Mine detection training based on expert skill

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ABSTRACT

Studies show that soldiers' mine detection capabilities with the PSS-12 hand-held metal detector are substandard and that their probabilities of detecting (PD) low-metal mines are dangerously low. Highly experienced PSS-12 operators, however, achieve PDs over 0.90 on high- and low-metal anti-tank (AT) and anti-personnel (AP) mines[1.]. Significantly, experts' detection techniques differ from conventional military PSS-12 operating procedures. We report three studies investigating whether instruction based on expert skill could bridge the observed performance gap. Basic research on human expertise has shown that instruction based on detailed scientific analyses of experts' behaviors and thought processes boosts skill acquisition dramatically. These studies tested the effects of an experimental detection training program based on knowledge and techniques learned from analysis of PSS-12 expertise. In Study 1 soldiers who had completed standard mine detection training participated as operators/trainees. This experiment used a pretest-posttest design. Mine simulants served as targets in testing and training. Targets simulated 5 different mines and represented high- and low-metal AT and AP mine types. Pretest performance failed to distinguish the treatment and control groups. Both achieved very low PDs on low metal mines. Treatment-group soldiers then received approximately 15 hours of experimental, hands-on training. Posttest results showed that the treatment group achieved an overall PD of 0.94. This PD exceeded the control group's by a factor of 3. The treatment group's PD on minimal metal targets (M14 simulants) was more than 6 times that of the control group. Study 2 tested a subset of the treated soldiers in the same setting, now wearing body armor. Results replicated those of Study 1. Study 3 tested treatment group soldiers on real mine targets. Several mines from each mine type were used. The surface of the test lanes was expected to increase detection difficulty. Soldiers nonetheless achieved an aggregate PD of 0.97 and showed significant improvement in detecting low-metal mines.

Keywords: cognitive engineering, expert operator, information processing, land mine detection, skill, training

1. INTRODUCTION

A wide variety of scientific and engineering disciplines are engaged in studying and developing technologies to solve the major problems that landmines, especially landmines with minimal metallic content, pose for the military[2., 3.] and civilian populations.[4] While recent field assessments of technologies show promising technical innovations, detection of mines by humans operating hand-held equipment currently plays a central role in clearance missions. This role is expected to persist for the foreseeable future.[5., 6.]

Unfortunately, the proficiency of land mine detection equipment operators is highly variable. Expert operators of the most commonly-used detector, the Schiebel AN19/PSS-12, exhibit mine detection probabilities (PDs) in excess of 0.90 across the spectrum of metallic mine types, e.g., high- and low-metal anti-tank and anti-personnel mines.[1.] Even these "top" detection rates threaten to shrink the small pool of experts, considering consequences of a single error in a live mine field. Of greater concern are findings that soldiers' PDs with metal detectors are well below the expert level and their PD for low-metal mines is far lower.[7., 8., 2.] If the most proficient operators are in danger, their less skilled comrades are in greater danger. Without more effective operator training, the success of wartime, peacekeeping, and humanitarian demining operations, as well as operators' lives and limbs, are in jeopardy.

This paper describes our application of an emerging technology to improving the safety and effectiveness of mine detection performed by human operators of the most commonly used hand-held detectors. The technology is called "cognitive engineering" and its scientific foundation consists of the principles, theories, and methods of the discipline of Cognitive Science**.** Essentially, this approach involves first "reverse engineering" human expertise, that is, analyzing the skill of an expert in a given domain. The product of analysis is a theoretical description of the functional components of expert skill, (e.g., knowledge structures, cognitive strategies, behavioral techniques, and their organization) that explains how an expert performs at a level worthy of the label "expert." Such a description then serves as the raw material for designing instruction intended to train novices.

We have investigated the value of cognitive engineering as a way to better train PSS-12 operators. Motivating this effort were two sets of scientific facts. First, basic research on human expertise has shown that skill acquisition can be dramatically accelerated when novices received instruction based on a detailed understanding of experts' behaviors and thought processes. [9., 10., 11., 12., 13.] Second, investigations documenting the performance of highly experienced mine detection personnel also showed that experts' detection techniques using the PSS-12 differed qualitatively from the operating procedures conventionally taught under US military doctrine and used by soldiers.[1., 14.] In the studies described below, we investigated whether instruction based on detailed analyses of expert skill could bridge the performance gap between less-experienced soldiers and experts.

2. STUDY 1

This study investigated baseline detection performance of US Army Combat Engineers who had received standard training on PSS-12 operation as well as the effects of their participation in an experimental PSS-12 training program. The basis for development of this experimental program was the knowledge, thought processes, and techniques of experts in land mine detection.[1., 13.]

2.1. Method

<u>Participants</u> Twenty-two soldiers who had received standard mine detection training participated in this experiment as trainees. All had just completed Advanced Individual Training at Ft. Leonard Wood's Engineer School and were awaiting assignment to duties at other Army posts. Twenty of the participants held MOS 12B qualifications; the others were 12Cs. Ten represented the 169th Engineer Battalion and twelve came from the 35th Engineer Battalion. Intact groups from the two units were used to minimize the possibility of experimental contamination across conditions.

One of the PI's served as instructor. This individual had never served in the armed services and had accumulated less than 5 hours of hands-on experience in detection of inert mine targets. He had over 20 years of academic teaching experience. His understanding of land mine detection was limited to investigation of the skills of an expert.[1., 14.]

<u>Design</u> A pretest-posttest design was used. Groups from the two battalions were randomly assigned to the treatment and control conditions. Both groups were pretested to determine baseline detection performance and assess group comparability. The treatment group received the experimental training over the next 5 weekdays. The control group was assigned regular duties that did not involve any PSS-12 operation during this period. The treatment group was posttested on the first day after a weekend break. Retesting of the control group occurred on the next day. Due to the unavailability of two members of the control group for posttesting, two replacements were chosen arbitrarily by battalion command and added to this group for the posttest.

<u>Equipment</u> The detection equipment used was the PSS-12 (designated AN-19 by its manufacturer, Schiebel Corporation). This device is a hand-held, pulsed electromagnetic induction metal detector. The sensor head of this device contains transmitter and receiver circuitry arranged in two concentric circles approximately 35 mm apart. The outer coil is 270 mm in diameter. The sensor head is attached to a lightweight, telescopic shaft that the operator grips to sweep the sensor head over the ground. Signals from the sensor are carried via shielded cable to an electronics unit worn by the operator on a shoulder strap. The system's electronic circuitry and battery compartment are housed in this unit, where a power switch, controls for sensitivity and volume, and a failure warning light are located also. The PSS-12 outputs an auditory signal in the 3000 Hz range to the operator when conductive material enters its sensor field. In standard configuration, signals are output via an earphone that can be worn over the ear, or worn near the ear.

Mine simulants served as targets in training and testing due to both the expense and the unavailability of a sufficient supply of real mines. The targets simulated 5 different mines (M14, PMA3 with safety, VS2.2, M16, and M15) and thus covered the full range of metallic mine types (anti-tank (AT) and anti-personnel (AP) mines with high metal (M) and low metal (LM) content). Note that M14s are minimal metal mines. Low-metal targets were created by inserting cylindrical metallic components, specially developed by the Office of the Program Manager - Mines, Countermines, and Demolitions [15.], into hockey pucks in a vertical orientation**.** I, K, and M inserts, respectively, were used to construct the M14, PMA3, and VS2.2 facsimiles. For the VS2.2 simulants, two pucks were glued together to achieve the appropriate depth of the M to achieve the highest possible fidelity. I and K inserts were similarly positioned in single pucks for M14s and PMA3s. To simulate high metal mines, common tin cans in sizes #302 and #10, respectively, were used to simulate M16s (bounding AP-Ms) and M15s (AT-Ms).

A computerized video tracking and display system developed at Carnegie Mellon University[16.] was employed as a training aid. This system was used to capture and display operators' coverage of the ground surface with the PSS-12's sensor head both in training and testing. Trainers were thus provided with objective 2-dimensional displays of an operator's coverage of the ground surface while engaged in search. In addition, replay of an entire lane sweep made feedback available to each trainee immediately upon completion of a lane sweep.

Five metal mason's trowels were used by operators primarily to perform regular in-field checks for unintended drift in sensitivity of their PSS-12s. They were also used to mark the ground surface in order to delineate clear from unswept portions of mine lane surfaces.

<u>Training and Test Site</u> A special facility for this project was developed at Ft. Leonard Wood and designed to provide a controlled field environment for training and testing. The facility included (1) a calibration lane, (2) a training matrix, and (3) 8 test lanes. All areas were level and contained bare, lossy soil. Prior to target burial, each area was swept to remove as much conductive material as possible. Targets in each area were buried at uniform depths. Depths were based on pilot testing and the desire to build a test environment that would maximally discriminate detection capabilities. Low metal targets (M14, PMA3, and VS2.2 simulants) were buried at a depth of 2 inches measured from the ground surface to the top surface of the target. Metal targets were buried at 4 inches. Cues for locating targets visually were eliminated by raking the ground surface.

The calibration lane was 4 m long and 1.5 m wide. It contained two M14 simulants and one each of the other targets. This area was used initially to train soldiers in the experimental group on procedures for setting sensitivity on the PSS-12 and afterward for sensitivity setting before each training and test exercise.

Test lanes were 18.7 m long and 1.5 m wide. Each contained 14 targets buried in random locations, separated so that their metallic signatures did not overlap. The distribution of mine types in each lane was weighted toward low-metal mines because prior studies have shown that they pose a greater detection problem. Each lane contained 5 M14s, 4 PMA3s, 3 VS2.2s, 1 M16, and 1 M15. Colored twine marked lane boundaries.

The training matrix consisted of an area 15 m square. Twine spaced at 1.5 m intervals formed rows and columns creating a matrix of 100 cells each 1.5 m square. Fifty of the cells contained targets. Cell selection was random, subject to the constraint that each row and each column have one of each mine type and that the signatures of the targets were non-overlapping.

The matrix arrangement served several purposes. One was to provide an area in which hands-on training exercises could take place simultaneously for as many as 5 trainees. Another was to support search exercises of varied length in lanes that resembled the test lanes. The most important purpose was to create a training area where ample practice with feedback could be given on different exercises without trainees memorizing target locations, and thus negating the learning value of the exercises. Procedures for impeding such memorization included organizing exercises so that trainees would always approach individual cells or lanes from novel directions (matrix rows or columns could serve as lanes) and regularly changing the matrix's labeling scheme.

<u>Training Program</u> Space limitations preclude a detailed description of training content, therefore only key elements will be described.

The foundation of training was an information-processing analysis performed by one of the authors on the mine detection skill demonstrated by a 30-year veteran of mine detection and clearance operations.[1., 14.] This work empirically established this operator's proficiency and also analyzed *how* he found mines. Essentially, the analysis decomposed the expert's skill into its most basic parts. The product was a detailed, empirically validated model of the specific equipment manipulations, perceptual information, knowledge, and thought processes (and the temporal organization of these skill elements) used by the expert in the process of searching for and detecting specific mine targets and discriminating mines from clutter.

Five principles guided the development of training. First, the content and organization of the expert model served as the blueprint for what to train and when. Second, considering that limited attentional and short-term memory capacities constrain human learning, we used the model's decomposition of expert skill into relatively simple perceptual, motoric, and cognitive tasks to devise exercises intended to develop the simplest and most basic skill components first. Third, because skills require practice to develop, direct instruction via a trainer's descriptions or demonstrations was minimized to maximize the hands-on experience trainees received in each of the training exercises. Fourth, feedback was given as soon as possible after each exercise. Finally, as trainees demonstrated competence on the most basic skill components, training advanced to exercises that combined existing competencies into larger, more complex activity units.

Component Training Activities Content of the training program involved (1) introduction of techniques used by experts, but not taught in conventional detection training that Engineers typically receive, and (2) hands-on practice with feedback on exercises applying these techniques. Each exercise is listed below along with a brief description. Order in the list reflects the training sequence.

PSS-12 Configuration and Procedures for Head-on-the-Ground Operation: Soldiers were shown how to configure the PSS-12 for operation with its sensor head in direct contact with the ground surface. Procedures for sweep were demonstrated. This technique represents a radical departure from US Army training and doctrine.

Sensitivity Setting: Procedures for setting the sensitivity were explained and demonstrated. The key feature involved setting sensitivity against the most difficult-to-detect mine target buried in the calibration lanes.

In-field Sensitivity Check: Sensitivity of the PSS-12 is known to drift under predictable and unpredictable circumstances. [17.] Procedures for monitoring sensitivity for unintended changes relative to the original setting were demonstrated by the instructor and later practiced by the soldiers.

Edge Detection Exercise: This exercise introduced trainees to the fundamental technique used to acquire patterns of information that signify buried mines. Individual trainees with appropriately configured PSS-12s were directed to specific elements of the training grid where the centers of buried mines of initially unknown type were marked. Facing the target mark from a predetermined orientation, each operator would place the detector's sensor head on the ground in a 3 o'clock orientation to the mark. Moving the head on a line perpendicular to the "North-South" line connecting the operator's center with the target mark, the trainee's task was to determine the point at which the detector sounded off while sweeping the head slowly in an East-to-West direction toward the mark. This position was marked with a small plastic golf ball marker and its distance to the target mark was measured and recorded by an observer. The type of mine was then revealed to the operator as well as the distance measured from mine center to the "edge" mark determined by the operator. Each operator performed this exercise on 5 different encounters with each mine type for a total of 25 mine encounters.

Footprint Development Exercise: This exercise introduced trainees to the patterns or "footprints" that identify and locate buried mines. It consisted of a trainee repeating the previously described Edge Detection technique from at least 5 different directions, e.g., advancing the sensor head from different perimeter points (E, S, W, SE, SW) toward a target mark. Each edge was to be marked with all marks remaining in place until the task was complete. All center-to-edge distances were measured, recorded, and reported to the operators along with the identity of the buried target. Trainees were instructed to explicitly describe the size and shape of each resulting pattern and compare and contrast the patterns obtained across trials.

"Airborne" Technique Exercise: High metal mines produce "footprints" that extend as far as a meter away from the mine's center. The purpose of the "Airborne" technique is to locate the mine target within the extended footprint as accurately as possible and *to avoid unplanned detonations caused by the sensor head contacting the prongs that trigger many high-metal antipersonnel mines such as M16s or Valmara 69s*. This technique involves fixing the sensor head so that it can be maintained in a position parallel to the ground surface while it is raised as high as 2-3 feet. By scanning the area within the footprint and progressively increasing the height of the sensor head until small upward or sideward, in-plane movements extinguish the PSS-12s output, this technique enables an operator to pinpoint the location of a buried mine by exploiting the tapered geometry of the PSS-12's sensing field.

Blind Detection Practice: Following practice of the preceding techniques, trainees engaged in a sequence of "blind" detection tasks. Initially, these tasks began with each trainee being directed to a specific cell of the training grid. In each cell, his task was to determine whether a mine was buried within the cell's boundaries using the techniques taught, and, if so, to mark its location as accurately as possible. Sweep coverage was monitored on a subset of cells using the automated recording system. Feedback on the accuracy of each declaration was provided before a trainee proceeded to the next cell. Each trainee then had the opportunity to resweep the cell to familiarize himself with the target's footprint. Blind detection in 5-cell lanes followed such single cell sweeps. Trainees then progressed from 5-cell sweeps to sweeps that covered entire 10-cell rows (or columns) of the training grid. Feedback on mine locations was provided on the conclusion of each trainee's sweep.

Training Goals The primary goal of the training program was to increase soldiers' detection capability. Ambitiously, we sought to achieve or better an aggregate PD of 0.92. This is the performance standard for detection specified in the Operational Requirements Document for the PSS-12.[18.] Discrimination of mines from clutter (measured by false alarm rate (FAR) and rate of advance (ROA)) are important for efficient mine detection, however, no formal efforts to improve FAR and ROA were incorporated in this program.

Maximizing PD was given priority for three reasons. First, failures to detect mines extract a far higher toll than false alarms or slow progress. Second, the pattern recognition capabilities that support a high PD are a prerequisite for discrimination. Thus, raising PD to acceptable levels first is a logical way to improve FAR later. Third, the practical impact of a high FAR is a slow rate of advance (ROA) because FAR and ROA are correlated.[8., 1.] Devoting limited training time to improving FAR at the expense of PD, however, increases the likelihood of missed targets and casualties in a real clearance operation. Our perspective is that minimizing casualties is more important than fast clearance operations, because the time spent on medical treatment in the field and casualty extraction adds to the many far more serious consequences of casualties. At the same time, recognizing the value of speed and efficiency -- *if PD is first maximized* -- we submit that maximizing PD first is the fastest practical route to decreasing FAR and increasing ROA with follow-up training.

Procedures Pretesting involved soldiers performing blind searches of 10-cell lanes of the training matrix. The experimental and control groups were tested in separate morning and afternoon sessions. Following instructions to carry out blind search using standard Army techniques and mine declaration procedures, each group was split in half to test 5 soldiers simultaneously on different lanes of the matrix. Each lane was 15 m x 1.5 m and contained one mine of each type. Each soldier completed at least 3 different lanes. Each soldier thus had at least 15 mine encounters. By alternating test runs between pairs of soldiers, each soldier rested after each sweep for a period required for his partner to sweep a lane.

Training for the experimental group began after a weekend break and continued for 5 consecutive days. After a brief overview of project goals and the training and testing schedule, training proceeded in the sequence of exercises listed above. Each soldier received an estimated 15-hours of hands-on experience with the PSS-12 in training activities.

Posttesting procedures were identical to pretesting except that soldiers carried out their sweeps on test lanes on which they had no prior experience. Each soldier was tested on three lanes yielding a total of 42 encounters per soldier. The experimental group was tested on the Monday following the previous week's training. The control group was tested on the following day.

Scoring In pretesting, training, and posttesting, soldiers made mine declarations by placing marking chips in the locations where they reported mines were buried. Hits were defined as declarations whose center fell within a 6 inch perimeter of the body of a target. Declarations that fell outside this boundary were scored as false alarms. PD was defined as the number of hits divided by the number of mine encounters.

Weather conditions throughout pretesting, training, and posttesting were clear and dry with daytime temperatures in the 50-70 F degree range.

2.2. Results

Pretest results showed that aggregate PDs for the experimental (0.58) and control groups (0.55) were statistically equivalent. This performance is well below the military standard, 0.92. Analyses of PD by target type showed no reliable group differences. However, considerable variability in PD for different mine types was observed. As expected, mines with high metallic content (0.83) were detected significantly more often than low-metal mines (0.40). PDs for AT-M and AP-M types for the combined group were 0.91 and 0.74, respectively. Overall PDs for AT-LM and AP-LM types were 0.65[i] and 0.26. Within the LM category, soldiers' PD for the targets with the least metal, M14 simulants, was 0.16.

Posttest data showed that the experimental group exceeded the PSS-12 ORD standard with an overall PD of 0.94. Figure 1 shows the pretest-posttest gains achieved by the experimental group for each target type as well as for M14s.[ii] All gains were statistically reliable except for the AT-M category, where PDs were consistently high.

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[i] A check performed on targets used in pretesting revealed that 4 VS2.2 (AT-LM) simulants were improperly buried with their metallic components at less than half of the intended depth. These targets showed a substantially higher PD than those buried according to specifications. This had the effect of inflating overall PDs as well as the AT-LM PDs in pretest results. The depths and positions of all targets in the training grid and the test lanes were subsequently checked and verified.

[ii] Error bars in Figures 1-3 represent 95% Confidence Intervals.

Group differences in posttest PDs were statistically reliable overall as well as for mine types, with one exception. The difference between the experimental group's PD (1.00) for AP-M targets and the control group's (0.90) was marginally significant. The magnitude of group differences was particularly striking for low metal targets on the posttest. For AT-LMs, the experimental group's PD of 0.96 was more than 3 times the PD of the control group. For AP-LMs, the difference increased to a factor of 4. For the most difficult targets, M14 simulants, the experimental group's PD (0.87) exceeded that of the control group (0.13) by over a factor of 6.

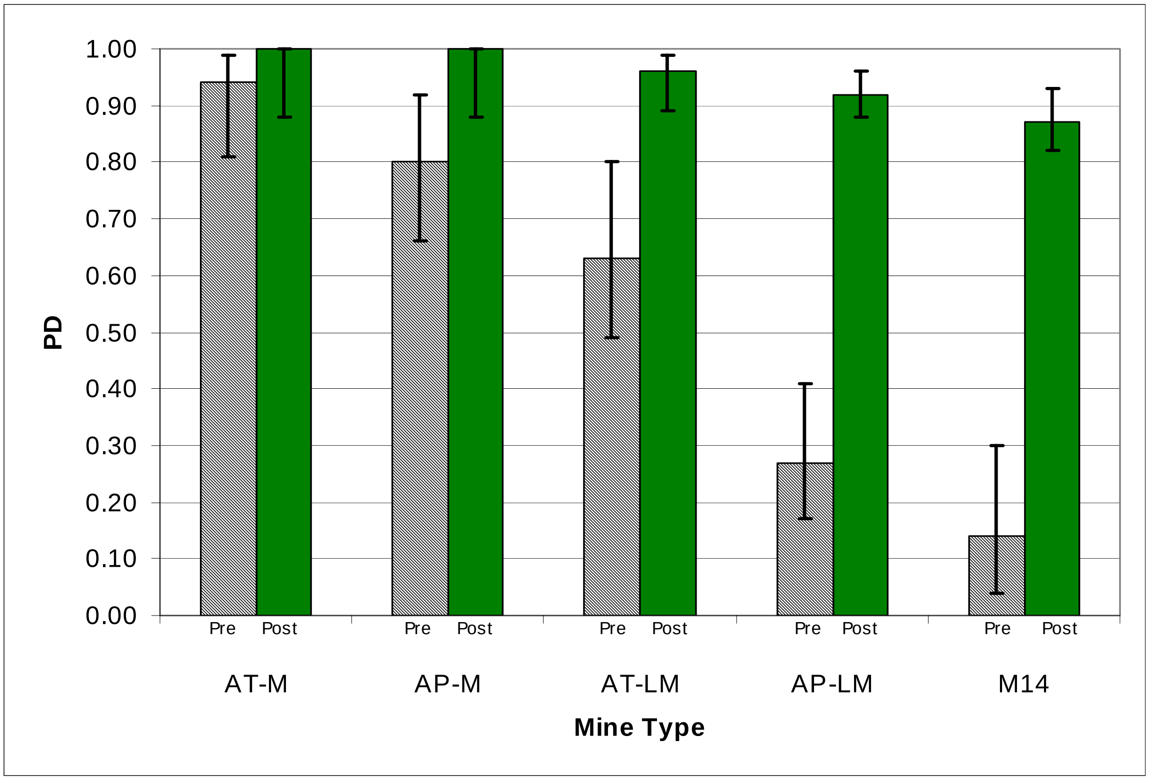

Figure 1

The false alarm rate (FAR) for the experimental group, 0.09 FA/m^2, in the posttest was slightly higher than that of the control group, 0.05, the difference being statistically reliable. Both FARs were well below the military standard of 0.6.

The mean rate of advance (ROA) for the control group (25.2 sec/m^2, SD = 9.9) almost met the military standard of 18. The treatment group's ROA was much slower (80.3 sec/m^2, SD = 30.4). Examination of the high variability of the experimental group's ROAs indicated both large individual differences and high within-individual, across-run variability. With regard to the latter, operators' sweep speeds were within the range of experts' on roughly a quarter of the test runs.

2.3. Discussion

The most striking aspects of the results are (1) the frequency with which low-metal targets are missed when soldiers employ conventional military techniques, and (2) the pretest-posttest gains achieved by the experimental group.

The number of targets missed by both groups in pretesting and by the control group in posttesting suggests that, were these troops assigned a real mine clearance mission, their current skill levels would put the success of the operation, and the troops involved, at serious risk. While the PSS-12 detection performance observed in independent studies is somewhat better than that seen here, the convergence of data from several tests, [6., 7] and the contents of after-action reports from several conflicts, suggests a serious training problem.[19., 3., 2.]

The large posttest gains of the experimental group suggest that training based on expert knowledge and techniques represents a viable solution to the problem of land mine detection with hand-held equipment. The experimental group's posttest PDs are the highest documented. We cannot attribute the magnitude of treatment gains exclusively to the experimental training, however. Had the control group received practice with their techniques equivalent to the amount the experimental group had on expert techniques, some gains could be expected. Clearly, substantial gains would be necessary, though, to reach the level of experimental group. We submit that flaws inherent in conventional military technique related to the prescribed height of the sensor head during sweep make such gains unlikely.

3. STUDY 2

Study 2 had two explicit goals. The first was to check the stability of the treatment effects demonstrated by the experimental group. The gains in PD achieved by the experimental group in Study 1 were sufficiently large to merit a partial replication.

The second goal was to test soldiers under more realistic conditions. A modest step in this direction involved testing soldiers of the experimental group wearing protective body armor that they would be expected to wear under operational conditions.

3.1. Method

Testing methods differed from those of the first study only in the features specified below.

Participants Six soldiers from Study 1's experimental group were tested. Two soldiers were unavailable on the day of retesting and size limitations of the available gear eliminated two others.

Equipment The BASIC P3I is an armored clothing system designed for use by personnel performing mine-clearing tasks. It is an ergonomically designed protective system devised to enhance the survivability of dismounted soldiers from the effects of blast and fragmentation of antipersonnel mines. The ensemble consists of helmet cover, face shield, collar, overvest, chest plates, arm protectors, armor groin protector, trousers, and overboots. These system components are worn in addition to the Personal Armor System for Ground Troops: helmet, vest, and standard combat boots. The ballistic material is 850 denier Kevlar KM2 with 30 plies on the upper leg and upper arm and 23 plies on the lower leg and lower arm. The collar is graduated from 30 to 10 plies as it comes around from the front of the throat to the side. The Helmet Cover overshell is Poly/Nylon, the same fabric as the BDU's, with 24 plies of KM2. One outfit of each size, small, medium, and large was available. The ensemble weight varies by size from 45.8 pounds for the small, 49.1 pounds for the medium and 52.7 pounds for the large size.

Weather conditions were clear and dry, however temperatures exceeded 80 F.

3.2. Results

In all respects, results replicated those of the preceding study. The overall PD achieved by soldiers wearing body armor (0.93) was virtually identical to that observed in the previous study (0.94). Analysis of PDs by target type revealed that correspondence between the two outcomes also occurred at this finer gain of analysis, as illustrated in Figure 2. FARs observed on the two occasions (0.10 vs. 0.09 FA/m^2) also corresponded closely. The mean ROA (69.4 sec/m^2) did not differ reliably from that observed in Study 1. Soldiers produced virtually the same proportion of runs (0.28) on which ROAs were in the expert range (30-50 sec/m^2).

3.3. Discussion

The results of Study 2 confirm the reliability and short-term persistence of the performance gains the treatment group achieved in Study 1.

Although performance of the experimentally-trained soldiers did not differ between the two studies, informal, qualitative observations indicate that they were stressed somewhat by the Body Armor worn. First, several reported more fatigue and discomfort in this study than they experienced in the previous study. The high frequency of postural shifts observed at short time intervals adds validity to the subjective reports. These observations, plus the performance data, suggest the skills acquired in training are robust to whatever stress was added by wearing Body Armor.

4. STUDY 3

Targets used in the previous studies were not actual mines, but mine simulants. Therefore, it remained to be seen whether the experimentally-trained soldiers had acquired knowledge and skills that transfer to detecting real mines. To address this issue, soldiers who received experimental training were transported to a site at Aberdeen Proving Ground (APG) where their capability to detect actual mines could be assessed.

A particular feature of the test lanes at this site, their hard-packed, crushed stone surface, led to the hypothesis that soldiers' detection performance would suffer. Whereas the loose, lossy soil surface of the training and test lanes at Ft. Leonard Wood made an operator's self-monitoring of his coverage of the lane surface a matter of visually examining the "wake" of soil displaced by movement of the PSS-12 sensor head, the new hard-packed surface resisted such marking. The combination of the absence of such feedback at APG, the likelihood of less-than-perfect lane coverage in trainees' sweeps, and the increased cognitive demands of monitoring surface coverage led to the expectation that PDs would drop from levels observed in the previous studies.

4.1. Method

Eight of the ten soldiers who received experimental training at Ft. Leonard Wood participated. The remaining two had been transferred to new posts and were thus unavailable for testing.

Targets included multiple representatives of each mine type. All were deactivated by interruption of their firing chain. AT-Ms included TM62Ms and M15s buried at 5 inches. AP-Ms included VS50s, M16s, and VAL69s set flush to the surface except for enough cover to prevent visual detection. AT-LMs included VS 2.2s, VS 1.6s, TM62P3s, and M19s at 3 inches. Representing AP-LMs were TS50s, PMA3s (with safety), and M14s buried at 1 inch. Twelve percent of the targets were AT-Ms, 24% were AP-Ms, 26% were AT-LMs, and 36% were AP-LM. Of the latter category, 80% were M14s which were 16% of the total number of mines.

Three weeks separated this activity from the previous study; during this time soldiers had no further PSS-12 experience. Therefore, prior to testing, soldiers participated in drills intended to refresh their skills and to familiarize them with the new environment.

The drills were performed on a training matrix adjacent to the test lanes. Its dimensions were identical to those of the Ft. Leonard Wood matrix, but its surface and targets mirrored conditions of the test lanes. Familiarization drills consisted of "footprint development" and two 15 m practice sweeps in the lanes of the matrix. Each soldier received 2.5-3 hours of hands-on operation in this preparatory phase.

Each soldier was tested on each of 4 test lanes, yielding a total of 49 mine encounters per soldier. The test lanes were 1.5 m wide and 25 m long, thus 34% longer than the lanes at Fort Leonard Wood. Order of lane assignments for testing was counterbalanced to the degree possible. Four soldiers were tested simultaneously on the different lanes. Weather conditions throughout familiarization and testing were dry, cool, and windy.

Scoring of declarations was performed by Geodetics personnel from the Aberdeen Test Center, thus providing accuracy to the nearest centimeter. Declarations were scored as hits or false alarms using a 6-inch halo.

Herman & Inglesias[16] sweep monitoring system was used to record sweep coverage of each of the soldiers on the surface of the test lane on which detection was expected to be most difficult, that is, the lane containing all low-metal AT and AP targets.

4.2. Results

Soldiers' overall PD was 0.97. Contrary to expectations, this was higher (albeit non-significantly) than either of the aggregate PDs of the previous studies. It is worth noting that when PDs for individual test runs were used as the unit for analysis, the median PD was 1.0. In other words, soldiers found all of the mines on more than half of their runs.

Figure 2 shows the PDs achieved by mine type. All exceed the 0.92 standard. Comparison of PDs for each mine type over the three studies shows values are not significantly different from one another with two noteworthy exceptions. First, the PD for AP-LM mines, 0.99, is significantly higher from the PDs from the other two studies. Likewise, the observed 1.00 PD obtained on M14s at APG is reliably higher than the comparable measures obtained on M14 simulants in the initial testing and in Study 2.

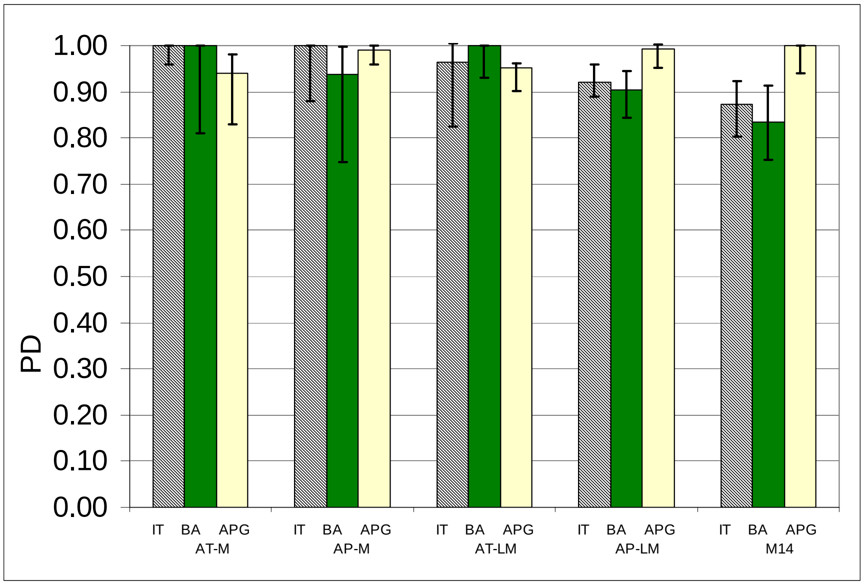

Figure 2

An error analysis shows that half of the total number of missed mines (10) had nearby declarations. The margins of error for these declarations averaged less than 3/4 inch outside of the 6 inch scoring halo. Thus, it is highly likely that the probing that would follow a declaration would have located these mines. Only a single missed AP target, a TS-50, did not have a nearby declaration. The four remaining misses all occurred on the same target, an M19 buried at 3 inches.

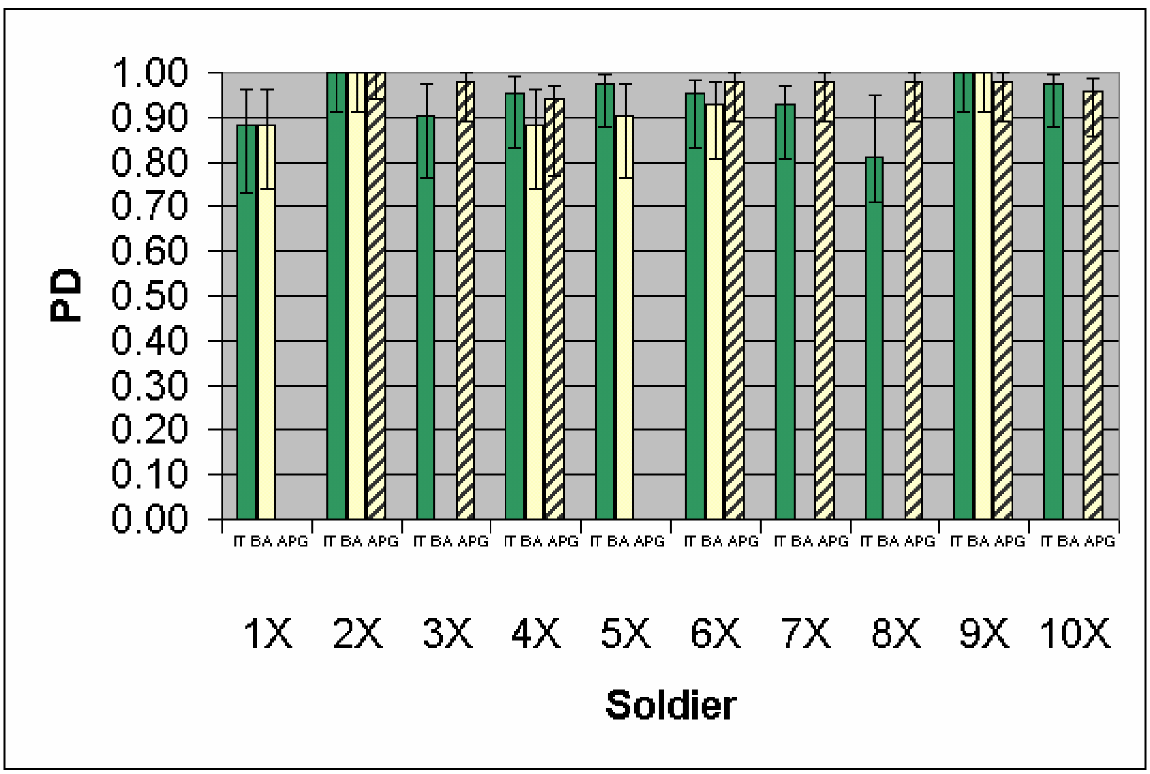

Figure 3

Figure 3 displays the PDs achieved by individual soldiers in this study as well as for the two preceding studies. All of the soldiers' aggregate PDs exceeded the 0.92 detection standard against APG's mines.

The mean FAR, 0.31, increased considerably (and reliably) relative to previous observations, however it remained well under the military standard, 0.60.

The mean ROA, 75.4 (SD = 23.2), did not differ reliably from the same measures observed in the two previous studies. The proportion of runs on which the ROA was in the expert range dropped slightly to 0.20.

4.3. Discussion

Predictions of potential problems in operators' sweep coverage and their negative consequences for PD were unsupported in testing. Warnings issued to operators directing them to pay careful attention to coverage were clearly heeded. Evidence for this inference is the observation that several operators displayed a degree of overlap that was probably unnecessary and certainly inflated ROA. These actions were consistent with prioritization of PD in performance.

It cannot be determined conclusively whether the detection gains seen in this study are due to shallower target depths, different targets, soldiers' learning, or a combination of these variables. There are indications that target depth and learning are contributing factors, however.

First, as demonstrated informally by expert operators, the closer the sensor head of a properly adjusted PSS-12 is to small metal components, the more salient the detector's response. Our own field experimentation using low-metal targets confirms this observation.

Evidence for learning comes primarily from the surprising incidence of correct rejections observed during testing. In such instances, soldiers received detector responses, but decided not to make declarations after developing spatial patterns (based on onset and offset of detector response) on the ground surface around the alerting signal's origin. Comments like "that's not a mine," "that doesn't look like a mine," and "I don't think it's a mine" accompanied many of these correct rejections. Such observations imply that some trainees developed the ability to discriminate the patterns of information produced by mines from the patterns produced by unknown sources, most likely either metallic clutter or conductive soil. It thus appears that training focused on improving detection also supports spontaneous development of discrimination capabilities.

5. GENERAL DISCUSSION AND CONCLUSIONS

The gains in detection performance achieved by soldiers receiving relatively brief training are evidence for the effectiveness of training based on scientific analyses of expert PSS-12 operators. While studies of complex skill acquisition in other domains have shown impressive gains as a result of similar interventions, none have shown such large and rapid improvements. Moreover, the gains are the largest where the need is the greatest; small, low-metal mines pose the most serious threat. This discovery that cognitive engineering works as an instructional technology in the current context is especially welcome, because few tasks punish human error as swiftly and savagely as mine detection.

Nearly as impressive as the overall detection accuracy the experimental group achieved is the fact that all of the soldiers tested in Study 3 achieved PDs exceeding the military standard. This result is interesting because general aptitude measures (GT) of the experimentally-trained group on the Armed Services Vocational Aptitude Battery range from 85 to 127. Thus, it appears that training effects swamp aptitude differences, although factors such as ceiling effects and measurement error in both detection performance and individual aptitude scores may be operating. We also point out that our results do not show that experimental training effects overcame all aptitude differences. Some substantial, statistically significant correlations appear between pretest-posttest change scores and several ASVAB subtest scores, though the small sample size raises uncertainty about their replicability. Nonetheless, we hope to investigate these intriguing relations in future studies with larger samples.

The results also demonstrate the value of mine simulants as training aids. The PDs observed in Study 3, which used inert, real mines as targets, suggest that basic detection skills developed on simulants transfer well. The ability to conduct effective training substituting simulants for actual, deactivated mines is significant as real mines are severely limited in their availability and are relatively expensive. Thus, using simulants can reduce training costs.

Finally, however successful this application of cognitive engineering has proven for developing mine detection capabilities, we state explicitly that the training carried out in this program does not prepare soldiers sufficiently for operations in live minefields. The current training has focused entirely on boosting PD; additional training to discriminate mines from metallic clutter is needed as well as greater attention to improving rate of advance. We have devised exercises intended to improve both dimensions of performance that could be incorporated easily into a basic training program and are eager to test their effectiveness.

To produce effective training for mine detection in tactical environments, the design of effective training environments requires as much attention as that devoted to the design and validation of training content. To engineer training that effectively transfers to safe, effective, and efficient detection of live mines in real missions, we argue that training environments should mirror as closely as possible the operational environments in which mine detection and clearance will occur. In addition to buried mines, such settings often contain additional threats such as surface mines, trip wires, booby traps, and unexploded ordnance; troops must be trained to deal with these hazards in addition to buried mines. Moreover, mines and the other hazards are encountered in a wide variety of environments; in hilly, rocky terrain; lands with a wide variety of vegetation; deserts and beaches; stream beds, and so on. Indeed, our studies of experts indicate that they modify their detection techniques to adapt to such environmental variations.

We strongly advocate development of training facilities that embody these environmental variations. We hope to study mine detection experts in such environments and subsequently train novices in them on the techniques used effectively by experts. Our current findings show how much operator training, informed by an understanding of expert skill, can improve mine detection.

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