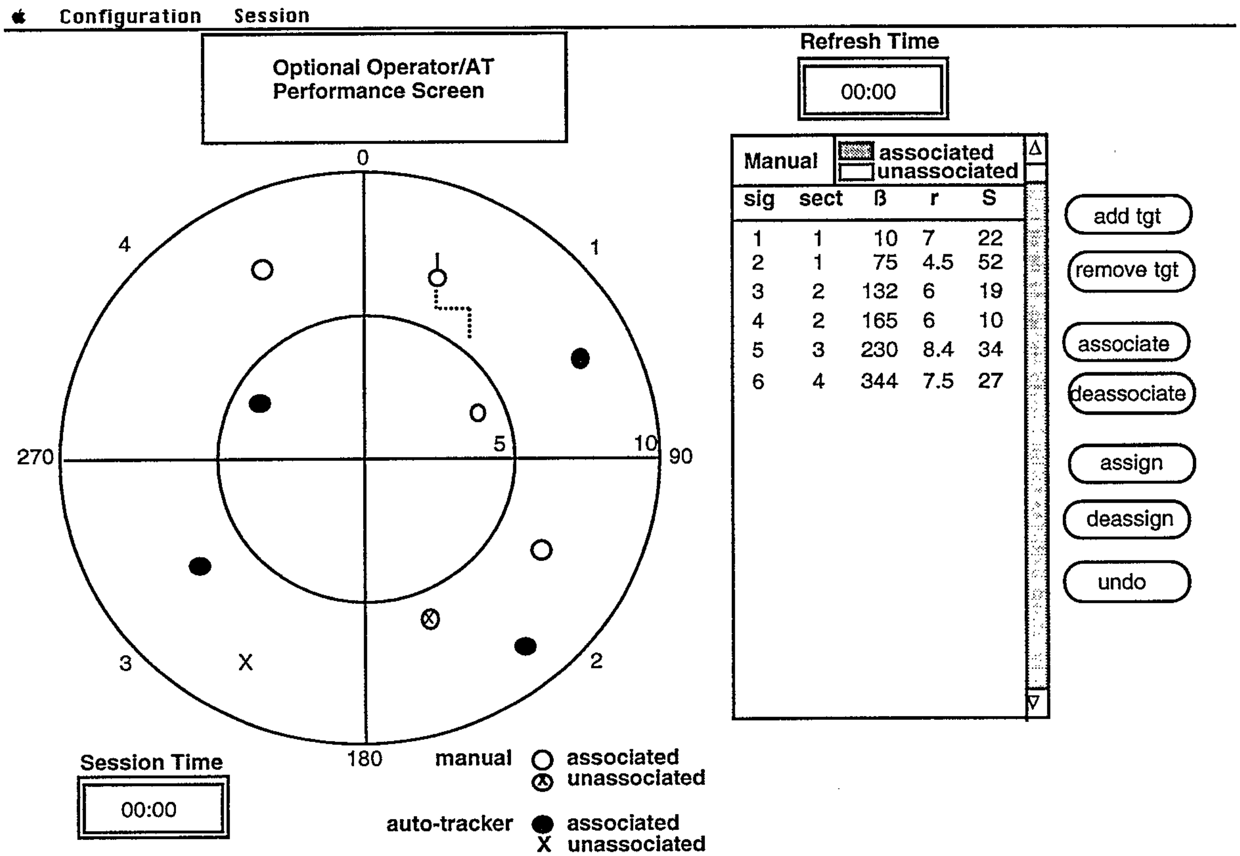

Figure 1: Schematic of the display for the Automated Tracking Simulation (ATS) system. The 'X' for the unassociated automated tracker marker appears as a white X in a black circle in the actual display. The dashed line in sector 1 of the tracking display shows the path traced out by that target. The solid line at the top of the same target shows the projected direction for that target. The numbers 1-4 are sector labels and the numbers 5 and 10 distance markers.

Task

The participant's task is to track the location of various vessels (objects), given a set of signals. An automated tracker (AT) can be activated to assist in this task. The ADTS has an automated detection capability as well. The AT and ADT (automated detector and tracker), when activated, act as filters or preprocessors for the manual task. The position of the targets in the tracking display must be updated every time new information appears in the signal table. With the ATS, this task can be carried out manually or the human can assign some or all of the targets to the AT. With the ADTS, the ADT automatically tries to update the position of all targets previously added to the tracking display and to add any new signals with a signal strength above a predefined threshold. If the automated system fails to add or update targets, it is the responsibility of the human to do this manually before new information arrives. With the ATS, targets assigned to the AT must be deassigned before they can be updated manually. With the ADTS, this step is not necessary.

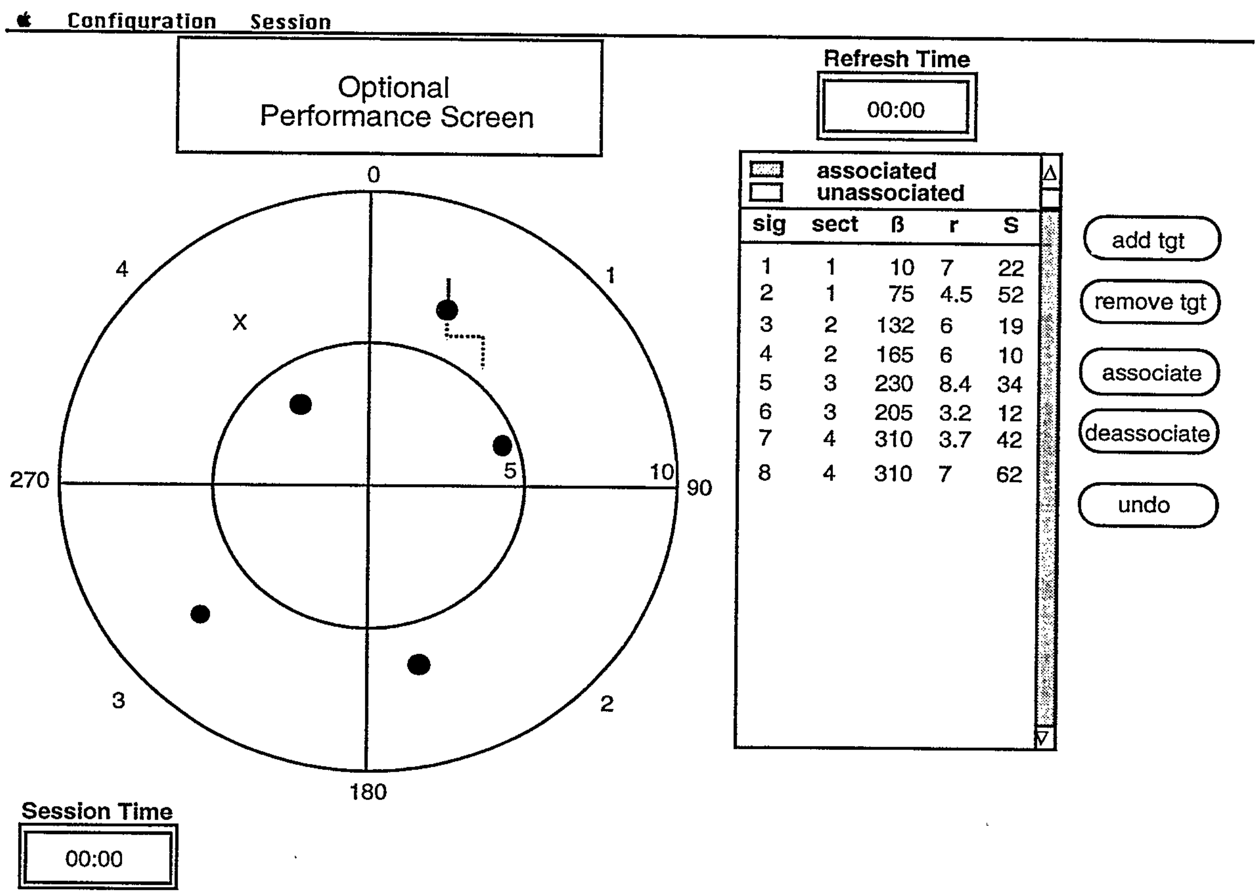

Figure 2: Schematic of the display for the Automated Detection and Tracking System. (See Figure 1 for further explanation.)

Target sets

Each target set or scenario was composed of several different targets. Each target followed either a straight line, zigzag, circular or experimenter-defined path. The scenarios were designed so that the number of targets with a signal strength below 20 was usually less than 10% on average. The number of non-target signals added on each update ranged from 2 to 8 and their signal strength was always less than 20.

Conditions

The study was a within-participant design with two independent variables - level of automation and number of targets. Three different levels were used, automated tracking only, automated detection and tracking with the detection threshold set at 100 so that no targets were detected (ADTS-100), and automated detection and tracking with the threshold set at 20 so that no non-targets or low strength targets were detected (ADTS-20). The second variable was number of targets, either 15 or 20. All participants completed four test scenarios under each combination of conditions.

The automation conditions were always carried out in order of increasing automation. This decision was made to offset the time cost associated with running these types of studies by using the participants and their data from a study with the ATS. Thus, all of the participants had initially completed an experiment using the ATS. Some of the data from that experiment were used for the ATS condition. The remaining two conditions could have been randomized, but for consistency, participants carried out the ADTS-100 condition followed by the ADTS- 20. The ordering of the number of targets and scenarios was randomized across participants within each level of automation and across each level of automation with the constraint that a scenario was never run twice in the same session.

Procedure

Participants read the experimental protocol describing the background research, the task, and the potential risks involved in participation. Any questions that participants had about the study were answered by the experimenter before an informed consent form was signed.

During training and test sessions, participants were seated in an adjustable chair at the normal working distance from the computer monitor (approximately 50 cm). The task was carried out in normal ambient illumination. Each session lasted from 1 to 1.5 hours and all participants were given the opportunity to take breaks between runs to reduce visual, mental, and postural fatigue. A list of actions that could be carried out with the ATS or the ADTS was located in a copy holder next to the monitor and was available to participants at all times during both the training and test sessions. As well, participants were told that they could make use of a pencil and paper situated on the computer table to make notes.

Initially, participants carried out 4 days of training followed by four test sessions using the ATS. On the first day of training, they completed five scenarios in which they had to monitor four targets at a time for 10 minutes. During each of the remaining training sessions they carried out four scenarios of 16 minutes duration. On days two and three, they monitored 6 targets at a time and on day four, they monitored eight. During the test sessions, they completed five different scenarios with 10, 15, and 20 targets.

Prior to testing on the ADTS, the participants completed an additional training session composed of four runs to allow them to become familiar with the changes in the task and the ADTS interface. The participants tracked 8 targets, using the scenarios from the final training session of the ATS experiment. A feedback window was present during the training sessions so that participants could monitor their level of performance.

The training session on the ADTS was followed by four test sessions. Test sessions consisted of four of the scenarios used in the ATS sessions with 15 and 20 targets. On the first two test sessions, participants carried out these eight scenarios under the ADTS-100 condition and on the third and fourth sessions they carried out the same scenarios under the ADTS-20 condition.

All test scenarios or runs were 16 minutes in length, with updates every 40 seconds. Five target signals were added in each update until the predefined maximum was reached (15 or 20 targets). A solid line traced out the last five positions (if available) of the target marker on the tracking display and a short line indicated the projected direction and speed of the target marker based on the last two updates. When a target moved out of the range of the tracking display, a new target was added. Throughout all the test sessions, the area searched by the AT was set to 60 and the probability of accepting a match had to be greater than 0.1 for signals with strength greater than 10 and 0.6 for lower strength signals. (The number 60 is strictly a function of the experimental control program.) Preliminary testing showed that the AT would track 80 to 90% of the targets in the test scenarios when those AT parameters were used.

At the start of each test session, participants were told how many targets they would be required to detect and/or track (15 or 20) to the best of their ability. During the first test session, they were also informed that the feedback window was no longer present on the tracking display. Participants were encouraged to take short breaks between runs.

RESULTS

A number of performance measures were calculated including hit rate, error rates for the different types of errors (misses, lost targets, and misassociations), false alarm rate, the percentage of signals handled manually and by the ADT and the amount of time the participants spent during each update handling signals. Performance was averaged across the last 20 updates for each of the four scenarios under the six different experimental conditions. The first four updates were discarded because the number of targets in the 20 target condition did not reach 20 until the fourth update.

Data from the ATS runs with 15 and 20 targets that used the four scenarios run in the ADTS conditions were combined with the ADTS data and a 3 (ATS, ADTS-100, ADT-20) x 2 (15 or 20 targets) x 4 (scenarios) within-participant analysis of variance was performed.

Table 1 shows average performance levels for the various measures. In most cases performance did not change significantly as level of automation increased. The only significant changes were in miss and false alarm rate. Misses declined significantly $F(2,10) = 4.5$, $p > 0.05$ with a posthoc t-test using the Tukey Studentized Range Test indicating that the miss rate for ADTS-20 was significantly lower than the miss rate using the ATS. Interestingly, the reduction in percentage of misses did not result in a significant improvement in hit rate. This probably occurred because the primary source of error in all conditions was misassociations and that error rate did not decrease with increasing automation.

Table 1: Mean time to handle targets and percent hits, misassociations, misses, losses, and false alarms as a function of task and number of targets.

Automation level	# of targets	Time (sec)	Hits	Misasso-ciations	Misses	Losses	False-alarms
ATS	15	17.4	79.1	14.6	5.2	1.3	06.4
	20	22.2	75.8	14.0	8.9	1.5	09.1
ADT-100	15	13.3	79.9	15.5	3.6	0.9	10.2
	20	18.9	78.1	15.1	6.0	0.8	15.6
ADT-20	15	12.1	81.8	14.6	2.9	0.6	10.7
	20	18.1	79.6	15.8	4.1	0.4	18.3

The other measure of performance that changed significantly across the three conditions was false alarm rate, $F(2,10) = 7.2$, $p > 0.05$. In this instance, there were a larger number of false alarms in the ADTS conditions than in the ATS. A posthoc t-test showed a significant difference between the ATS and ADTS-20.

To assess the source of the false alarms, the percentage of noise signals handled manually and by the AT were calculated (Figure 3) for each task. Both manual and AT/ADT generated false alarms increased, but the largest increase was in the number of manual false alarms.

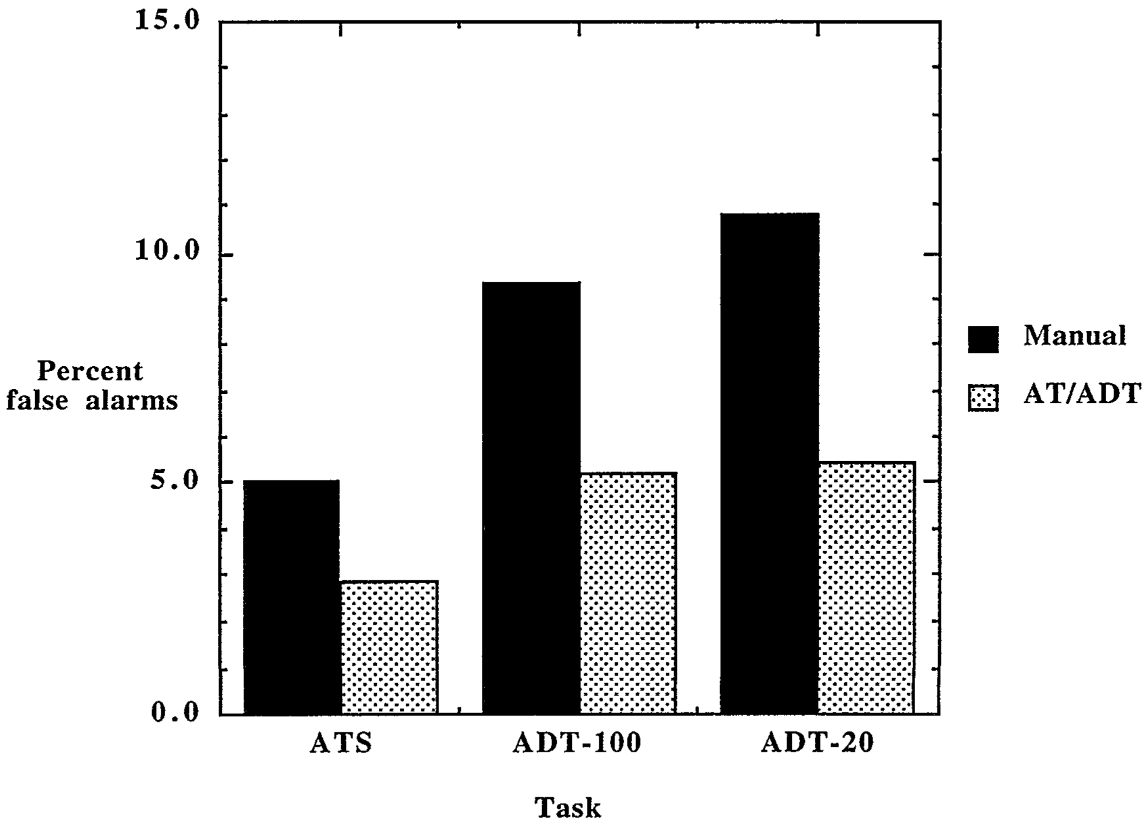

Figure 3: Comparison of percentage of false alarms generated by participants and by AT under the three levels of automation.

The three levels of automation were run at two different levels of task difficulty which was defined as number of targets that had to be monitored. Our interest was in whether the changes in the task had a differential effect as a function of task difficulty. As shown in Table 1, performance declined and response time increased as the number of targets that had to be monitored increased. The changes in response time and hit rate were both significant, $F(2,5) = 105.7$, $p < 0.01$ and $F(2,5) = 6.6$, $p < 0.05$ respectively. The decrease in hit rate was primarily due to a significant increase in number of misses, $F(2,5) = 58.6$, $p < 0.01$.

False alarm rate also increased significantly, $F(2,5) = 73.8$, $p < 0.01$. However, there was no interaction between task type and task difficulty.

DISCUSSION

The primary purpose of this study was to determine if the changes in the task that occurred in adding an automated detector affected the performance of the participants in any way. With the detection threshold of the ADT set to 100, it had been anticipated that there might be a small decrease in the time taken to update the position of the targets because fewer operations were required to correct AT errors. With the threshold set to 20 a further slight improvement in response time might be expected. The ADT would add high-strength targets that it had failed to update. However, since the lost rate was already very low, this was not expected to have much of an impact.

Average time taken per update did decrease an average of 4 seconds with the ADT as compared to the ATS, but the improvement was not significant. The significant changes that did occur were a decrease in misses and an increase in false alarms, in particular manual false alarms, in both ADT conditions. This would be consistent with the participant spending more time to find low strength targets. Since the change occurred in both ADT conditions, it appeared to be associated more with the change in task rather than the presence of an automated detection function for high strength targets.

An alternative explanation is that the change in strategy was due to experience. All the participants had completed several sessions using the ATS under similar conditions before they started the sessions with the ADTS. It may be that it takes considerable experience with the simulation before participants become sufficiently experienced at the task that they start trying new strategies to improve their performance. With a reliable AT, the primary way of improving performance is to reduce the number of missed and misassociated targets. Without feedback, missed targets are more noticeable than misassociated targets.

Given the order that the different automation conditions were carried out in, this hypothesis cannot be ruled out. However, a subset of the participants in the original experiment with the ATS also participated in a second experiment that was carried out on the ATS. The false alarm rates in all three studies are shown in Figure 4. As will be noted, the false alarm rate of participants in the second study using the ATS did not increase. However, they only had to monitor 10 targets while those in the study using the ADT monitored either 15 or 20 targets. Those in the ten target condition may not have felt the need to try alternative strategies to improve their performance. The scenarios were designed so the percentage of low strength targets was usually less than 10%, This translates into about 1 target per update in the 10 target condition and two targets per update in the 20 target condition. That could account for the difference in false alarm rate between the 10 target and 20 target conditions. On the other hand, the noise signal rate was constant across all target conditions. Thus, the probability of selecting a target signal out of the non-target signals by chance was potentially higher in the 15 and 20 target conditions.

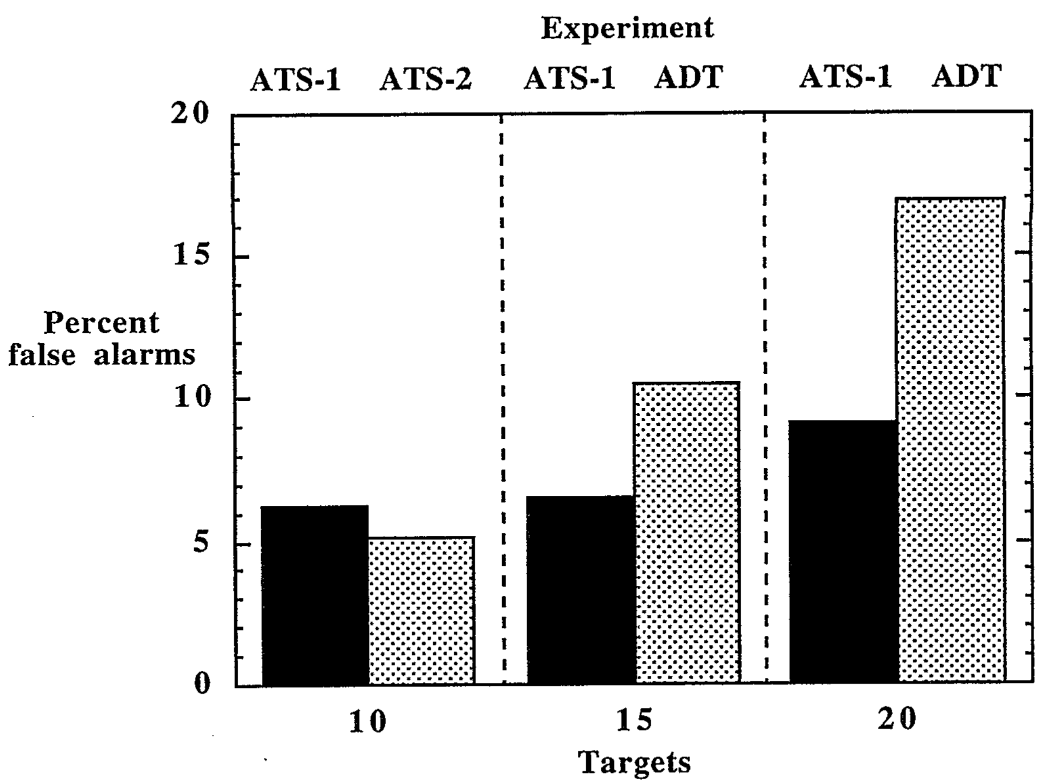

Figure 4: Comparison of false alarm rate in first experiment with ATS, second experiment with ATS and experiment with ADTS as a function of number of targets. (See text for details).

Overall the results suggest that the change in task does not lead to substantive changes in performance under the test conditions used in this study. Further research is required to determine the influence of the threshold level of the automated detector and task variables such as number of targets on the usefulness of the ADT.

CONCLUSION

An experiment was run to determine if the task changes that resulted from the inclusion of an automated detection function in a simulation designed to study the use and usefulness of an automated tracker would have a significant impact on performance. It was found that hit rate and the mean time taken to handle the signals on each update did not change significantly as a result of the change in task. Further studies are required to determine the conditions under which the addition of an automated detector will and will not have a beneficial effect on these types of performance measures.

Percentage of misses declined and manually induced false alarm rate increased significantly suggesting a change in the user's strategy when carrying out the ADTS task. However, an alternative hypothesis, that the change of strategy was due to the increased experience level of the participants in the ADTS task, could not be ruled out. If the change in strategy was due to the change in task, then the availability of an automated detection function might lead to better performance during scenarios with a large number of weak targets.

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McFadden, S. M., Giesbrecht, B. L., & Gula, C. A. (1997). Use of an automatic tracker as a function of its reliability. *Ergonomics,* Accepted for publication.

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