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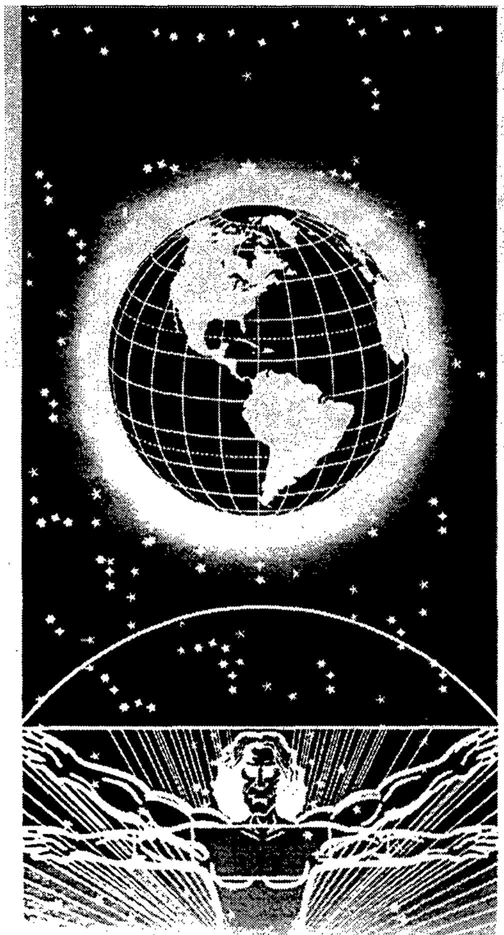

UNITED STATES AIR FORCE RESEARCH LABORATORY

EFFECTS OF TEL CONFUSERS ON OPERATOR TARGET ACQUISITION PERFORMANCE WITH SAR IMAGERY

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FOR THE COMMANDER

JOHN F. KENT, COL, USAF, BSC
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The present study examined the effects of the number of M-548 confuser vehicles (from zero to four) on TEL target acquisition performance with simulated synthetic aperture radar imagery at 2 ft and 4 ft resolutions. The vehicles were positioned at orientations of 0 degrees (head-on), 45 degrees, 90 degrees (broadside), 135 degrees, and 180 degrees (tail-on) in low, medium, or high clutter backgrounds. Upon viewing each of 1560 images, ten operators determined whether the TEL target appeared in the scene, rated their confidence, and identified the TEL's location if they thought it was present. The results revealed that decision-making time was slower and operator confidence was poorer at the 4 ft image resolution as compared to 2 ft. Further, perceptual sensitivity, reaction time, and confidence were all degraded in high clutter scenes and when the TEL was positioned at 0 degrees and 180 degrees as compared to oblique and broadside orientations. Finally, number of confusers had no effect on operators' hits, false alarms, perceptual sensitivity, response bias, or confidence; however, reaction times were slower when two or three confusers appeared in the image. The radar return of the M-548 cargo truck may have been sufficiently different from the TEL target so as not to be particularly confusing.

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PREFACE

This effort was conducted by the Information Analysis and Exploitation Branch, Crew System Interface Division, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/HECA), Wright-Patterson Air Force Base, Dayton, Ohio. The project was completed under Work Unit 71841044, "Target-Related Studies." Logicon Technical Services, Inc. (LTSI), Dayton, Ohio, provided support under contract F41624-94-D-6000, Delivery Order 7. Mr. Donald Monk was the Contract Monitor.

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INTRODUCTION

Mobile ground targets such as mobile missile launchers, surface-to-air threats, tanks, and other vehicles that can relocate rapidly represent a continuing challenge for U. S. defense forces. Since our involvement in Operation Desert Storm, one of the highest U. S. defense priorities has been to counter the threat posed by theater missiles (TMs). Throughout this conflict, detecting and locating mobile missile launchers such as the Scud-B transporter-erector-launcher (TEL) proved to be a difficult task for air defenses, in part because mobile missile launchers are able to move to a safe site to refuel and rearm within three to five minutes of a launch. Once the vehicle has left the launch site, it may be impossible to reacquire. In point of fact, according to Fulghum (1994), not a single Iraqi TEL was destroyed during the Gulf War. Consequently, the U.S. Theater Air Defense (TAD) has been expanded to include not only aircraft defense but also defense against TMs and their supporting infrastructure.

Various sensor technologies (sensors, sensor management subsystems, automatic target cueing and recognition [ATC/ATR] subsystems, and operator interfaces) are expected to contribute significantly to attempts to improve our ability to find, fix, track, target, engage, and destroy TMs and their associated infrastructure. Synthetic aperture radar (SAR) sensors, on both surveillance and attack platforms, are of particular interest since this type of sensor is able to function at all times of day and night and in adverse weather conditions, can be employed over long standoff ranges, supports accurate geolocation of detected/identified targets, and is capable of producing the level of image quality required for high confidence target acquisition and fratricide avoidance. Currently, SAR sensors are or will be employed on the Joint Surveillance Target Attack Radar System (J-STARS [E-8C]) developmental surveillance system, the U-2S reconnaissance system, several developmental unmanned aerial vehicle (UAV) reconnaissance systems, and the F-15E, B-1B, and B-2 attack systems to support navigation and weapon delivery. The use of SAR imagery for target detection, acquisition, and destruction can be affected by a number of factors, including image resolution, background clutter in the surrounding terrain, target orientation and the presence of nontarget objects in the scene that may be easily confused with the target.

Image Resolution

Image resolution refers to the quality of the imagery produced by the SAR sensor. At very coarse resolutions, gross features such as size and shape may be the only perceptible characteristics of a potential target. At higher resolutions, finer details of the object can be discerned. In general, as image resolution improves, two objects can occur closer in proximity to each other and still be perceived as separate objects rather than as a single entity. Recent investigations using both actual and simulated

SAR imagery have explored the impact of image resolution on the detection of mobile ground targets such as the TEL, revealing that performance accuracy typically increases as the resolution improves (Davis, See, Shacklett, & Kuperman, 1996; Kuperman, Wilson, & Davis, 1993; Kuperman, Wilson, & Perez, 1988; See & Kuperman, 1995). For example, using actual SAR imagery from the F-15E, Davis et al. demonstrated that the detection rate of a TEL target was significantly improved at a resolution of 4 ft by 6 ft per pixel (M = 94%) as compared to 8.5 ft by 8.5 ft per pixel (M = 87%).

Other studies have shown, however, that such performance improvements may become negligible as resolution increases beyond an already high level (Kuperman, Wilson, & Davis, 1993; Kuperman, Wilson, & Perez, 1988; See & Kuperman, 1995). In the See and Kuperman investigation, resolutions of 8.5 ft, 5 ft, 3 ft, and 1 ft were examined in the context of simulated SAR imagery. The results indicated that operators' ability to detect a TEL target vehicle improved from the 8.5 ft resolution to the 3 ft resolution, whereupon no further improvements in performance were observed. In fact, the only indication that the 1 ft resolution might represent an improvement over the 3 ft resolution was the finding that operators were significantly faster at correctly rejecting nontarget images at the finest resolution; their detection ability itself did not differ at the two highest resolutions nor did their reaction time for correct detections of the TEL target.

Background Clutter

Another aspect of the imagery that may affect detection performance is background clutter. Clutter in a scene is often defined in terms of the "busyness" of the background in which a potential target is embedded and may include both natural and artificial sources (Toms & Kuperman, 1991). For example, high clutter may be characterized by the presence of geographical features such as dense forests that can make a target more difficult to discriminate or by the presence of large numbers of artificial objects (e.g., nontargets, decoys, and other target-like objects). Low levels of clutter might be presented by a desert scene with minimal vegetation or the presence of few confusing man-made objects.

In an investigation of the effects of background clutter on the detection of relocatable targets in simulated SAR imagery, Kuperman, Wilson, and Perez (1988) defined clutter as the amount of vegetative coverage in a scene and examined four different types: (1) a forested background, representing the greatest overall vegetative coverage and tree height; (2) tree clutter, with moderate coverage and moderately tall trees; (3) bushes, a background containing short trees and brush with only a few tall trees; and (4) a river background containing a river with very limited forest coverage. Operator performance efficiency was lowest in the forested background and increased progressively as the background changed from trees to bushes to the river; i.e., as the amount of clutter decreased.

Several other studies wherein clutter was also defined in terms of vegetative coverage have produced similar results. For example, using simulated SAR imagery, See and Kuperman (1995) defined low, medium, and high levels of clutter according to the tree density in the scene. Their results indicated that the hit rate for detecting a TEL was not affected by background clutter; however, operators' false alarms did increase as the tree density increased from a low level to a medium or high level. Thus, as the clutter became more pronounced, operators were more inclined to incorrectly designate a nontarget object as the TEL target. Similarly, in two other studies using actual SAR imagery collected at Eglin Air Force Base, Florida, performance effectiveness was adversely affected by background clutter, defined in terms of both the amount and type of vegetative coverage (Davis, See, Shacklett, & Kuperman, 1996; See, Davis, & Kuperman, 1997). The three levels of clutter included in both studies were referred to as the open (low), treeline (medium), and sparse (high) background sites. The results in both studies indicated that the hit rates for detecting and for locating a TEL target declined as the clutter increased; however, the false alarms did not increase significantly.

In yet another study of background clutter, Cole and Hughes (1984) demonstrated that the presence of clutter can reduce the prominence of a target, interfering with both its attention-getting quality (the probability that the object will be noticed when the observer has not been told of its likely occurrence) and its accessibility to search (its ability to be quickly and reliably located when the observer is specifically directed to search for and locate it). In their study, Cole and Hughes had 50 observers drive a vehicle around a predetermined route. Thirty-five targets, disks of different sizes and reflectances, were positioned along the route where normal traffic signs might be located. One group of observers was told to verbally report all objects that attracted their attention along the route (attention conspicuity). The second group of observers was told to verbally report the presence of all disk targets and conventional road traffic devices (search conspicuity). The route was chosen to provide a variety of normal driving environments including arterial roads, residential streets, and shopping centers (the most cluttered of the three environments). The results indicated that differences in hit rates for the three road types were highly significant for both attention and search conspicuity and were believed to be attributable to visual clutter. Specifically, conspicuity of the targets was reduced in the shopping center sections of the route as compared to the conspicuity of the same targets in the arterial road and residential sections. Consequently, both attention and search conspicuity were reduced in shopping centers, as revealed by lower hit rates.

Vehicle Orientation

Common sense dictates that target vehicle orientation should impact the operator's ability to detect, locate, and identify a potential target. Intuitively, a broadside view of a vehicle should yield the greatest level of performance accuracy since, in most cases, it affords the best view of the object's discriminating features. However, the effect of vehicle orientation with ground targets has not yet been studied systematically; hence, the impact of changes in orientation remains to be quantified. To date, the only relevant studies of vehicle orientation and detection/recognition performance have been conducted in maritime environments. Whitehurst (1976) studied the effects of ship orientation on the range at which a ship could be recognized as a merchant ship or combat ship. The targets were four 1:1250 scale models of merchant and combat ships videotaped against a simulated ocean background at orientations of 10°, 30°, 50°, 70°, and 90° off the bow. Simulated distance from the target varied from 36 km to 8 km in 4 km increments. Participants viewed each image on a television monitor and indicated whether the target was a merchant or combat ship. The results revealed that the probability of ship recognition increased as the orientation of the ship increased from 10° to 90° (broadside) across all ranges examined. For example, at a range of 26 km, a broadside target could be correctly recognized 80% of the time; a target oriented at 10°, only about 10% of the time. Viewed another way, the results showed that a target could be correctly recognized 80% of the time at a range of about 26 km when the approach was broadside. By comparison, when the approach was 10° off bow, the same level of performance could be achieved only at a much closer range of 8 km.

In a similar investigation, Mocharnuk, Gaudio, and Suwe (1981) examined the effects of ship orientation, ship type, and contrast on target acquisition with simulated infrared imagery. The targets were six ships positioned either bow on (head-on, 0°) or port abeam (broadside, 90°). The imagery was constructed by photographing 1:1250 scale models of the ships with simulated "white-hot" polarity infrared signatures against a uniform black background. The ships were divided into two classes according to their country of origin. During the task, observers viewed a dynamic presentation of the imagery at starting ranges of 20, 22, or 24 km, with a constant closing rate of 282 m/s. At the end of each presentation, observers were asked to categorize the ship by pressing the correct key on a response box. Dependent variables included range at classification (simulated range to the target when the recognition button was pressed) and accuracy of the categorization. With respect to the range at classification, a multiple regression model showed that ship orientation accounted for more of the variance (about 21%) than contrast, ship type, and accuracy. Further analysis showed that observers were able to classify the ships at greater range when the orientation was 90° as opposed to 0°. Analyses of response accuracy produced similar results. As before, ship orientation accounted for more variance than did ship type. The authors hypothesized that the effect of ship orientation was probably due to differences in both the number and prominence of the cues that are present at the different target orientations. Following the experiment, observers reported that relatively few good cues were available at 0° (head-on) as compared to 90° (broadside). At 0°, the cues were more subtle and observers had to rely on different cues such as the shape and width of the bow, making classification more difficult.

Confusers

A Definition of Confusers.

An operator's ability to detect a predesignated target can depend not only on the extent to which the vehicle's features are discernible given its orientation, the image resolution, and the background clutter in the scene, but also on the presence of other objects referred to as "confusers." Greening (1974) defines confusers, or false targets, as "objects which resemble target objects to a greater or lesser degree" (p. 25). He further points out that the distinction between "clutter" and "confusers" is not always clear in the real world. The distinction can be made only in relation to the target object for which the operator is searching. For example, pieces of clutter that actually do resemble the target may be considered confuser objects that will require fixation and evaluation during search because of their target-like appearance. However, if targets are fairly distinctive (e.g., vehicles, buildings, bridges), they will generally not be easily confused with background clutter. In this case, the search task would primarily be affected by the presence of other vehicles or structures similar to the target and not by the presence or absence of a high level of texture or clutter in the background. In essence, the principal distinction between clutter and confusers is whether the clutter is texture-like (diffuse irregular background) or target-like. The former would be considered clutter, whereas the latter would be considered confusers. Behaviorally, the distinction appears to be between objects that are sufficiently target-like to require a close fixation for a classification decision, and those which can be discarded peripherally. As targets become less isolated and well-defined, the distinction becomes less clear cut.

When confusers are present in a scene, both their type and number can be critical to operator performance. The type of confusers is important because decision-making time will depend on the degree of similarity of each confuser to the anticipated appearance of the target image. A confuser that closely resembles the target may require several fixations before a decision is reached. The number of confusers is also important because decision time will increase as the number of nontarget objects to be examined and rejected increases (Greening, 1974). As Greening points out, a number of early studies have shown that the time to acquire a target increases as the number of confusers increases and as the confusers become more similar to the target. In general, the average search time for a target among a collection of nontargets identical to one another and differing from the target only in size can be determined from the following equation:

$$\bar{t} \propto \frac{1}{(d_B - d_T)^2} \qquad [1]$$

where $\bar{t}$ is the mean response time, d_B is the angular diameter of background objects, and d_T is the angular diameter of targets. Further, the number and type of confusers may affect not only decision-making time but also detection accuracy itself. After inspecting and evaluating the objects present in the scene, the operator may select one of the confusers as the target and miss the actual target vehicle. The corresponding probability of detection for the case in which confusers are identical to one another and differ from the target only in size can be obtained by means of the following equation:

$$P_S = \frac{\pi \ (d_B - d_T)^2}{Am^2} \qquad [2]$$

where P_S is the single glimpse probability of detection; A is the area to be searched; m is an empirically determined constant; d_B is the angular diameter of background objects; and d_T is the angular diameter of targets. As Greening reports, the probability of fixating a nontarget object is reduced by half if the length differs by 50%.

A Definition of Similarity.

Given that confusers are defined in terms of their similarity to a predesignated target, it is important to specify how the degree of similarity itself is determined. O'Kane, Biederman, Cooper, and Nystrom (1997) provide one method for specifying similarity based on Biederman's (1987) theory of shape representation, which holds that objects can be represented as an arrangement of viewpoint invariant parts. Viewpoint invariant shape properties are features of edges that do not change as the object is rotated in depth; consequently, the object's three-dimensional shape can be easily ascertained from its two-dimensional image properties. Examples of such properties include whether an edge is straight or curved, whether two edges are parallel or not, and the type of vertex that is formed when two edges meet. Viewpoint-invariant properties can be contrasted with metric properties, which do vary with the object's orientation. Metric properties include aspect ratio (length-to-width ratio), length, and degree of curvature of an edge. Human shape recognition is largely based upon the recognition of viewpoint-invariant properties. In their investigation, O'Kane et al. (1997) developed a similarity metric defined by the magnitude and number of viewpoint-invariant part differences between a pair of vehicles and demonstrated its ability to predict confusion rates in a real-world identification task involving highly similar objects.

To develop the similarity metric, a "similarity tree" was constructed by examining near-range high-contrast infrared imagery of 15 Russian and U.S. military vehicles. For each vehicle, salient, easily detectable features that could distinguish the vehicles from one another were noted: wheels or tracks, presence of a gun, presence of a cargo bed, etc. The primary dimension for distinguishing among the vehicles, which would serve as the trunk of the similarity tree, was the presence of wheels versus tracks. Other features of the wheeled and tracked vehicles provided limbs and branches on the similarity tree that could further distinguish among the vehicles within each category. Using the similarity tree, the degree of similarity between any two vehicles could be quantified as the nodal distance between them. For example, the UAZ-469 and the M151 were assigned a similarity of 1 since the only feature separating them was the presence of doors on the cab. On the other hand, the UAZ-469 (wheeled) and the T62 (tracked), which were separated by 9 nodes because they differed on a number of dimensions, were assigned a similarity rating of 9.

Eighteen male tank gunners were asked to view each thermal image and identify the vehicle by name if possible or by basic-level category (tank, armored personnel carrier, and truck) if the exact vehicle type could not be determined. Of those trials in which observers provided vehicle identifications, 55% were correct responses and 45% were confusion errors. Examination of the confusion errors by nodal distance indicated that confusions were far more likely to occur at small distances (1, 2, and 3) as opposed to large distances (7, 8, and 9). For example, of the total number of confusions, 25% occurred at a nodal distance of 1 and fewer than 5% at a distance of 9. The correlation between the nine nodal distances and the mean confusion rates at each distance was -.88. That is, as the nodal distance between vehicles decreased (as they became more similar), the likelihood of their confusion increased.

In a second experiment wherein the observers were forced to make an identification response (i.e., were not permitted to use basic-level categories), the majority of confusion errors again occurred at the three smallest nodal distances. At the three largest distances, percentages of confusion errors were all less than chance. Additional analysis also indicated that the visibility of the two features judged to be most critical for identifying a vehicle correlated at .74 with the overall percentage of correct responses. When factors such as range, size, signal-to-noise ratio, and orientation were added, the correlation increased to only .79, implying that the more critical features for object identification were the viewpoint-invariant shape properties used to construct the similarity tree. In sum, the results of the two experiments revealed that the probability of confusing one object with another could be predicted from a similarity measure based on the number of the discriminations that must be made to differentiate the two objects as well as their prominence or visibility.

Performance Effects of Target/Nontarget (T/NT) Similarity and Nontarget/Nontarget (NT/NT) Similarity.

In terms of object similarity in a search and detection task, Duncan and Humphreys (1989) demonstrated that the similarity of nontarget (confuser) objects to one another (NT/NT similarity) is as critical to performance as their similarity to the target (T/NT similarity). They reached their conclusion following the completion of a series of experiments in which alphabetic characters were used as targets and nontargets (e.g., searching for a 45°-tilted *T* among nontarget *T*s that were either upright or rotated 90° clockwise). Their results showed first that search difficulty, as indexed by search time, increased as the similarity between targets and nontarget distractors increased. Thus, it became harder to identify the target when the confusers or distractors were target-like as opposed to when they were very different from the target. Second, search difficulty increased as the similarity among the nontargets themselves decreased. That is, as the nontargets became more varied, it took longer to find the target object. Third, the results indicated that T/NT and NT/NT similarity interacted; specifically, increasing T/NT similarity had little effect on performance when NT/NT similarity was high, and decreasing NT/NT similarity had little effect when T/NT similarity was low. Practically speaking, the interaction between T/NT and NT/NT similarity implies that performance effectiveness can be understood only by considering both variables together. The best scenario, in terms of rapid search time, will tend to occur when the target and nontargets are dissimilar and all of the nontargets are similar to one another. In this situation, the target will be distinctive because it will differ drastically from a number of surrounding objects that all look the same.

In an attempt to explain these outcomes, Duncan and Humphreys developed a theory based on the concepts of template matching and spreading suppression. According to their explanation, visual input from a scene is first segmented into groups of items that are similar in appearance or are proximal to one another. Thus, items in a scene with the same color, motion, or shape will tend to group together into what are called structural units. Structural units are hierarchical. Thus, the entire scene may serve as one structural unit that is subdivided into smaller units based on the principles of similarity and proximity. These in turn are subdivided into smaller structural units (e.g., individual objects). To serve as the focus for further action, part of the visual input must be selected for access to visual short term memory (VSTM). Duncan and Humphreys propose that structural units act as wholes to compete for and gain access to the capacity-limited VSTM. Entry to VSTM begins with a template matching process used to classify each structural unit as either a potential target or nontarget. That is, each element is matched against the observer's template, or concept of the target's appearance. Those units that most closely match the template receive the highest weights and are most likely to enter VSTM and become the focus of current behavior for further processing. This aspect of the theory explains why increasing T/NT similarity is detrimental to visual search. As nontargets become more similar to the target object, they more closely match the observer's target template and therefore receive high weights that may parallel the weight given to the actual target. Consequently, nontargets and targets will compete equally for access to VSTM; ultimately, the target may not be the focus of current behavior.

The concept of spreading suppression is used to explain why high NT/NT similarity is beneficial. According to the theory, structural units possess what is referred to as weight linkage. Thus, a change in weight for one unit will be distributed to other units in proportion to the strength of their grouping. Consequently, such units tend to gain or lose entry to VSTM together. Weight linkage translates into efficient rejection of strongly grouped nontargets through a process of spreading suppression. Hence, when the nontargets are highly similar to one another, they can be rejected as a group, speeding the search process. When nontargets are dissimilar, they will not be strongly grouped, their weights will vary depending on their degree of similarity to the target, and they will have to be examined and assessed independently. Decreasing NT/NT similarity reduces the opportunity for spreading suppression of grouped nontargets.

In summary, according to the theory, there are two sufficient conditions for efficient visual search. The first is that NT/NT similarity should be greater than T/NT similarity. If this is so, the nontargets will form strong groups with low weights; spreading suppression will enable them to be rejected for access to VSTM, leaving only the target object. The second condition is that T/NT similarity should be low so that nontarget weights will be negligible; again the target will have the greatest likelihood of entering VSTM. As the authors note, however, their ideas were developed on the basis of highly artificial laboratory search tasks; hence, it remains to be seen whether these notions generalize to the real world.

One indication that they might apply to real-world tasks comes from a study conducted by Birkmire, Karsh, Barnette, Pillalamarri, and Breintenbach (1991). The authors examined the confusability of the target signatures of four tracked and four wheeled military vehicles embedded in one of twelve different levels of white noise designed to simulate actual sensor imagery. Detection (perception of a possible target vehicle), recognition (perception of target category—wheeled or tracked), and identification (determination of actual target name—e.g., Abrams tank) performance were assessed. On average, operators took only 4.5 seconds to detect a target and verbalize its identity and location in an image. With respect to performance accuracy, detection and recognition performance were similar for the wheeled and tracked vehicles; however, the wheeled vehicles were more easily identified than the tracked. The authors postulated that the greater degrees of similarity among the tracked targets made them more easily confusable with one another than was true for the wheeled targets.

The authors also point out that confusion between two targets in a set depends not only on the amount of features they jointly share but also on how those features are shared with other targets in the set. For example, in their study, the Abrams tank target elicited many more "Abrams" responses than "Concept" responses; however, when the Concept tank appeared, both "Abrams" and "Concept" responses occurred equally often. This performance difference stemmed from the differences in similarity of each target to the other two tanks (Bradley and Test Bed) in the set. Namely, the Abrams tank had some features in common with all three of the other tanks and elicited an equal number of incorrect "Bradley," "Concept," and "Test Bed" identifications when it was presented; these false identifications, however, were still significantly less than the number of correct responses to the Abrams tank. The Concept tank, on the other hand, shared features primarily with only two of the other tanks in the set (Bradley and Abrams), and these two tanks were each named just as often as the Concept when the Concept tank appeared; hence, the number of correct responses did not exceed the false identifications. Such outcomes imply that if the target set is changed, the relative criticality of a given feature will change and will be reflected in the overall pattern of the confusion matrix. In other words, to use Duncan and Humphreys' (1989) phraseology, "confusability" will depend on both T/NT similarity and NT/NT similarity.

Recent Studies of Confusers in Actual and Simulated Environments.

Several recent studies examining the effects of number of confusers on operator performance have corroborated the general conclusion that detection time and accuracy deteriorate as the number of confusers increases (Greening, 1974), demonstrating its applicability in various types of realistic and artificial environments. For example, Boersema and Zwaga (1985) examined the effects of number of advertisements on the search for a target routing sign in a railway station. The target routing sign was white-on-blue. The distractor advertisements varied in number and size, but none was blue. The results showed that the presence of the advertisements was detrimental to search performance; however, the introduction of only one advertisement in a scene tended to reduce the percentage of correct detections of the routing sign more so than the additional introduction of a second and third advertisement.

In a subsequent study, Boersema, Zwaga, and Adams (1989) again examined the effects of distractor advertisements on target search for routing signs using color slides of scenes in railway stations and other public environments for their stimuli. Each scene contained routing signs with white lettering on a blue rectangle as well as zero, one, or three advertisements. The ads were all rectangular, but none was blue in color. Upon viewing each slide, participants were instructed to find the target destination as quickly as possible and its associated arrow in the scene's routing information before pressing a button to terminate the scene. Subsequently, they verbally reported the direction of the arrow. In two of the three scenes examined, search time (finding and fixating on the sign) increased systematically with the number of advertisements; however, processing time (reading the sign and deciding on the response) and overall reaction time were unaffected. Analysis of the eye movement data showed that the number of eye fixations in those two scenes also increased systematically with the number of distractors. Thus, the results indicated that the search time for relevant information increased as the number of distractors increased due to an increase in the number of fixations during search. However, further analysis indicated that only some of the additional fixations actually fell on the advertisements. Hence, the increased number of fixations was not simply due to the presence of more distractor objects. The authors postulated that the introduction of distractors in the scene results in less efficient scanning. Consequently, the increase in search time when ads are introduced only partly consists of time spent actually fixating the distractors.

In a third investigation, Boersema and Zwaga (1993) studied the effect on search performance of the number of distractors in an artificial environment. Images consisted of a target object and zero, one, or three distractors superimposed on a continuous background of gray and pastel triangles. The target and distractors consisted of rectangular areas with one or more strings of simple symbols inserted in them. The target area was always blue with white symbols and always contained a small white arrow pointing left, right, up, or down. Participants were required to examine each image and press a button as soon as they located the target; subsequently, they verbally reported the direction of the arrow in the target. As in the previous study with realistic scenes, both search time and the number of eye fixations during search increased systematically with the number of distractors in two of the three scenes used.

Holahan, Culler, and Wilcox (1978) conducted a similar type of investigation in which they examined the effects of number of distractors in a simulated traffic environment. The target was an octagonal replica of a standard red stop sign with white lettering. The distractors were square replicas of commercial signs with white lettering on either a red, orange, blue, green, or black background. A different four-letter word was printed on each distractor sign. For each 35 cm x 25 cm scene, the number of distractors was either 2, 4, 6, or 10; they were located either proximate to the target (no further than 11.4 cm from the target) or distant from the target (no closer than 11.4 cm to the target). The target was either present (requiring a "stop" response from the observer) or absent (requiring a "go" response from the observer). The results indicated that observers' mean reaction time increased systematically as the number of distractors in the scene increased. Further, reaction time was significantly elevated when distractors were proximate to the target, indicating that the location of distractors relative to the target is critical to a driver's ability to discriminate a traffic sign effectively.

Finally, Pashler (1987) studied the effects of the number of target-confusable distractors on visual search performance with alphabetic characters. Target-distractor similarity was manipulated between trials so that observers could not anticipate the discriminability level on a given trial. Observers searched for a target letter among a circular display of six items and indicated whether it was present or not on each trial. The primary variables of interest were target presence/absence and the number of target-confusable distractors (0, 1, 3, or 5). The target was the capital letter *C*; similar distractors were capital *G*s and dissimilar distractors were capital *X*s and *L*s. The results indicated that as the number of target-confusable distractors increased, both the reaction time for correct responses and the error rate (misses and false alarms) increased. In addition, reaction time increased more sharply on target-absent trials. The authors explained these results by means of a two-stage model of visual search. Initial processing takes the form of a parallel analysis of the display during which each display position is analyzed for its similarity to the target. If target-distractor similarity is low or if the target and background are well-learned, the observer might respond on the basis of the first stage. Otherwise, processing proceeds to the second stage, which involves a sequential examination of each item in the display exceeding a certain value of "target-likeness." The serial examination continues until a target is located, or until each item has been examined and the target is determined to be absent. Thus, according to the model, as the number of target-like objects increases, reaction time increases because this second stage of processing is required for more items. Further, reaction time increases more on target-absent trials because every item must be examined sequentially before a decision can be made.

The Theory of Signal Detection

Sensitivity and Bias.

Reaction time and the percentage of correct detections are the most common dependent variables in many studies of target detection performance. A somewhat more sophisticated method for assessing performance effectiveness in many types of detection tasks, including target acquisition, comes from a model of perceptual processing known as the theory of signal detection (TSD) (Gescheider, 1985; Green & Swets, 1966; Macmillan & Creelman, 1991; Wilson, 1992). A TSD application entails the derivation of two independent measures of performance: perceptual sensitivity (d') and response bias. The d' index of sensitivity is a perceptual measure that provides a bias-free estimate of the operator's ability to discriminate targets from nontargets. The index of response bias, c, provides an independent assessment of the operator's general willingness to make a detection ("target") response, which can vary on a continuum from conservative to lenient. Both measures are derived from operators' hits (correct detections) and false alarms (errors of commission) during the course of a task. A detection theory analysis is preferable to separate examinations of hits and false alarms since it permits performance to be characterized independently in terms of sensing abilities and decision making processes with measures that simultaneously take both the hits and false alarms into account, as reflected in the computing formulae for sensitivity and bias:

$$d' = z_{FA} - z_{H} \quad [3]$$

$$c = .5\,(z_{FA} + z_{H}) \quad [4]$$

In each formula, z represents the standard normal deviate associated with proportions of hits (H) and false alarms (FA), both of which enter directly into the derivation of each TSD index.

The derivation of each index is portrayed graphically in Figure 1. According to TSD, the detection of a target is said to occur against a background of noise that is always present. The levels of sensory activation produced by the noise (N, nontargets) and the signal-plus-noise (SN, targets) are assumed to distribute normally with unit variance. The operator's ability to differentiate between the signal and noise, d', is represented by the magnitude of the distance between the two distributions. As the operator's ability to differentiate the target from nontargets increases, the distance between the noise and signal-plus-noise distributions increases, and d' will increase. In general, d' scores range from 0 (no ability to discriminate targets from nontargets) to about 4 (near perfect performance). The operator's willingness to make a detection response, c, is the distance of the criterion from the intersection of the two distributions in standard units. The criterion represents the operator's cutoff for responding "target" (activation levels that exceed the criterion) versus "nontarget." Hence, when the criterion is located at the intersection, bias will be neutral ($c = 0$) since "target" and "nontarget" responses will be equally probable. Bias will be conservative (positive c scores) if the criterion is located to the right of the intersection and lenient (negative c scores) if it is to the left.

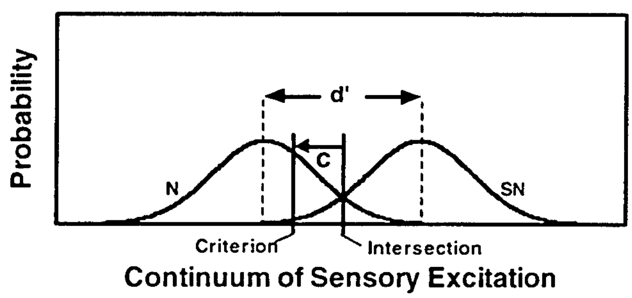


Figure 1: The TSD indices of sensitivity (d') and response bias (c).

In many detection tasks in which TSD is applied, including target acquisition, observers may be required not only to detect the presence of a target but also to designate its location. Thus, once they have determined that a target is present, observers must decide which of several alternative "target-like" objects present in the scene has the greatest probability of being the target. The probability of correctly designating the target's location when it is present is derived from the joint probability of making both a correct detection of the target and a correct identification of its location. Under these circumstances, it is still possible to apply TSD and obtain estimates of operator sensitivity and bias, with some modification. The d' index of operator sensitivity can be interpreted as the operator's ability to differentiate the actual target from other alternative "target-like" objects that may be present. It is estimated, from either a computational formula or tables of d', on the basis of the number of alternatives available for designation and the operator's ensuing proportion of correct localizations (Hacker & Ratcliff, 1979; Macmillan & Creelman, 1991). The index of bias in a target localization task provides a measure of the operator's degree of caution or conservatism in making the designation response. Its calculation is the same as that for target detection, with the proportion of correct localizations substituted for hits (Macmillan & Creelman, 1991).

Receiver Operating Characteristic Curves.

In addition to the calculation of d' and c, the performance results of a target acquisition task are commonly portrayed through the receiver operating characteristic (ROC) curve (Gescheider, 1985; Green & Swets, 1966; Macmillan & Creelman, 1991). An ROC curve for target detection represents the tradeoffs in hits and false alarms for a given level of sensitivity as the response bias shifts from conservative to lenient. Examples of ROC curves for target detection are depicted in Figure 2. The diagonal line in the figure represents a case in which the operator is unable to discriminate targets from nontargets ($d' = 0$). For higher levels of sensitivity, the ROC curve is displaced further from the chance diagonal, as can be seen in the curves in Figure 2 for d' values of .5, 1, 2, and 3. Thus, movement between curves represents changes in operator sensitivity, or detection capability. Movement in a left-to-right direction along a single curve represents a change in criterion from conservative to lenient for that level of sensitivity. In a practical setting, ROC curves are useful for determining tradeoffs between hits and false alarms both within and between given levels of sensitivity.

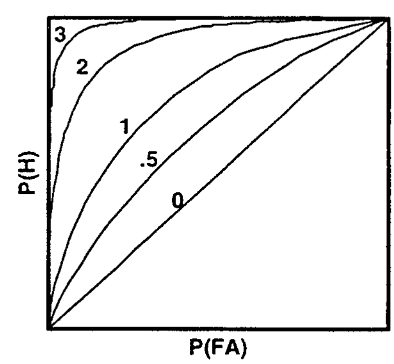


Figure 2: Receiver operating characteristic curves showing d' values from 0 to 3.

In the case of a target acquisition task that involves both detection and localization, more than one type of ROC curve must be generated to provide a comprehensive assessment of observers' performance. First, the conventional ROC curve plotting the proportion of hits as a function of the proportion of false alarms is obtained. In addition, a separate curve for localization performance, referred to as the localization receiver operating characteristic (LROC), is used to portray the proportion of correct localizations as a function of the proportion of false alarms (Macmillan & Creelman, 1991; Starr, Metz, Lusted, & Goodenough, 1975; Swensson & Judy, 1981; Swets et al., 1979).

Examples of ROC curves for a detection-plus-localization task are portrayed in Figure 3. The ROC curve for detection is derived in the usual manner from proportions of hits and false alarms. The LROC curve for localization, on the other hand, is obtained from only those hits that have been correctly localized. Thus, the LROC depicts the functional relation between proportions of correctly localized hits and proportions of false alarms as the criterion for a positive detection decision varies from conservative to lenient. As exemplified by the curves in Figure 3, LROC curves will fall short of the concomitant ROC curve for detection, due to the fact that some of the correct "target" responses on target trials will not be accompanied by correct localizations. Such responses would be classified as hits for the conventional ROC curve, but they would not be classified as correct localizations for the LROC curve. In short, because it is easier to respond "target" or "nontarget" than to specify one of n possible locations, curves such as the LROC fall below their associated ROC curve.

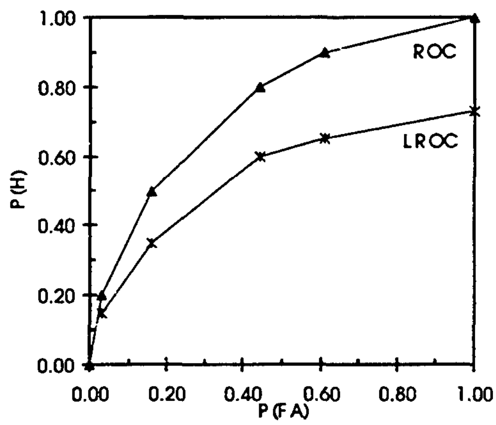


Figure 3: Hypothetical curves for detection (ROC) and localization (LROC).

It should be noted that curves such as the LROC are not "true" ROC curves. Unlike ROC curves for detection, LROC curves may not end at (1, 1). The endpoint of the LROC curve is derived from the proportion of correct localization judgments across all target images and will therefore end at (1, 1) only when localization performance is perfect. Consequently, the LROC should be interpreted with caution. It can best be used as a general guideline to indicate, for example, whether localization performance is satisfactory or whether additional training might be necessary to bridge the gap between detection and localization.

The Present Study

The primary purpose of the present study was to quantify the effect of number of confusers on operators' detection and localization performance, confidence, and reaction time when searching for a TEL target positioned at various orientations in low, medium, and high clutter backgrounds with 2 ft and 4 ft resolution simulated SAR imagery. As such, the current investigation constitutes an incremental exploration of the problem of TEL target detection. In previous studies, we have explored the detection and localization of a TEL target at various image resolutions, and under different conditions of clutter (Davis, See, Shacklett, & Kuperman, 1996; See, Davis, & Kuperman, 1997; See & Kuperman, 1995). In this study, we examined the added effects of the presence of TEL confusers on TEL target detection and localization.

As described earlier, previous studies have demonstrated that the presence of confusers can have a detrimental impact on search performance, producing deteriorations in reaction time and detection probability as the number of confusers increases. To date, however, no studies have concentrated upon TEL target detection in the presence of confusers. Such studies have also not applied TSD to assess performance effectiveness in terms of operator sensitivity and bias when confusers are present. Further, systematic investigation of the effects of orientation has not yet been undertaken with ground vehicles, let alone a TEL target. The goal of the present study was to fill these voids. We expected that performance effectiveness would decline 1) as the number of confusers in the scene increased, 2) as the orientation deviated from a 90° broadside view of the TEL, 3) as the background clutter increased, and 4) as the resolution deteriorated from 2 ft to 4 ft.

METHOD

Participants

The participants were nine airmen and one civilian from various organizations at Wright-Patterson Air Force Base, OH, ranging in age from 31 to 59 years ($M = 42$, $SD = 9$). They included Weapons System Operators (WSO), Instructor WSOs (IWSO), Instructor Radar Navigators (IRN), Pilots, and Instructor Pilots. They had flown in A-10s, B-52s, C-141s, F-4s, F-15s, F-16s, and F-111s. Only two of the observers worked with SAR imagery as part of their current job assignment. Of the remainder, four had previous flight experience with SAR imagery. The remaining individuals had participated in other target acquisition studies performed in this lab with either FLIR or SAR imagery. All of the operators had normal or corrected-to-normal 20/20 vision.

Design

The design was a 2 (resolution) x 2 (target presence) x 2 (scene type) x 3 (clutter) x 4 (number of confusers) x 5 (target orientation) repeated measures design. The two levels of SAR image resolution were 2 ft and 4 ft. Target presence referred to the fact that the target was not present in all of the images; some images contained no vehicles at all ("empty" scenes) and some contained only the confuser. The three levels of clutter were defined according to the number of trees present in the scene: low (15 trees), medium (45 trees), and high (135 trees). Within each level of clutter, two different tree placement configurations were used to provide the two levels of scene type, designated simply as A and B. The number of confusers present in a scene was either 0, 1, 2, or 3. The TEL target was positioned in orientations of 0° (head-on), 45°, 90° (broadside), 135°, and 180° (tail-on).

Apparatus

Vehicles.

The two vehicle types included in the study were the TEL target and an M-548 confuser. The TEL is a four axle eight-wheeled vehicle carrying a Scud missile that can be launched at ground targets. The TEL is 13.36 m long x 3.02 m wide x 3.5 m high and weighs 37,400 kg when loaded with a missile ("SS-1 'Scud,'" 1996). The missile itself is 11.16 m long and is carried horizontally on the TEL until launch, at which time it is raised to the vertical position at the back of the TEL. In the current study, the missile was always carried in its horizontal, stowed position on the TEL.

The M-548 confuser is a five-wheeled tracked cargo carrier used in the U. S. Army to fulfill a number of functions, including use as a resupply vehicle for self-propelled artillery units equipped with M109 and M110 weapons. The engine and crew compartment are at the front of the vehicle. The cargo compartment in the rear of the vehicle has an opening in the back with two doors. The cargo area can be enclosed using a standard vinyl-coated nylon cover supported by bows. A ring mount on top of the cab may be fitted with a 7.62 mm or 12.7 mm machine gun for air and local defense (as it was in the present investigation). A winch is mounted at the front of the vehicle. The M-548 is 5.9 m long x 2.7 m wide x 2.7 m high ("United Defense," 1996-97, p. 504). The vehicle has been employed by the ATR development community as a confuser in the testing of ATR algorithms.

Stimuli.

The stimuli consisted of simulated SAR imagery created with X-Patch ES software and computer-aided design (CAD) models of the TEL and M-548. The CAD models of the vehicles were obtained from Veridian, Inc., which has been developing a SAR database under contract to the Target Recognition Branch, Sensor and ATR Technology Division, Sensor Directorate, of the Air Force Research Laboratory (AFRL/SNAT), Model-Based Vision Laboratory (MBVLAB). The database, which can be accessed through the laboratory's home page at http://www.mbvlab.wpafb.af.mil/internal/ (though some sections are password-protected), is envisioned as a long-term repository for various forms of sensor data and associated information such as maps, photographs, algorithms, and performance results. One of the projects currently included in the database, Moving and Stationary Target Recognition (MSTAR), has involved the collection of SAR imagery of a variety of vehicles, including the TEL and the M-548 cargo truck. As a result of this image collection effort, we were able to obtain CAD models of the TEL and its designated confuser vehicle, the M-548.

The CAD models of the vehicles were used in conjunction with the X-Patch ES SAR simulation software to create the SAR imagery needed to fulfill the experimental design objectives. The X-Patch ES software enables one to develop any of a number of different backgrounds into which various types of targets can then be embedded. In addition, the programmer can control such factors as grazing angle, image resolution, and target location, making it possible to generate an almost endless variety of simulated SAR images. The end result is a set of images that may be much more realistic in appearance than what can be achieved with other simulation packages. For the current study, we began by generating the low, medium, and high clutter backgrounds at two different image resolutions (2 ft and 4 ft) and a constant grazing angle of 15° (grazing angle is the angle formed between the ground and the line of sight from the sensor to the target). The backgrounds were developed by altering the tree density in the scene; tree diameter and height remained constant. The number of trees in the low, medium, and high clutter backgrounds were 15, 45, and 135, respectively. Within each Resolution x Clutter condition, two different scenes (referred to as A and B) were created by varying the placement of the trees in the image. This was done to introduce some variety in the image set and avoid inordinate repetition of the same scene during the experimental session. The 2 (resolution) x 2 (scene type) x 3 (clutter) combination provided the base set of 12 empty scenes (containing no targets or confusers) used in the study.

Images with vehicles were created by embedding the CAD models of the TEL and M-548 into the X-Patch ES input data files scenes. Each simulated SAR output image contained either no vehicles, one confuser, one TEL, or one TEL plus one, two, or three confusers. Hence, the maximum number of vehicles per image was four. For this reason, vehicle placement was determined by dividing the image into quadrants and placing no more than one vehicle randomly within each quadrant. The vehicles were positioned in orientations of either 0° (head-on), 45°, 90° (broadside), 135°, or 180° (tail-on). In any given image, the orientation of the TEL target represented the independent variable of concern. The orientations of the confusers, when present, were allowed to vary randomly, within the constraints imposed by the five pre-selected levels of orientation.

Quadrant assignment for each vehicle was determined by first dividing the images into five sets according to the number and type of vehicles present: 1) target only, 2) confuser only, 3) target plus one confuser, 4) target plus two confusers, and 5) target plus three confusers. Within each set, 30 images needed to be generated to produce the required 2 (resolution) x 3 (clutter) x 5 (target orientations) image set. This procedure resulted in the Scene A images. Once vehicle placement for the 30 images within each set had been determined for Scene A, they were duplicated against the Scene B background. For the target-only and confuser-only images, the basic strategy was to represent each combination of vehicle orientation and quadrant location at least once in the set of 30 images. Within the quadrant, the vehicle was placed randomly in an open area where it would not be obscured by trees or tree shadows. For the target-plus-confuser images, the most critical objective was to represent each combination of target orientation and quadrant location at least once since the orientation of the target was the experimental manipulation of concern. Once that had been accomplished, the intent was to represent as many combinations of target orientation, target location, confuser orientation, and confuser location as possible in each set of 30 images. The vehicles were always placed in separate quadrants, but they could be located anywhere from 66 pixels to 402 pixels of each other ($M = 202$, $SD = 62$). The resulting images were 512 pixels by 512 pixels in size and were displayed using the green gun of the monitor. Including both the 6 empty background scenes and the 150 images containing vehicles, the final image set consisted of 156 Scene A images and 156 Scene B images, for a total of 312 unique SAR images.

A similar procedure was used to generate 12 unique practice images, designed to familiarize the participants not only with the appearance of the radar returns for the TEL and M-548 but also with the procedures to be followed for each image presentation. Of the practice images, six contained a single TEL target and six contained a single M-548 confuser. The six images consisted of low, medium, and high clutter backgrounds at both the 2 ft and 4 ft resolutions; half of these were Scene A images and half were Scene B. Further, each vehicle was positioned at least once in each of the five possible orientations and in each of the four possible quadrants of the display. Thus, by the time the experimental session began, the participants had seen both of the vehicles in all of the potential image resolutions, clutter backgrounds, orientations, and quadrants in which they would subsequently appear.

During the experimental session, the imagery was presented in 5 blocks of 312 images, for a total of 1560 images. The 312 images consisted of 156 Scene A images (78 at the 2 ft resolution and 78 at 4 ft) and 156 Scene B images (78 at 2 ft and 78 at 4 ft). Within each block, the images were presented in sub-blocks based on resolution; within sub-blocks, the presentation order was random. Half of the participants began each block with the 2 ft resolution, and the other half began each block with the 4 ft resolution. Across blocks, the images in each set were identical (though they were presented in a different order each time). Replicates were presented to permit the derivation of reliable estimates of hit and false alarm percentages for the subsequent calculation of sensitivity and response bias as well as the generation of ROC curves. The replicates were presented in five blocks for three reasons. First, presenting replicates across blocks rather than within a block would decrease the likelihood that participants would base their decisions on recall of their responses during earlier trials (i.e., it would be harder to recall across blocks as opposed to within blocks). Second, this presentation format would allow an assessment of potential practice effects on performance. Third, at the completion of a block of trials, each participant could individually decide whether to complete additional blocks or return at a later time. It was expected that scene type would not have a significant effect on performance and would therefore permit the data to be collapsed across this variable, thereby producing ten replicates of each image instead of five.

Equipment.

Data collection occurred in the Crew Aiding and Information Warfare Analysis Laboratory (CIWAL) located in the Air Force Research Laboratory at Wright-Patterson Air Force Base, OH. A Silicon Graphics O2 computer was used for stimulus presentation and data collection. The computer monitor was placed on a table slightly below eye level, and participants sat approximately 70 cm from it. They used a keypad placed in front of the monitor to indicate their target/nontarget decision and confidence for each image and a computer mouse to designate the location of the TEL target if they believed it to be present. Prior to the experiment, the brightness and contrast controls of the monitor were adjusted to clearly display each step of a 16-step gray scale without oversaturating the monitor. A TOPCON BM-7 luminance colorimeter was used to measure the luminance of the 100% and 50% white fields from the gray scale each week for the duration of the study. The luminance of the 100% white field varied from 40.9 cd/m^2 to 42.1 cd/m^2 (M = 41.6, SD = 0.6), and the luminance of the 50% white field ranged from 11.3 cd/m^2 to 11.7 cd/m^2 (M = 11.5, SD = 0.2). Participants were instructed not to adjust the brightness and contrast controls during data collection. The overhead lights in the room were dimmed during the experimental session so as to minimize glare on the monitor while providing sufficient light for participants to complete their task.

Procedure

When individuals reported to the CIWAL facility to participate in the study, the experimenter first gave them a brief oral description of the experiment and then asked them to read a standard consent form and sign it if they wished to participate. After the individual signed the consent form and responded to a general background questionnaire, the experimenter presented a more detailed briefing of the study, which included a description of the TEL and M-548 vehicles and the various resolutions, orientations, and scene backgrounds in which they would appear. The experimenter provided SAR images of each vehicle in each of its five orientations at both the 2 ft and 4 ft resolutions for the participant to study. These images were also available for review between blocks.

Following the briefing, the experimenter tested the individual's vision using a standard Snellen eye chart and then escorted the participant to the room where the task would be completed. The lights were dimmed and once the individual was seated comfortably in front of the computer, the experimenter described the procedure to be followed during each image presentation in both the practice and experimental sessions. A READY prompt first appeared in the center of a black background on the computer screen. When ready to begin the trial, the participant pressed a labeled READY button on the keypad to bring up a SAR image. Following the appearance of the image, the observer first had to decide whether or not the TEL target was present in the image or not and simultaneously rate his/her confidence in that decision. Once the decision had been reached, the operator pressed one of six labeled buttons on the keypad: (1) target definitely not present, (2) target probably not present, (3) target possibly not present, (4) target possibly present, (5) target probably present, and (6) target definitely present. Thus, a response of 1, 2, or 3 signified that the operator thought a target was not present in the image, whereas a response of 4, 5, or 6 corresponded to a decision that the target was present in the image. Responses of "definitely," "probably," and "possibly" represented variations in the operator's confidence in the detection decision, ranging from high to low confidence. If the operator decided that the target was not present, the image disappeared from the screen and was replaced by the READY prompt for the next image. If the operator thought the TEL target was present, the image remained on the screen so that he could designate the location of the target in the scene. A message instructing the observer to designate the location of the TEL with the mouse pointer appeared beside the image. Once the localization response had been made, the image disappeared from the screen and the READY prompt for the next image appeared. This sequence, which is depicted in Figure 4, was repeated until all 312 images in the block had been completed. At this point, the operator notified the experimenter that the block was over and decided whether to continue with additional blocks or return at a later time to complete the study. Six of the participants completed all five blocks in one session; two participants completed the blocks in two separate sessions on the same day; and the remaining two operators finished the experiment in two separate sessions over a two day period.

A practice session with 12 images preceded the first block of experimental trials. The purpose of the practice session was to familiarize the observers with the nature of the task and the appearance of the vehicles in the SAR imagery. The experimenter was present during the practice session to answer any questions and provide performance feedback when needed but left the room when the individual was ready to begin a block of experimental trials. The operators were encouraged to take breaks between images as needed. Further, in between the sub-blocks of 2 ft and 4 ft resolution images, a message appeared on the screen instructing the operator to take a break. Individuals who completed multiple blocks at once were also permitted to take a break between blocks while the experimenter made the necessary preparations on the computer. The duration of each block ranged from 13 to 53 minutes (M = 25, SD = 9).

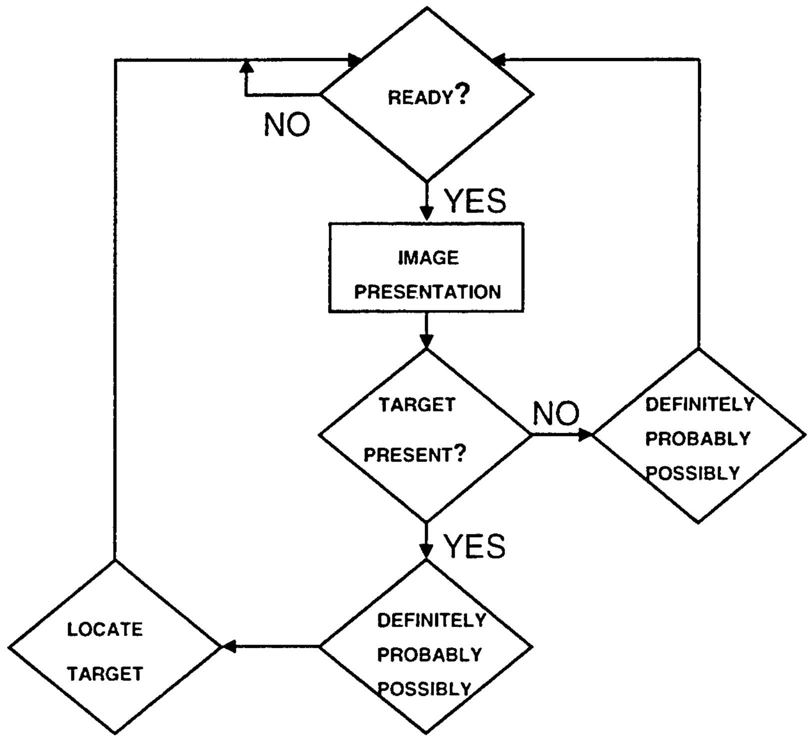


Figure 4: The sequence of events during each trial.

RESULTS

The dependent variables that were analyzed in the present study included proportions of hits and false alarms; the signal detection theory measures of perceptual sensitivity and response bias; reaction times (RTs) for hits, false alarms, misses, and correct rejections; and operator confidence. In most cases, 2 (resolution) x 3 (clutter) x 4 (number of confusers) x 5 (vehicle orientation) repeated-measures analyses of variance (ANOVAs) were used to test the statistical significance of the means. The alpha level for all ANOVAs was set at .05. Probabilities for any effect containing three or more levels (e.g., clutter, number of confusers, and orientation) were obtained via the Huynh-Feldt epsilon adjustment to degrees of freedom (Huynh & Feldt, 1970, 1976). Where needed, post hoc analyses in the form of correlated *t*-tests were conducted. For the purposes of this study, any comparison with a probability of .01 or less was considered statistically significant.

Hits and False Alarms

The derivation of hits and false alarms in the current study represents a departure from the procedures we used in a similar study where participants were also asked to make both detection and localization responses (Davis, See, Shacklett, & Kuperman, 1996). In the 1996 study, participants viewed SAR patch maps containing either empty scenes with no vehicles present or scenes containing the TEL target to be detected plus two additional support vehicles. As in the present study, their task was to determine whether the TEL was present in the image (detection) and to designate its location if they believed it to be present (localization). In the 1996 study, a hit was defined as a "detection" response to a target image, and a false alarm was defined as a "detection" response to an empty scene. The correct detections were further identified as either correct or incorrect localizations of the TEL vehicle, and the signal detection theory measures of sensitivity and bias were computed for both detection and localization. With this type of procedure, a "correct detection" response to a target image will be classified as a hit, *regardless* of whether the localization response itself is correct or not. Thus, in some instances, the localization response may indicate that the "hit" resulted not from correct identification of the target but from inspection of some other object that the operator believed to be the target, an object that may even be far removed from the actual location of the TEL. One may then legitimately ask whether the detection response should have been classified as correct in the first place. Did the observer truly "detect" the target?

To circumvent these difficulties in the current investigation, we defined a hit as a keypad response of 4 (target possibly present), 5 (target probably present), or 6 (target definitely present) to a target image that was subsequently accompanied by a correct localization of the TEL vehicle. If the localization was incorrect, the response was considered simultaneously to be a miss (since the operator did not locate the TEL target) and a false alarm (since the operator incorrectly chose some other object as the TEL). If the operator initially responded with a 1 (target definitely not present), 2 (target probably not present), or 3 (target possibly not present) to a target image, that response was considered a miss only. Thus, each target image produced both a proportion of hits and a proportion of false alarms. Recall also that the image set contained some images with only a single M-548 confuser present. In accordance with the traditional applications of signal detection theory, these images produced either correct rejections (responses of 1, 2, or 3) or false alarms (responses of 4, 5, or 6). The false alarms for these images were used to establish a baseline for the number of false alarms that might be expected with images containing 2, 3, or 4 confusers (since these were not present in the actual image set). Within each experimental condition, the false alarms associated with the target images were then added onto this baseline to derive the total proportion of false alarms in each condition. Technically, the empty background scenes in the experiment could also produce either correct rejections or false alarms. However, since none of the operators made any false alarms with these images, they were not included in the totals.

In essence, this procedure combines the operator's detection response and localization response to target images to determine whether the decision is a hit or a false alarm. In contrast to our 1996 study, the detection and localization responses will not be subjected to separate analyses. In this case, a hit can be considered a "true" hit since the operator not only detected the target but also correctly selected it from all the other objects and vehicles present in the scene.

Preliminary Analyses.

Prior to conducting the full factorial analyses of hits and false alarms in the present study, several preliminary inspections of the data were completed. First, in an effort to verify that none of the images in the image set was an "outlier," the hits and false alarms associated with each unique image were examined. Only 3% of the images were associated with hits below 90% (the minimum was 68%), and only 1% produced false alarms of 10% or greater (the maximum was 30%). Because visual inspection of these images indicated no anomalies, none of the images was dropped from the image set.

Second, in order to determine whether the presentation order of image resolution affected operator performance, *t*-tests of both the hits and false alarms were conducted. All operators saw both levels of image resolution, but half of them always evaluated the 2 ft resolution first (the "24" group) and the other half always saw the 4 ft resolution first (the "42" group). Mean proportions of hits were .98 (SD = .02) for the "24" group and .95 (SD = .05) for the "42" group, a difference that was not statistically significant, t (8) = .9, p > .05. Mean proportions of false alarms for the two groups were .01 (SD = .003) and .02 (SD = .013), respectively. As with the hits, this difference was not significant, t (8) = 2.2, p > .05.

Third, a test of the effects of scene type was completed. Recall that two versions of each image were generated, differing only in the placement of the trees and vehicles within the scene. Changes in scene type were used to produce variety in the image set so the images would not simply appear to be repetitions of each other. Thus, scene type was not expected to impact operator performance. Neither the difference in hits between the "A" and "B" scenes (M = .00017) nor the difference in false alarms (M = .00047) was statistically significant, p > .05.

Finally, the effects of block were examined to study changes in performance with repeated practice. A one-way ANOVA of the proportion of hits was statistically significant, F (4,36) = 5.0, p < .04. The hits tended to increase over blocks from a mean of .90 (SD = .12) in the first block to a mean of .99 (SD = .01) in the fifth block. However, post hoc testing indicated that none of the differences in means was statistically significant, $p > .01$. With respect to the analysis of false alarms, mean false alarms were .03 (SD = .03) in the first block and only .004 (SD = .003) in the fifth block. The drop in false alarms over block was not significant, $F(4,36) = 3.5$, $p > .05$.

Hits.

Following the preliminary inspections of the data, analysis of the four primary independent variables was begun. Mean proportions of hits in each condition of resolution, background clutter, number of confusers, and vehicle orientation are portrayed in Table 1. As can be seen in the table, the overall proportion of hits in the study was quite high and did not deviate greatly from this level, indicating that the operators seldom mistook the confuser for the TEL. (Note: inspection of the data revealed that on the TEL trials where operators indicated that a target was definitely, probably, or possibly present, they correctly located the TEL 99.3% of the time. They erroneously chose the confuser only 0.5% of the time and some other object in the background a mere 0.2% of the time.) In fact, the proportion of hits was identical at the 2 ft and 4 ft resolutions and was nearly constant as the number of confusers increased from 0 to 3. Within each resolution, there did appear to be some variation as a result of vehicle orientation. Orientations of 0° and 180° tended to be associated with the lowest proportions of hits, whereas the hits for orientations of 45°, 90°, and 135° were more or less similar to one another. A summary of the ANOVA of the means in Table 1 can be found in Table 2. In accordance with observations of the means in Table 1, none of the main effects of resolution, clutter, number of confusers, and orientation was statistically significant. However, vehicle orientation did enter into several interactions.

Table 1. Mean Proportions of Hits (Standard Deviations in Parentheses) in Each Condition.

		NUMBER OF CONFUSERS												
		0			1			2			3			
		BACKGROUND CLUTTER												
RES	ORIENT	L	M	H	L	M	H	L	M	H	L	M	H	MEAN
	0°	.94	.92	.92	.94	.95	.89	.95	.92	.92	.91	.94	.90	.92
		(.03)	(.08)	(.05)	(.05)	(.00)	(.09)	(.02)	(.05)	(.06)	(.06)	(.02)	(.06)	(.06)
	45°	.95	.95	.95	.94	.93	.95	.93	.95	.94	.95	.94	.94	.94
		(.00)	(.00)	(.02)	(.05)	(.08)	(.02)	(.05)	(.02)	(.02)	(.00)	(.05)	(.02)	(.04)
2 ft	90°	.91	.92	.93	.95	.93	.92	.93	.94	.94	.94	.95	.93	.93
		(.09)	(.06)	(.05)	(.02)	(.05)	(.05)	(.05)	(.05)	(.05)	(.05)	(.02)	(.05)	(.05)
	135°	.95	.95	.95	.95	.94	.95	.95	.95	.95	.95	.94	.93	.95
		(.00)	(.02)	(.02)	(.02)	(.05)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.05)	(.02)
	180°	.92	.92	.90	.91	.87	.92	.92	.92	.72	.93	.94	.94	.90
		(.05)	(.05)	(.07)	(.09)	(.09)	(.06)	(.08)	(.05)	(.14)	(.05)	(.02)	(.05)	(.09)
	Mean	.94	.93	.93	.94	.92	.93	.94	.94	.90	.94	.94	.93	.93
		(.05)	(.05)	(.05)	(.05)	(.07)	(.06)	(.05)	(.04)	(.11)	(.04)	(.03)	(.05)	(.06)
	0°	.91	.85	.90	.92	.91	.87	.92	.89	.86	.91	.90	.90	.90
		(.11)	(.15)	(.14)	(.08)	(.11)	(.17)	(.08)	(.13)	(.10)	(.11)	(.14)	(.09)	(.12)
	45°	.95	.95	.95	.93	.95	.93	.95	.94	.92	.93	.93	.95	.94
		(.00)	(.02)	(.02)	(.05)	(.02)	(.08)	(.02)	(.05)	(.11)	(.08)	(.05)	(.02)	(.05)
4 ft	90°	.94	.95	.95	.94	.94	.94	.93	.92	.94	.94	.95	.93	.94
		(.05)	(.02)	(.02)	(.05)	(.05)	(.05)	(.05)	(.08)	(.05)	(.02)	(.02)	(.05)	(.04)
	135°	.95	.95	.95	.95	.95	.95	.94	.94	.95	.95	.94	.95	.95
		(.00)	(.02)	(.00)	(.02)	(.02)	(.02)	(.05)	(.05)	(.02)	(.00)	(.05)	(.02)	(.03)
	180°	.92	.92	.89	.91	.89	.92	.90	.90	.92	.91	.88	.92	.91
		(.08)	(.08)	(.08)	(.09)	(.11)	(.08)	(.09)	(.14)	(.08)	(.11)	(.16)	(.06)	(.10)
	Mean	.93	.92	.93	.93	.93	.92	.93	.92	.92	.93	.92	.93	.93
		(.06)	(.08)	(.08)	(.06)	(.08)	(.09)	(.06)	(.10)	(.08)	(.08)	(.10)	(.06)	(.08)
		.94	.93	.93	.93	.93	.92	.93	.93	.91	.93	.93	.93	
		(.06)	(.07)	(.06)	(.06)	(.07)	(.08)	(.06)	(.07)	(.10)	(.06)	(.07)	(.05)	
	MEAN		.93			.93			.92			.93		.93
			(.06)			(.07)			(.08)			(.06)		(.07)

Table 2. Summary of a 2 (resolution) x 3 (clutter) x 4 (no. confusers) x 5 (orientation) ANOVA of Hits.

Source	*df*	*MS*	*F*	*p*
Resolution	1, 9	.006	< 1	NS
Clutter	2, 18	.013	3.8	NS
No. Confusers	3, 27	.006	2.3	NS
Orientation	4, 36	.087	3.1	NS
Resolution x Clutter	2, 18	.006	6.7	.008
Resolution x No. Confusers	3, 27	.001	< 1	NS
Resolution x Orientation	4, 36	.013	< 1	NS
Clutter x No. Confusers	6, 54	.003	2.4	.04
Clutter x Orientation	8, 72	.004	3.2	.006
No. Confusers x Orientation	12, 108	.004	1.7	NS
Resolution x Clutter x No. Confusers	6, 54	.004	1.5	NS
Resolution x Clutter x Orientation	8, 72	.004	2.2	NS
Resolution x No. Confusers x Orientation	12, 108	.006	4.0	.002
Clutter x No. Confusers x Orientation	24, 216	.006	4.9	.0001
Resolution x Clutter x No. Confusers x Orientation	24, 216	.005	2.8	.008

The Resolution x Clutter interaction is depicted graphically in Figure 5. As can be seen in the figure, the proportion of hits was slightly higher at the 2 ft resolution as compared to 4 ft in the low and medium clutter backgrounds; in the high clutter background, the trend inexplicably reversed itself. This reversal may have been due to the fact that clutter was defined as the number of trees per image rather than per area. Thus, since the image size remained constant, the same number of trees occupied what appeared to be a larger area at the 4 ft resolution than was true for the 2 ft resolution. Hence, the high clutter background was extremely cluttered at the 2 ft resolution but much more open at the 4 ft resolution, making it relatively easier to detect vehicles in the open spaces when the resolution was poorer. While the same number of trees (clutter objects) appeared in the high clutter background at both resolutions, the low resolution imagery actually appeared visually to be less cluttered. Post hoc correlated *t*-tests were conducted to determine whether the hits differed between the 2 ft and 4 ft resolutions within each level of background clutter. None of the differences was statistically significant ($p > .01$).

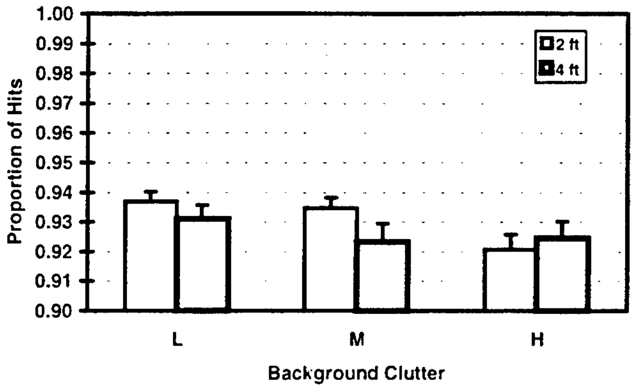


Figure 5: Mean proportion of hits at the 2 ft and 4 ft resolutions in the low (L), medium (M), and high (H) clutter backgrounds.

The interaction between clutter and number of confusers is portrayed in Figure 6. The figure reveals that the proportion of hits was relatively constant as the number of confusers increased in the low and medium clutter backgrounds. However, in the high clutter background, the proportion of hits dropped noticeably when two confusers were present before returning to the level common to the other conditions. A comparison of the low, medium, and high clutter backgrounds at each number of confusers indicated that the only significant difference occurred between the low and high backgrounds when two confusers were present ($p < .003$). In that condition, a lower proportion of hits occurred in the high clutter background as compared to low clutter.

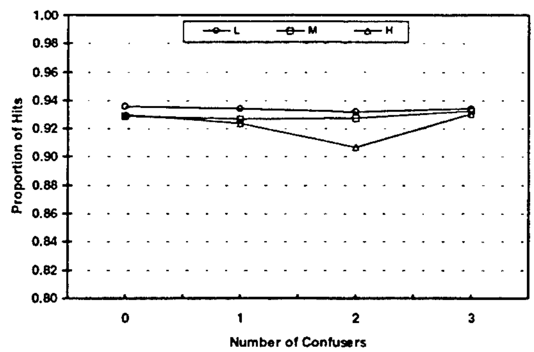


Figure 6: Mean proportion of hits as a function of number of confusers for the low (L), medium (M), and high (H) clutter backgrounds.

The nature of the Clutter x Orientation interaction can be readily seen in the distinctive pattern of the plot in Figure 7. Namely, differences among the three levels of clutter were apparent only when the orientation was either 0° or 180°; otherwise, the proportions of hits in the low, medium, and high clutter backgrounds were nearly identical. Post hoc tests indicated that the only significant difference was between the low and high clutter backgrounds at an orientation of 0° ($p < .004$).

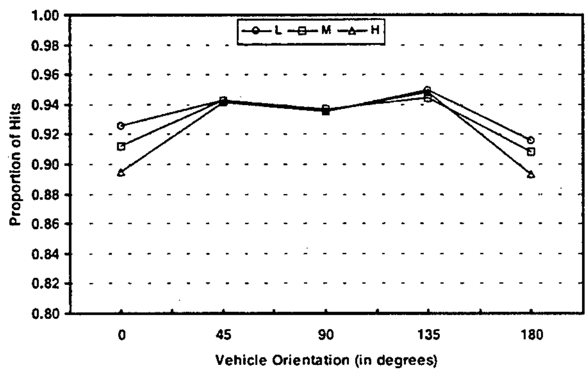


Figure 7: Mean proportion of hits as a function of vehicle orientation for the low (L), medium (M), and high (H) clutter backgrounds.

The Resolution x Number of Confusers x Orientation interaction is portrayed in the two plots of Figure 8. The first plot shows the proportion of hits as a function of vehicle orientation for each level of confusers at the 2 ft resolution. The second plot shows the same relationship at the 4 ft resolution. Inspection of the two plots reveals that the interaction appeared to stem primarily from the 2 ft resolution. At the 4 ft resolution, there was very little variation among the levels of confusers as the orientation changed from 0° to 180°. The same can be said of the 2 ft resolution for all orientations except 180°, where the proportion of hits was highest when three confusers were present and lowest when two confusers appeared in the scene. To determine where the significant differences lay, post hoc correlated *t*-tests were conducted. Within each resolution, the proportions of hits associated with 0, 1, 2, and 3 confusers were compared within each level of vehicle orientation. The only significant difference occurred at an orientation of 180° in the 2 ft resolution—the proportion of hits was significantly greater when three confusers were present as opposed to when only two were present ($p < .0004$).

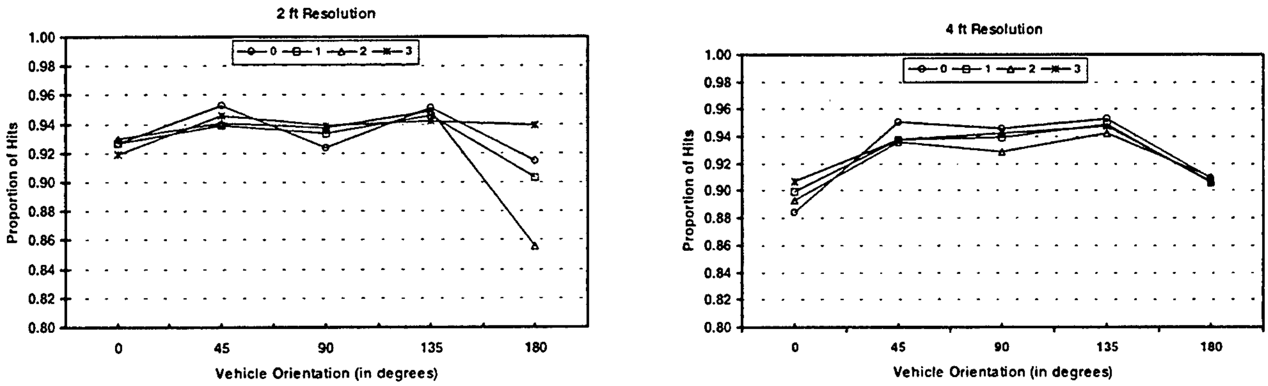


Figure 8: Mean proportion of hits as a function of vehicle orientation for each number of confusers at the 2 ft (left) and 4 ft (right) resolutions.

The three plots in Figure 9 depict the three-way interaction between clutter, number of confusers, and orientation. The first plot shows the proportion of hits as a function of vehicle orientation for each level of confusers in the low clutter background. The second plot shows the same relationship in the medium clutter background, and the third portrays high clutter. The three plots reveal that the variation in detection performance among the four levels of confusers tended to increase as the background clutter increased, particularly at the lowest and highest vehicle orientations. Post hoc testing indicated that the proportions of hits associated with each number of confusers within each vehicle orientation did not differ significantly from one another in the low and medium clutter backgrounds ($p > .01$). In the high clutter background, there were significant differences between one and two confusers ($p < .005$) and between two and three confusers ($p < .003$) when the orientation was 180°. The proportions of hits were significantly greater when one confuser or three confusers were present as opposed to when two confusers appeared in the scene.

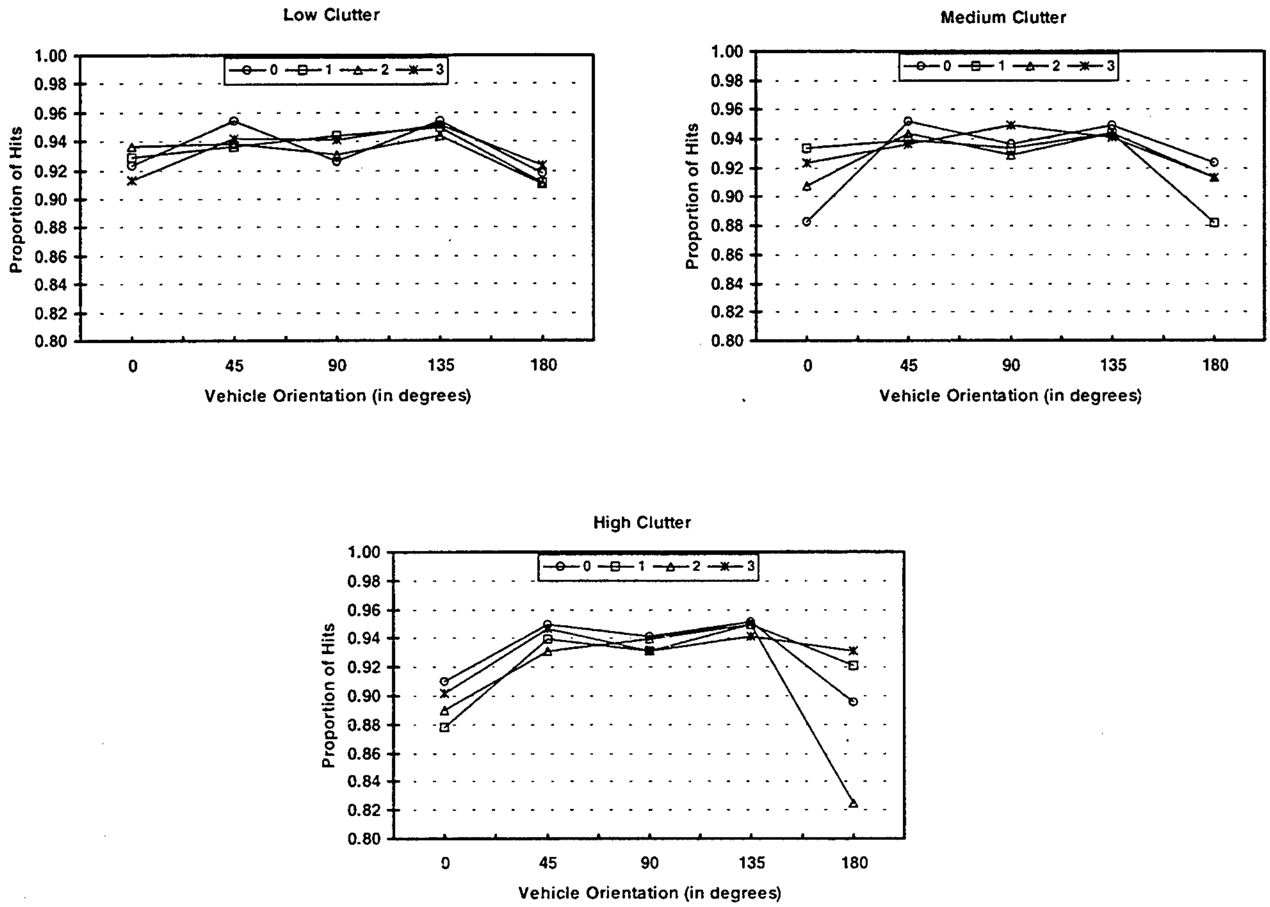


Figure 9: Mean proportion of hits as a function of vehicle orientation for each number of confusers in the low (right), medium (left), and high (bottom center) clutter backgrounds.

Finally, in the analysis of hits, the four-way interaction between resolution, clutter, number of confusers, and orientation was also statistically significant. The nature of this interaction is portrayed in the six plots of Figure 10. The first three plots depict the proportion of hits as a function of vehicle orientation for each number of confusers in the low, medium, and high clutter backgrounds at the 2 ft resolution. The last three plots show the same relationships for the low, medium, and high clutter backgrounds at the 4 ft resolution. At the 2 ft resolution, minor fluctuations in hits among the four levels of confusers occurred at each vehicle orientation when the clutter was low and medium. In the high clutter background, performance variation was primarily limited to the highest vehicle orientation. At the 4 ft resolution, performance variation was more or less confined to the lowest and highest orientations in the medium and high clutter backgrounds. Post hoc correlated *t*-tests revealed that, at the 2 ft resolution, the only significant difference occurred in the high clutter background at an orientation of 180°—the proportion of hits was greater when three confusers were present as opposed to two ($p < .0012$). At the 4 ft resolution, none of the differences was statistically significant ($p > .01$).

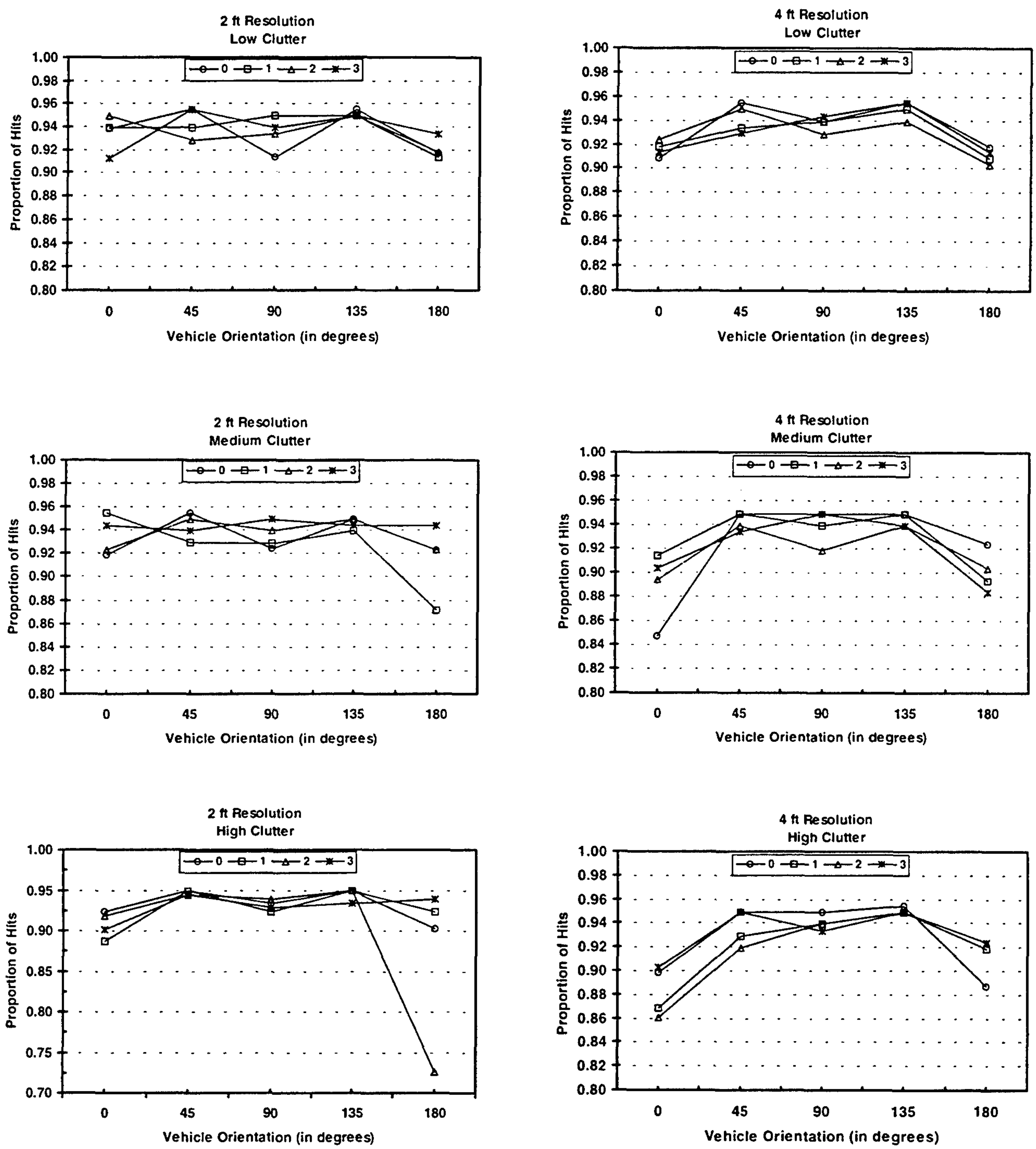


Figure 10: Mean proportion of hits as a function of vehicle orientation for each number of confusers at each image resolution and clutter level.

False Alarms.

Mean proportions of false alarms in each condition of resolution, background clutter, number of confusers, and vehicle orientation are portrayed in Table 3. The figures in the table reveal that the overall percentage of false alarms in the study was only 4%. The false alarms were slightly lower at the 2 ft resolution as compared to 4 ft. In addition, they were slightly lower when 0 or 1 confusers were present as opposed to when 2 or 3 confusers appeared in an image. Within each level of resolution, the false alarms tended to be higher at orientations of 0° and 180° as well. A summary of the ANOVA of the means in Table 3 appears in Table 4. The only significant main effects were for clutter and orientation. Further, orientation entered into a number of two-way and three-way interactions. With respect to the main effect for clutter, the proportion of false alarms was somewhat higher in the high clutter background ($M = .04$, $SD = .01$) as opposed to low ($M = .03$, $SD = .01$) and medium ($M = .03$, $SD = .01$). However, post-hoc testing revealed that none of the differences was significant, $p > .01$. With regard to the main effect for orientation, the proportions of false alarms were higher at orientations of 0° ($M = .04$, $SD = .02$) and 180° ($M = .05$, $SD = .03$) as compared to 45° ($M = .03$, $SD = .003$), 90° ($M = .03$, $SD = .004$), and 135° ($M = .03$, $SD = .004$). Post hoc testing indicated that none of the differences attained statistical significance at the .01 level.

Table 3. Mean Proportions of False Alarms (Standard Deviations in Parentheses) in Each Condition.

		NUMBER OF CONFUSERS												
		0			1			2			3			
		BACKGROUND CLUTTER												
RES	ORIENT	L	M	H	L	M	H	L	M	H	L	M	H	MEAN
	0°	.04	.04	.03	.04	.04	.03	.04	.04	.03	.05	.04	.03	.04
		(.06)	(.01)	(.01)	(.06)	(.01)	(.01)	(.06)	(.02)	(.01)	(.07)	(.01)	(.01)	(.04)
	45°	.02	.03	.02	.02	.03	.02	.03	.03	.03	.02	.03	.03	.03
		(.00)	(.01)	(.00)	(.00)	(.01)	(.00)	(.01)	(.01)	(.01)	(.00)	(.01)	(.01)	(.01)
2 ft	90°	.04	.03	.03	.03	.03	.03	.03	.02	.03	.03	.03	.03	.03
		(.04)	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.00)	(.01)	(.01)	(.01)	(.01)	(.01)
	135°	.02	.02	.03	.03	.02	.02	.03	.02	.02	.02	.03	.02	.02
		(.00)	(.00)	(.01)	(.01)	(.00)	(.00)	(.01)	(.00)	(.00)	(.00)	(.01)	(.00)	(.005)
	180°	.03	.03	.09	.03	.03	.09	.03	.03	.15	.03	.03	.09	.05
		(.01)	(.01)	(.06)	(.01)	(.01)	(.06)	(.01)	(.02)	(.12)	(.01)	(.01)	(.06)	(.06)
	Mean	.03	.03	.04	.03	.03	.04	.03	.03	.05	.03	.03	.04	.03
		(.03)	(.01)	(.04)	(.02)	(.01)	(.04)	(.03)	(.02)	(.07)	(.03)	(.01)	(.04)	(.03)
	0°	.04	.05	.04	.04	.05	.04	.05	.05	.04	.04	.07	.05	.05
		(.02)	(.04)	(.02)	(.02)	(.04)	(.02)	(.05)	(.04)	(.02)	(.02)	(.09)	(.04)	(.04)
	45°	.02	.03	.02	.02	.03	.03	.02	.03	.03	.03	.03	.02	.03
		(.00)	(.01)	(.00)	(.00)	(.01)	(.02)	(.00)	(.01)	(.01)	(.01)	(.01)	(.00)	(.01)
4 ft	90°	.03	.03	.02	.03	.03	.03	.03	.03	.02	.03	.03	.03	.03
		(.01)	(.01)	(.00)	(.01)	(.01)	(.02)	(.01)	(.01)	(.00)	(.01)	(.01)	(.01)	(.01)
	135°	.03	.03	.03	.03	.03	.03	.04	.03	.03	.03	.03	.03	.03
		(.01)	(.01)	(.01)	(.01)	(.01)	(.01)	(.02)	(.01)	(.01)	(.01)	(.02)	(.01)	(.01)
	180°	.04	.03	.04	.05	.03	.06	.05	.03	.05	.05	.04	.05	.04
		(.04)	(.02)	(.04)	(.06)	(.02)	(.09)	(.04)	(.02)	(.07)	(.07)	(.06)	(.05)	(.05)
	Mean	.03	.03	.03	.04	.03	.04	.04	.03	.03	.04	.04	.04	.04
		(.02)	(.02)	(.02)	(.03)	(.02)	(.04)	(.03)	(.02)	(.03)	(.04)	(.05)	(.03)	(.03)
		.03	.03	.04	.03	.03	.04	.04	.03	.04	.03	.04	.04	
		(.03)	(.02)	(.03)	(.03)	(.02)	(.04)	(.03)	(.02)	(.06)	(.03)	(.04)	(.03)	
	MEAN		.03			.03			.04			.04		.04
			(.03)			(.03)			(.04)			(.03)		(.03)

Table 4. Summary of a 2 (resolution) x 3 (clutter) x 4 (no. confusers) x 5 (orientation) ANOVA of False Alarms.

Source	*df*	*MS*	*F*	*p*
Resolution	1, 9	.0003	< 1	NS
Clutter	2, 18	.0048	4.1	.03
No. Confusers	3, 27	.0009	2.9	NS
Orientation	4, 36	.0257	6.1	.016
Resolution x Clutter	2, 18	.0056	2.4	NS
Resolution x No. Confusers	3, 27	.0006	2.0	NS
Resolution x Orientation	4, 36	.0028	< 1	NS
Clutter x No. Confusers	6, 54	.0004	1.8	NS
Clutter x Orientation	8, 72	.0114	7.2	.001
No. Confusers x Orientation	12, 108	.0006	3.9	.02
Resolution x Clutter x No. Confusers	6, 54	.0007	3.0	NS
Resolution x Clutter x Orientation	8, 72	.0071	3.3	.03
Resolution x No. Confusers x Orientation	12, 108	.0005	4.2	.005
Clutter x No. Confusers x Orientation	24, 216	.0005	3.8	.008
Resolution x Clutter x No. Confusers x Orientation	24, 216	.0004	2.5	NS

The Clutter x Orientation interaction is portrayed graphically in Figure 11. As can be seen in the figure, the proportion of false alarms tended to be higher overall when the vehicle orientation was either 0° or 180° as opposed to 45°, 90°, or 135°. In addition, the low, medium, and high clutter backgrounds exhibited little variation within each orientation, except at the 180° level. Post hoc correlated *t*-tests were conducted to test the statistical significance of the differences among the low, medium, and high clutter backgrounds within each orientation. As expected on the basis of the plot in Figure 11, high clutter differed significantly from low ($p < .007$) and medium ($p < .009$) at the 180° orientation. Specifically, the proportion of false alarms was elevated in the high clutter background as compared to low and medium clutter when the vehicle orientation was 180°. No other differences were statistically significant.

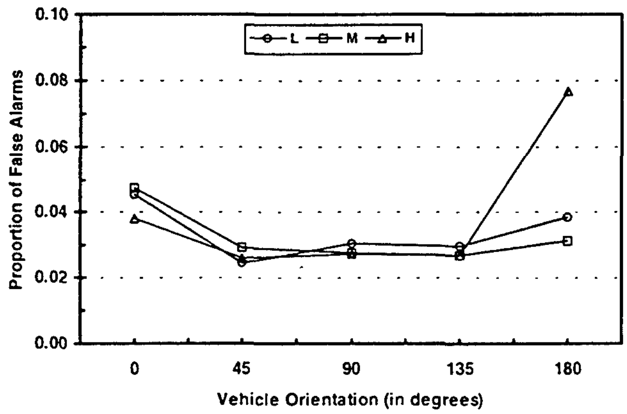


Figure 11: Mean proportion of false alarms as a function of vehicle orientation for the low (L), medium (M), and high (H) clutter backgrounds.

The interaction between number of confusers and orientation is depicted in Figure 12. Inspection of the figure reveals that the proportions of false alarms associated with each level of confusers were nearly identical at all orientations except 180°, where variations among the four levels of confusers were apparent. Namely, the proportion of false alarms was greatest when two confusers were present and lowest when no confusers appeared in the image. In fact, this was the only difference to reach statistical significance during post hoc testing ($p < .002$).

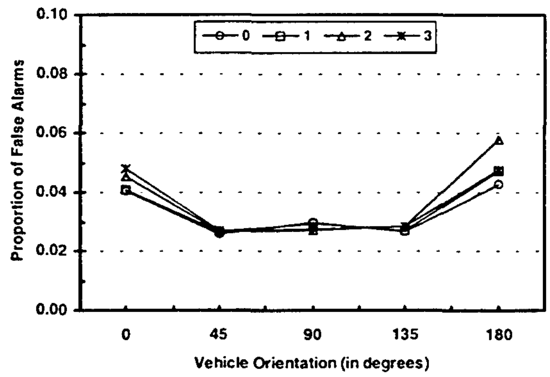


Figure 12: Mean proportion of false alarms as a function of vehicle orientation for each number of confusers.

The Resolution x Clutter x Orientation interaction appears in Figure 13, which plots the proportion of false alarms as a function of vehicle orientation for each level of background clutter and image resolution. As can be seen in the figure, the interaction appears to stem primarily from variations among the three levels of clutter at the 2 ft resolution when the orientation was 180°. In that condition, the proportion of false alarms was noticeably higher in the high clutter background as compared to low and medium clutter. The same relationship was not observed at the 4 ft resolution, where there was little variation among the three levels of clutter at each vehicle orientation. Post hoc correlated *t*-tests revealed that none of the differences among the three levels of clutter within each resolution and orientation was large enough to attain statistical significance at the .01 level.

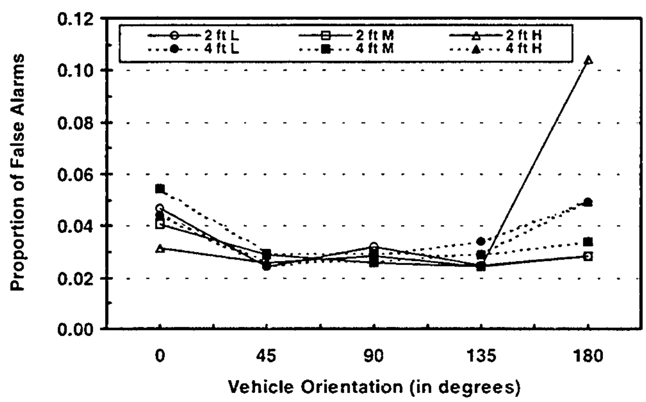


Figure 13: Mean proportion of false alarms as a function of vehicle orientation in the low (L), medium (M), and high (H) clutter backgrounds at the 2 ft and 4 ft resolutions.

The three-way interaction between resolution, number of confusers, and orientation is portrayed in the two plots of Figure 14. The first plot shows the proportion of false alarms as a function of vehicle orientation for each number of confusers at the 2 ft resolution. The second plot shows the same relationship at the 4 ft resolution. At both resolutions, there tended to be little variation among the four levels of confusers at each orientation. The only exception was the 180° orientation at the 2 ft resolution, where the false alarms were greatest when two confusers were present. Post hoc testing indicated that the false alarms were indeed significantly greater when two confusers appeared in a scene than when zero ($p < .004$), one ($p < .007$), or three ($p < .004$) were present, but only when the orientation was 180° at the 2 ft resolution. No other differences were statistically significant ($p > .01$).

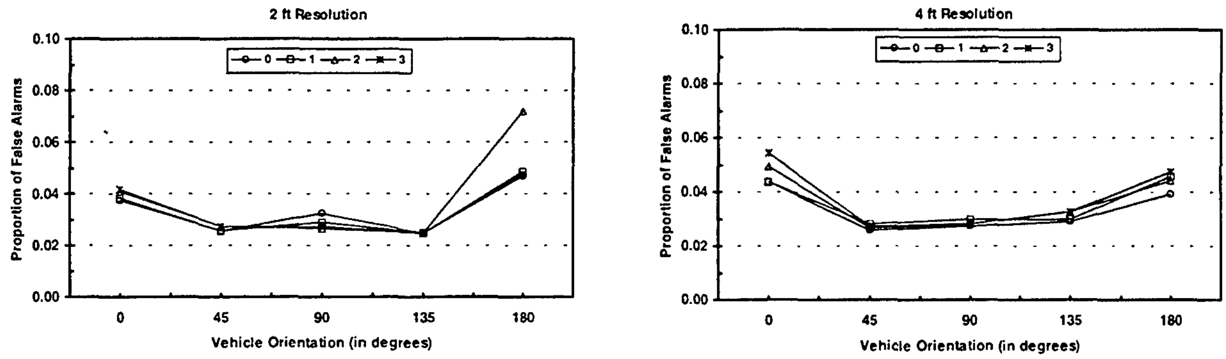


Figure 14: Mean proportion of false alarms as a function of vehicle orientation for each number of confusers at the 2 ft (left) and 4 ft (right) resolutions.

The final significant interaction in the analysis of false alarms was the Clutter x Number of Confusers x Orientation interaction, which appears in the three plots of Figure 15. The first plot shows the proportion of false alarms as a function of vehicle orientation for each number of confusers in the low clutter background. The second plot shows the same relationship in medium clutter, and the third depicts high clutter. Examination of the three plots reveals that little performance variation occurred among the levels of confusers within each level of orientation in the low and medium clutter backgrounds. However, in the high clutter background, there was some disparity at the highest orientation. Namely, when two confusers were present, the false alarms were higher than when zero, one, or three confusers appeared in the image. Post hoc correlated *t*-tests were conducted to determine whether any differences among the numbers of confusers within each orientation and clutter background were statistically significant. As expected from inspection of Figure 15, the only significant differences occurred in the high clutter background when the vehicle orientation was 180°—the false alarms were significantly higher when two confusers were present as compared to when there were zero ($p < .007$) or three ($p < .008$).

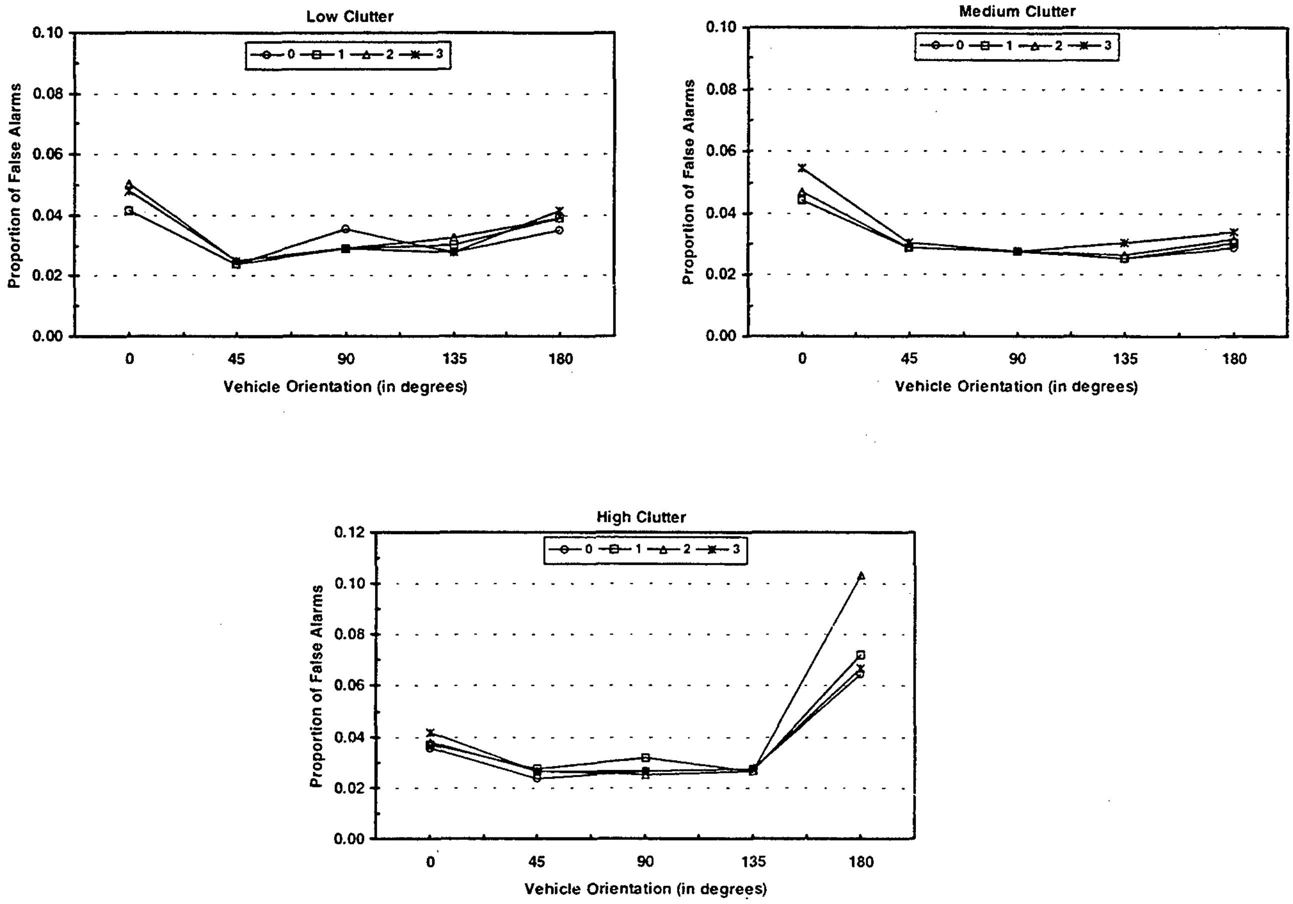


Figure 15: Mean proportion of false alarms as a function of vehicle orientation for each number of confusers in the low (left), medium (right), and high (bottom center) clutter backgrounds.

Perceptual Sensitivity and Response Bias

The proportions of hits and false alarms in each condition were used to derive the signal detection theory measures of perceptual sensitivity (d') and response bias (c). Although the task was set up as a detection-plus-localization task, we did not derive separate estimates of sensitivity and bias for detection and localization. Instead, as described earlier, we used participants' detection and localization responses to obtain a single "true" hit rate and a false alarm rate for each image. The hit and false alarm proportions were then used to obtain d' and c via computing formulae 3 and 4 (see Introduction). Prior to calculating these indices, proportions of 0 and 1 were first adjusted by means of the procedure recommended by Snodgrass and Corwin (1988) to permit the derivation of perceptual sensitivity and bias when such values are encountered.

Perceptual Sensitivity.

The mean perceptual sensitivity in each condition of resolution, background clutter, number of confusers, and vehicle orientation is portrayed in Table 5. The overall d' of 3.4 in the study falls within the range of what would be classified as a moderately easy task, according to guidelines provided by Craig (1984). That is, the task of detecting the TEL target when confusers could potentially be present can be characterized as moderately easy for the operators. As can be seen in Table 5, the level of sensitivity remained stable at 3.4 despite fluctuations in image resolution and the number of confusers present in the scene. Within each image resolution, however, there did appear to be some variation as a result of vehicle orientation. Specifically, sensitivity tended to be lowest when orientation was either 0° or 180°. A summary of the ANOVA of the means in Table 5 appears in Table 6.

Table 5. Mean Perceptual Sensitivity (Standard Deviations in Parentheses) in Each Condition.

		NUMBER OF CONFUSERS												
		0			1			2			3			
		BACKGROUND CLUTTER												
RES	ORIENT	L	M	H	L	M	H	L	M	H	L	M	H	MEAN
2 ft	0°	3.4	3.3	3.4	3.4	3.5	3.2	3.5	3.2	3.3	3.2	3.4	3.2	3.3
		(0.4)	(0.3)	(0.4)	(0.4)	(0.2)	(0.5)	(0.4)	(0.4)	(0.4)	(0.7)	(0.2)	(0.4)	(0.4)
	45°	3.7	3.6	3.6	3.6	3.5	3.6	3.5	3.6	3.6	3.7	3.5	3.5	3.6
		(0)	(0.1)	(0.1)	(0.3)	(0.4)	(0.1)	(0.3)	(0.2)	(0.2)	(0)	(0.3)	(0.3)	(0.2)
	90°	3.3	3.5	3.5	3.6	3.5	3.4	3.5	3.6	3.6	3.5	3.6	3.5	3.5
		(0.7)	(0.4)	(0.3)	(0.2)	(0.3)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)	(0.2)	(0.3)	(0.3)
	135°	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.5	3.6
		(0)	(0.1)	(0.2)	(0.2)	(0.3)	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.2)	(0.3)	(0.2)
	180°	3.4	3.4	2.9	3.4	3.2	3.0	3.4	3.4	1.8	3.5	3.6	3.1	3.2
		(0.3)	(0.3)	(0.4)	(0.6)	(0.5)	(0.4)	(0.5)	(0.4)	(0.8)	(0.4)	(0.2)	(0.4)	(0.6)
	Mean	3.5	3.5	3.4	3.5	3.4	3.4	3.5	3.5	3.2	3.5	3.5	3.4	3.4
		(0.4)	(0.3)	(0.4)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)	(0.8)	(0.4)	(0.2)	(0.4)	(0.4)
4 ft	0°	3.3	2.9	3.2	3.3	3.2	3.1	3.2	3.2	2.9	3.3	3.2	3.1	3.2
		(0.5)	(0.9)	(0.7)	(0.4)	(0.7)	(0.8)	(0.7)	(0.9)	(0.6)	(0.6)	(1.0)	(0.6)	(0.7)
	45°	3.7	3.6	3.6	3.5	3.6	3.5	3.6	3.5	3.5	3.5	3.4	3.6	3.6
		(0)	(0.2)	(0.1)	(0.3)	(0.2)	(0.6)	(0.1)	(0.3)	(0.6)	(0.5)	(0.4)	(0.1)	(0.3)
	90°	3.5	3.6	3.6	3.5	3.5	3.5	3.4	3.4	3.6	3.5	3.6	3.5	3.5
		(0.3)	(0.2)	(0.1)	(0.3)	(0.3)	(0.5)	(0.3)	(0.4)	(0.3)	(0.2)	(0.2)	(0.4)	(0.3)
	135°	3.6	3.6	3.6	3.5	3.6	3.6	3.4	3.6	3.6	3.6	3.5	3.5	3.5
		(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.2)	(0.5)	(0.4)	(0.2)	(0.2)	(0.5)	(0.2)	(0.3)
	180°	3.3	3.4	3.1	3.2	3.3	3.3	3.2	3.4	3.3	3.3	3.3	3.3	3.3
		(0.5)	(0.6)	(0.6)	(0.6)	(0.7)	(0.8)	(0.7)	(0.8)	(0.8)	(0.9)	(0.9)	(0.6)	(0.7)
	Mean	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
		(0.4)	(0.5)	(0.4)	(0.4)	(0.5)	(0.6)	(0.5)	(0.6)	(0.5)	(0.5)	(0.7)	(0.5)	(0.5)
		3.5	3.4	3.4	3.5	3.4	3.4	3.4	3.4	3.3	3.5	3.4	3.4	
		(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.5)	(0.4)	(0.5)	(0.7)	(0.5)	(0.5)	(0.4)	
	MEAN		3.4			3.4			3.4			3.4		3.4
			(0.4)			(0.4)			(0.6)			(0.5)		(0.5)

Table 6. Summary of a 2 (resolution) x 3 (clutter) x 4 (no. confusers) x 5 (orientation) ANOVA of Perceptual Sensitivity.

Source	*df*	*MS*	*F*	*p*
Resolution	1, 9	0.11	< 1	NS
Clutter	2, 18	1.0	8.6	.003
No. Confusers	3, 27	0.26	2.4	NS
Orientation	4, 36	7.2	7.9	.0006
Resolution x Clutter	2, 18	0.77	3.7	.04
Resolution x No. Confusers	3, 27	0.04	< 1	NS
Resolution x Orientation	4, 36	0.70	1.0	NS
Clutter x No. Confusers	6, 54	0.08	1.5	NS
Clutter x Orientation	8, 72	0.81	5.3	.0005
No. Confusers x Orientation	12, 108	0.16	2.0	NS
Resolution x Clutter x No. Confusers	6, 54	0.14	1.7	NS
Resolution x Clutter x Orientation	8, 72	0.61	4.6	.002
Resolution x No. Confusers x Orientation	12, 108	0.21	5.2	.0001
Clutter x No. Confusers x Orientation	24, 216	0.20	4.0	.0001
Resolution x Clutter x No. Confusers x Orientation	24, 216	0.20	2.9	.006

As expected from examination of the means in Table 5, the main effects for resolution and number of confusers were not statistically significant; however, the effects for clutter and vehicle orientation were. Mean sensitivity was slightly higher in the low clutter background ($M = 3.5$, $SD = 0.2$) as compared to medium ($M = 3.4$, $SD = 0.2$) and high ($M = 3.4$, $SD = 0.2$). Only the difference between the low and high clutter backgrounds was statistically significant ($p < .004$). With respect to the main effect for orientation, perceptual sensitivity was lower at orientations of 0° ($M = 3.2$, $SD = 0.4$) and 180° ($M = 3.2$, $SD = 0.4$) than at 45° ($M = 3.6$, $SD = 0.2$), 90° ($M = 3.5$, $SD = 0.2$), and 135° ($M = 3.6$, $SD = 0.1$). Post hoc correlated t-tests revealed that sensitivity was significantly lower at orientations of 0° and 180° as compared to orientations of 45° and 135° ($p < .005$ for all four comparisons). No other comparisons were statistically significant ($p > .01$).

The interaction between resolution and clutter is portrayed in Figure 16. As can be seen in the figure, sensitivity was higher at the 2 ft resolution as compared to 4 ft in the low and medium clutter backgrounds, but not in the high clutter scenes where the trend reversed. Post hoc correlated t-tests were conducted to determine whether the two levels of resolution differed within each level of clutter. None of the differences in means was statistically significant ($p > .01$).

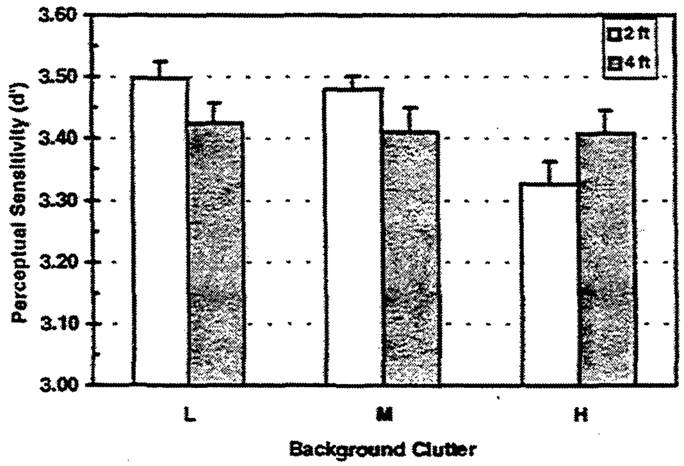


Figure 16: Mean perceptual sensitivity at the 2 ft and 4 ft resolutions in the low (L), medium (M), and high (H) clutter backgrounds.

The Clutter x Orientation interaction is depicted in Figure 17. As can be seen in the figure, there were virtually no differences among *d'* scores associated with each level of clutter at each orientation. The only exception was the orientation of 180°, where operator sensitivity in the high clutter background dropped noticeably from that in the low and medium clutter backgrounds. As expected from inspection of Figure 17, the only significant differences occurred at the highest vehicle orientation, where sensitivity was significantly lower in the high clutter background as compared to low ($p < .009$) and medium clutter ($p < .003$). No other differences were statistically significant ($p > .01$).

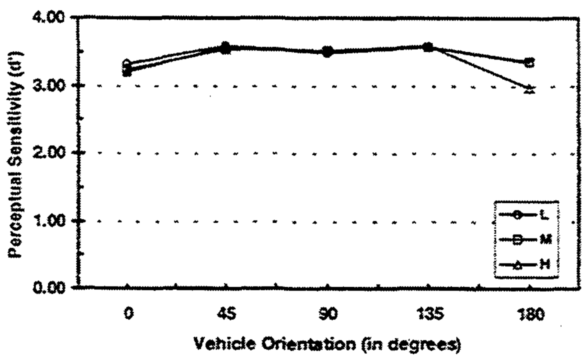


Figure 17: Mean perceptual sensitivity as a function of vehicle orientation in the low (L), medium (M), and high (H) clutter backgrounds.

Figure 18 portrays the significant three-way interaction between resolution, clutter, and orientation. The nature of this interaction illustrates the fact that the significant Clutter x Orientation interaction depicted in Figure 17 is further modified by the effects of resolution. Specifically, as can be seen in Figure 18, the drop in sensitivity in the high clutter background at the 180° orientation was a result of poorer performance at the 2 ft resolution rather than the 4 ft resolution. Indeed, post hoc testing indicated that operator sensitivity was significantly poorer in the high clutter background as compared to low ($p < .003$) and medium ($p < .004$) clutter, but only at the 2 ft resolution for a vehicle orientation of 180°. No other differences were significant ($p > .01$).

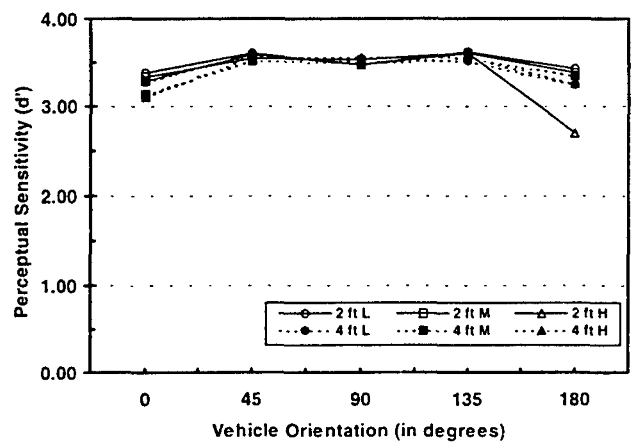


Figure 18: Mean perceptual sensitivity as a function of vehicle orientation in the low (L), medium (M), and high (H) clutter backgrounds at the 2 ft and 4 ft resolutions.

The Resolution x Number of Confusers x Orientation interaction is illustrated in the two plots of Figure 19. The first plot shows mean perceptual sensitivity as a function of vehicle orientation for each level of confusers at the 2 ft resolution. The second plot shows the same relationship at the 4 ft resolution. These two plots reveal that any variation in d' at each level of confusers was confined primarily to the orientation of 180° at the 2 ft resolution. In all other instances, sensitivity tended to remain stable at each orientation despite fluctuations in the number of confusers. Post hoc correlated t-tests were conducted to determine whether any fluctuations in d' among the four levels of confusers within each orientation and resolution were significantly different. The results indicated that operator sensitivity was significantly higher at an orientation of 180° at the 2 ft resolution when no confusers were present as opposed to when two confusers appeared in the scene ($p < .003$). Further, in the same orientation/resolution condition, sensitivity was inexplicably higher when three confusers were present as opposed to two ($p < .0001$). None of the remaining comparisons attained statistical significance at the .01 level.

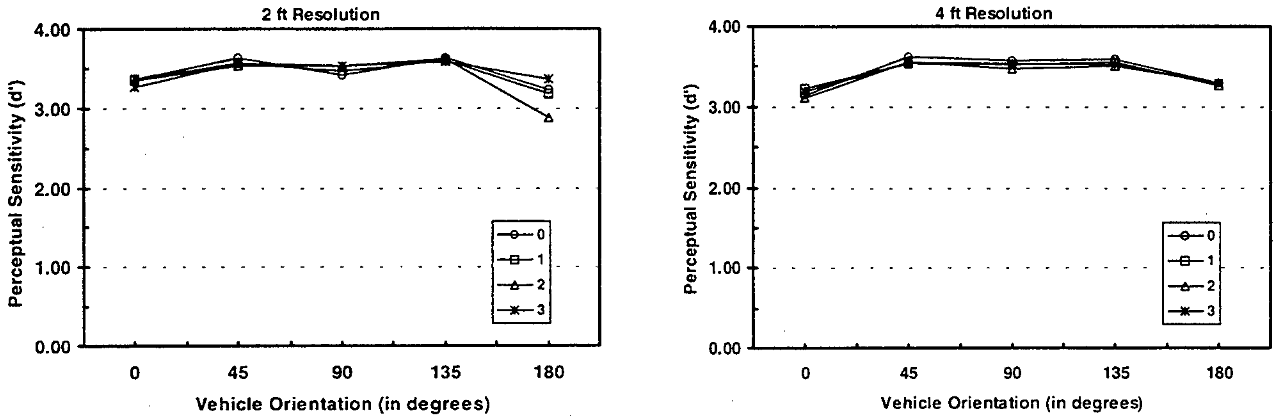
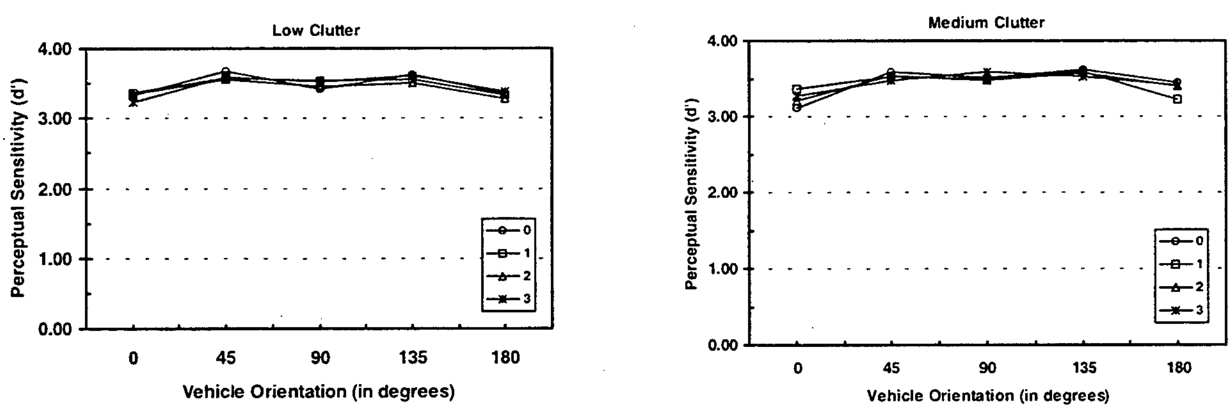


Figure 19: Mean perceptual sensitivity as a function of vehicle orientation for each number of confusers at the 2 ft (left) and 4 ft (right) resolutions.

The three-way interaction between clutter, number of confusers, and orientation is depicted in the three plots of Figure 20. The first plot shows mean sensitivity as a function of vehicle orientation for each number of confusers in the low clutter background. The second plot shows the same relationship for medium clutter, and the third illustrates high clutter. As can be seen in the plots, variations in sensitivity among the four levels of confusers at each orientation tended to occur only in the high clutter background at 180°. In that condition, mean *d'* was noticeably lower when two confusers were present as compared to the remaining three levels of confusers. Post hoc tests revealed this condition to be the only source of significant differences in *d'*. Specifically, in the high clutter background and a vehicle orientation of 180°, sensitivity was significantly lower when two confusers were present as compared to one ($p < .001$) or three ($p < .0009$).



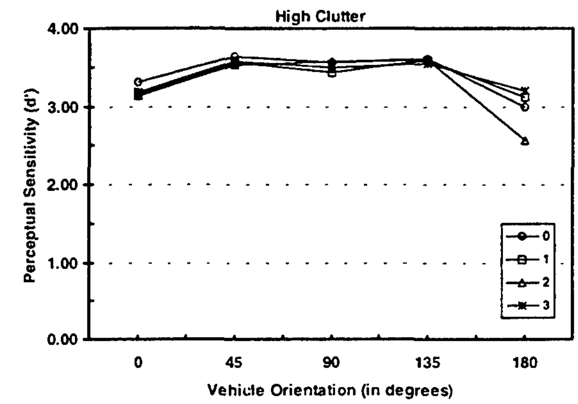
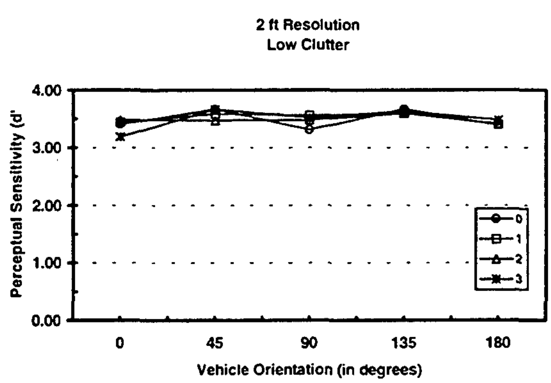
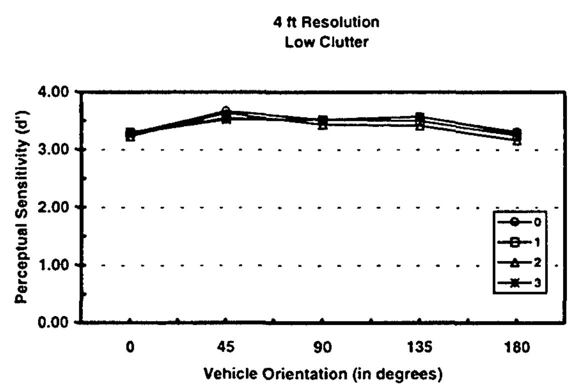


Figure 20: Mean perceptual sensitivity as a function of vehicle orientation for each number of confusers in the low (left), medium (right), and high (bottom center) clutter backgrounds.

Finally, in the analysis of operator sensitivity, the four-way interaction between resolution, clutter, number of confusers, and orientation was statistically significant. The nature of the interaction is portrayed in the six plots of Figure 21. The first three plots show mean sensitivity as a function of vehicle orientation for each number of confusers at the 2 ft resolution for low, medium, and high clutter. The last three plots show the same relationship at the 4 ft resolution for low, medium, and high clutter. As can be seen in the six plots, differences in operator sensitivity among the four numbers of confusers at each vehicle orientation tended to be confined to an orientation of 180° at the 2 ft resolution in the high clutter background; namely, when two confusers were present, *d'* was lower than in the remaining three levels of number of confusers. Post hoc tests revealed that operator sensitivity was indeed significantly lower in this condition when two confusers were present as opposed to when zero ($p < .002$), one ($p < .0007$), or three ($p < .0004$) appeared in the image. No other differences were statistically significant ($p > .01$).





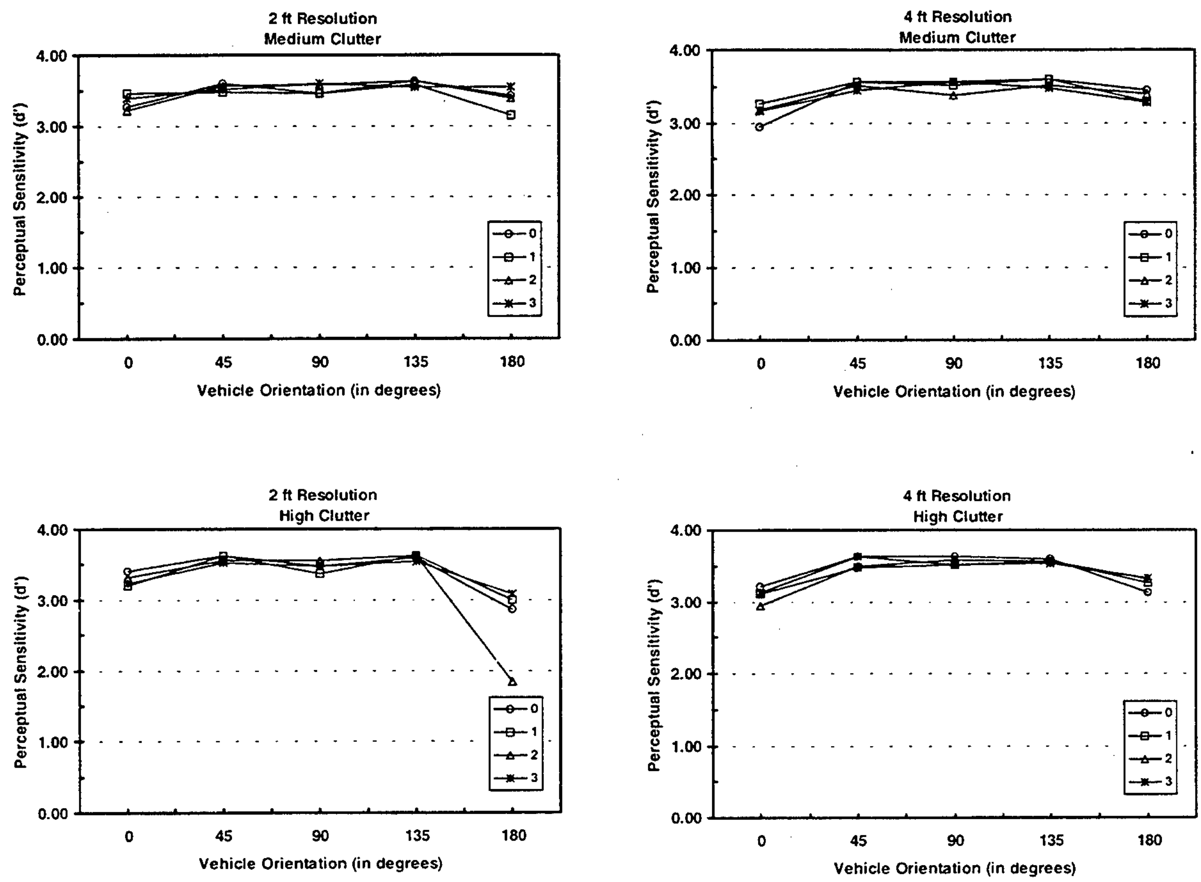


Figure 21: Mean perceptual sensitivity as a function of vehicle orientation for each number of confusers at each image resolution and clutter level.

<u>**Response Bias.**</u>

An analysis of response bias accompanied the examination of perceptual sensitivity to determine whether operators tended to be conservative or lenient in their detection responses. Mean values of response bias in each condition of resolution, clutter, number of confusers, and orientation appear in Table 7. The overall response bias of 0.16 indicates that the operators were more or less neutral in their decision-making (i.e., they were not more inclined to make "target" responses nor were they more biased toward "nontarget" responses). As can be seen in the table, response bias in the various conditions deviated little from the grand mean. In particular, the means at the 2 ft and 4 ft resolution were identical, and the means associated with each number of confusers were very similar. A summary of the ANOVA of the means in Table 7 is presented in Table 8. None of the main effects was statistically significant. The only two significant effects were the Clutter x Orientation interaction and the Clutter x Confusers x Orientation interaction.

Table 7. Mean Response Bias (Standard Deviations in Parentheses) in Each Condition.

		NUMBER OF CONFUSERS												
		0			1			2			3			
		BACKGROUND CLUTTER												
RES	ORIENT	L	M	H	L	M	H	L	M	H	L	M	H	MEAN
	0°	0.13	0.14	0.22	0.11	0.04	0.28	0.09	0.13	0.18	0.16	0.08	0.26	0.15
		(0.23)	(0.24)	(0.11)	(0.24)	(0.09)	(0.22)	(0.20)	(0.15)	(0.18)	(0.17)	(0.13)	(0.19)	(0.19)
	45°	0.14	0.11	0.16	0.19	0.17	0.16	0.21	0.13	0.17	0.14	0.15	0.15	0.16
		(0.00)	(0.07)	(0.06)	(0.13)	(0.21)	(0.06)	(0.14)	(0.06)	(0.06)	(0.00)	(0.16)	(0.02)	(0.10)
2 ft	90°	0.16	0.21	0.17	0.13	0.21	0.20	0.17	0.19	0.17	0.15	0.15	0.21	0.18
		(0.16)	(0.15)	(0.15)	(0.10)	(0.14)	(0.16)	(0.17)	(0.13)	(0.15)	(0.16)	(0.01)	(0.16)	(0.14)
	135°	0.14	0.16	0.15	0.15	0.19	0.16	0.15	0.16	0.16	0.16	0.17	0.21	0.16
		(0.00)	(0.06)	(0.01)	(0.01)	(0.13)	(0.06)	(0.01)	(0.06)	(0.06)	(0.06)	(0.06)	(0.14)	(0.07)
	180°	0.25	0.23	0.04	0.21	0.34	-0.02	0.21	0.21	0.24	0.17	0.17	-0.07	0.16
		(0.14)	(0.17)	(0.36)	(0.15)	(0.22)	(0.36)	(0.14)	(0.16)	(0.35)	(0.08)	(0.11)	(0.30)	(0.25)
	Mean	0.17	0.17	0.15	0.16	0.19	0.16	0.17	0.16	0.19	0.16	0.14	0.15	0.16
		(0.14)	(0.15)	(0.18)	(0.14)	(0.18)	(0.22)	(0.15)	(0.12)	(0.19)	(0.11)	(0.11)	(0.21)	(0.16)
	0°	0.17	0.28	0.17	0.16	0.12	0.22	0.08	0.16	0.30	0.14	0.10	0.15	0.17
		(0.28)	(0.21)	(0.24)	(0.26)	(0.22)	(0.27)	(0.12)	(0.15)	(0.21)	(0.21)	(0.11)	(0.22)	(0.22)
	45°	0.14	0.13	0.16	0.21	0.13	0.17	0.16	0.15	0.20	0.19	0.16	0.16	0.16
		(0.00)	(0.10)	(0.06)	(0.14)	(0.10)	(0.07)	(0.06)	(0.16)	(0.17)	(0.13)	(0.13)	(0.06)	(0.11)
4 ft	90°	0.15	0.13	0.16	0.15	0.15	0.15	0.19	0.19	0.19	0.15	0.13	0.19	0.16
		(0.16)	(0.10)	(0.06)	(0.16)	(0.16)	(0.02)	(0.16)	(0.21)	(0.13)	(0.12)	(0.10)	(0.10)	(0.13)
	135°	0.09	0.15	0.11	0.10	0.15	0.13	0.10	0.15	0.13	0.09	0.14	0.12	0.12
		(0.08)	(0.09)	(0.07)	(0.08)	(0.01)	(0.10)	(0.09)	(0.10)	(0.10)	(0.08)	(0.06)	(0.07)	(0.08)
	180°	0.16	0.19	0.25	0.17	0.26	0.14	0.17	0.22	0.12	0.14	0.23	0.14	0.18
		(0.25)	(0.09)	(0.24)	(0.29)	(0.17)	(0.13)	(0.18)	(0.16)	(0.10)	(0.14)	(0.20)	(0.17)	(0.18)
	Mean	0.14	0.18	0.17	0.16	0.16	0.16	0.14	0.18	0.19	0.14	0.15	0.15	0.16
		(0.18)	(0.13)	(0.16)	(0.20)	(0.15)	(0.14)	(0.13)	(0.16)	(0.16)	(0.14)	(0.13)	(0.14)	(0.15)
		0.16	0.17	0.16	0.16	0.18	0.16	0.15	0.17	0.19	0.15	0.15	0.15	
		(0.16)	(0.14)	(0.17)	(0.17)	(0.17)	(0.18)	(0.14)	(0.14)	(0.17)	(0.13)	(0.12)	(0.18)	
	MEAN		0.16			0.16			0.17			0.15		0.16
			(0.16)			(0.18)			(0.15)			(0.14)		(0.16)

Table 8. Summary of a 2 (resolution) x 3 (clutter) x 4 (no. confusers) x 5 (orientation) ANOVA of Response Bias.

Source	*df*	*MS*	*F*	*p*
Resolution	1, 9	0.003	< 1	NS
Clutter	2, 18	0.02	< 1	NS
No. Confusers	3, 27	0.02	1.7	NS
Orientation	4, 36	0.03	< 1	NS
Resolution x Clutter	2, 18	0.02	< 1	NS
Resolution x No. Confusers	3, 27	0.001	< 1	NS
Resolution x Orientation	4, 36	0.04	< 1	NS
Clutter x No. Confusers	6, 54	0.01	1.4	NS
Clutter x Orientation	8, 72	0.15	5.6	.0003
No. Confusers x Orientation	12, 108	0.02	1.3	NS
Resolution x Clutter x No. Confusers	6, 54	0.006	< 1	NS
Resolution x Clutter x Orientation	8, 72	0.05	1.1	NS
Resolution x No. Confusers x Orientation	12, 108	0.02	2.3	NS
Clutter x No. Confusers x Orientation	24, 216	0.02	3.6	.0001
Resolution x Clutter x No. Confusers x Orientation	24, 216	0.02	2.0	NS

The Clutter x Orientation interaction is portrayed in Figure 22. As can be seen in the figure, there was little variation in response bias among the three levels of clutter within each orientation when the orientation was 45°, 90°, or 135°. However, when the orientation was 0°, response bias tended to be more conservative in the high clutter background than in the low and medium clutter scenes. When the orientation was 180°, this trend reversed so that response bias became relatively more lenient in high clutter than in low and medium clutter. Post hoc testing revealed that the only significant difference was between the medium and high clutter backgrounds at the 0° orientation ($p < .01$).

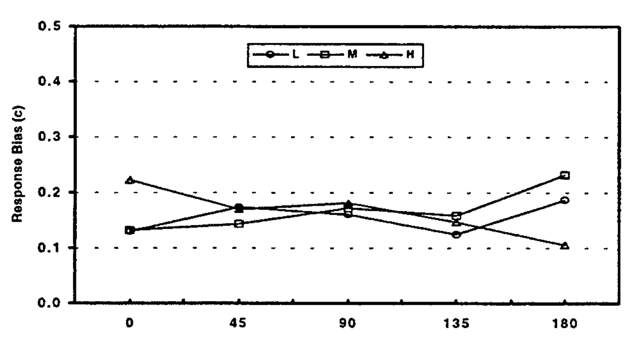
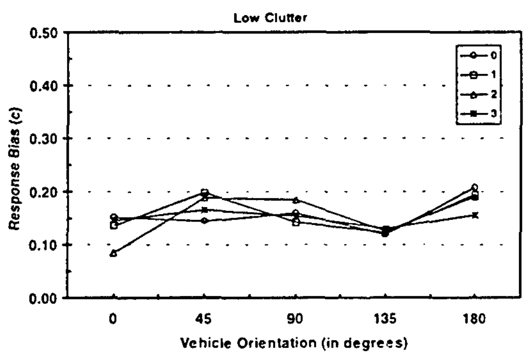
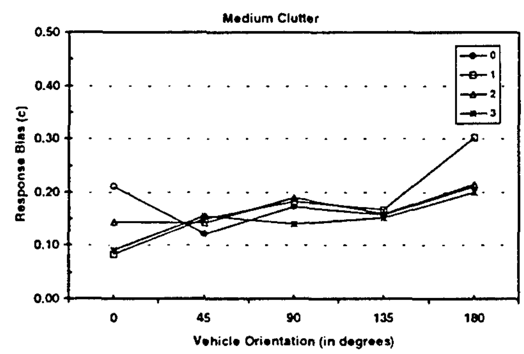


Figure 22: Mean response bias as a function of vehicle orientation in the low (L), medium (M), and high (H) clutter backgrounds.

The Clutter x Number of Confusers x Orientation interaction is depicted in the three plots of Figure 23. The first plot shows mean response bias as a function of vehicle orientation for each number of confusers in the low clutter background. The remaining two plots show the same relationship in the medium and high clutter backgrounds. As can be seen in the figure, there was some variation in response bias among the four levels of confusers within each orientation at all three clutter levels. The differences were most apparent in the medium (at the 0° and 180° orientations) and high (at the 180° orientation) clutter backgrounds. Post hoc correlated *t*-tests were conducted to determine whether the four levels of confusers within each orientation and clutter background differed from one another. Only the difference in response bias associated with two versus three confusers at 180° in the high clutter background was statistically significant ($p < .01$). Response bias was relatively more conservative when two confusers were present.





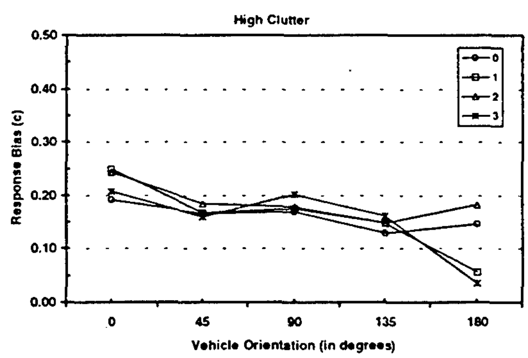


Figure 23: Mean response bias as a function of vehicle orientation for each number of confusers in the low (left), medium (right), and high (bottom center) clutter backgrounds.

Reaction Times

In addition to examining performance measures such as hits, false alarms, sensitivity, and bias, we also analyzed operators' decision-making reaction times. Reaction times were classified as RTs for hits, correct rejections, misses, or false alarms, depending on the image type and the operator's decision. For example, if the operator responded "target" to an image containing only the confuser vehicle, the RT for that response was classified as a false alarm reaction time.

RT for Hits.

Mean reaction times for hits in each condition of resolution, clutter, number of confusers, and orientation are presented in Table 9. Overall, operators took just over 3 seconds to respond correctly to target imagery. As can be seen in the table, they were somewhat faster at the 2 ft resolution as compared to 4 ft. In addition, RT tended to increase progressively as the number of confusers increased. Within each resolution, there was also a noticeable tendency for RT to be higher at the 0° and 180° orientations as compared to 45°, 90°, and 135°. A summary of the ANOVA of the means in Table 9 appears in Table 10. As can be seen in the table, all of the main effects were statistically significant as were a number of the interactions.

Table 9. Mean Reaction Time (seconds) for Hits (Standard Deviations in Parentheses) in Each Condition.

		NUMBER OF CONFUSERS												
		0			1			2			3			
		BACKGROUND CLUTTER												
RES	ORIENT	L	M	H	L	M	H	L	M	H	L	M	H	MEAN
2 ft	0°	2.7	3.1	4.2	0.8	3.4	3.4	3.5	3.1	3.5	3.4	3.8	4.9	3.5
		(0.9)	(1.1)	(2.0)	(0.9)	(1.6)	(1.0)	(1.3)	(0.8)	(0.7)	(0.9)	(1.3)	(1.2)	(1.3)
	45°	2.5	2.2	2.6	2.6	2.5	2.7	2.5	2.6	2.8	2.8	2.8	2.8	2.6
		(0.8)	(0.6)	(0.8)	(1.0)	(0.9)	(1.0)	(0.7)	(0.8)	(1.0)	(1.1)	(0.8)	(1.2)	(0.9)
	90°	2.2	2.4	2.5	2.4	2.4	2.7	2.9	2.3	2.4	2.7	2.9	3.1	2.6
		(0.6)	(0.7)	(0.8)	(0.8)	(0.7)	(0.7)	(0.8)	(0.5)	(0.6)	(0.8)	(1.1)	(0.8)	(0.8)
	135°	2.4	2.5	2.5	2.4	2.5	2.7	2.5	2.9	2.7	2.5	3.0	3.0	2.6
		(0.9)	(1.0)	(0.8)	(0.9)	(0.7)	(0.9)	(0.9)	(1.1)	(0.9)	(0.8)	(1.0)	(0.9)	(0.9)
	180°	2.6	2.9	3.0	2.8	3.5	3.3	3.1	3.2	5.1	4.3	1.0	3.6	3.4
		(0.8)	(0.9)	(0.9)	(0.7)	(1.2)	(1.0)	(0.8)	(1.3)	(1.7)	(1.0)	(1.2)	(0.9)	(1.2)
	Mean	2.5	2.6	3.0	2.6	2.9	3.0	2.9	2.8	3.3	3.2	3.3	3.5	3.0
		(0.8)	(0.9)	(1.3)	(0.8)	(1.2)	(1.0)	(1.0)	(1.0)	(1.4)	(1.1)	(1.2)	(1.2)	(1.1)
4 ft	0°	3.5	4.2	4.7	3.6	4.1	4.9	3.9	4.3	5.3	4.5	4.1	5.0	4.4
		(1.0)	(1.3)	(1.6)	(1.2)	(1.5)	(1.9)	(1.6)	(2.2)	(2.2)	(1.7)	(1.2)	(1.6)	(1.6)
	45°	3.0	2.6	2.8	2.7	2.6	2.8	3.2	3.2	3.5	3.2	3.2	3.2	3.0
		(0.8)	(1.0)	(1.1)	(0.9)	(0.8)	(0.8)	(1.4)	(1.2)	(1.2)	(1.2)	(1.1)	(1.2)	(1.0)
	90°	2.4	2.5	2.5	2.9	2.4	2.4	2.8	2.9	2.9	2.6	3.3	3.3	2.8
		(0.8)	(1.0)	(0.9)	(0.9)	(0.9)	(0.7)	(1.0)	(1.1)	(1.2)	(0.9)	(1.0)	(1.4)	(1.0)
	135°	2.5	2.4	2.6	2.5	2.6	2.8	2.9	2.9	2.8	3.0	3.1	3.5	2.8
		(0.9)	(0.8)	(0.8)	(0.8)	(0.9)	(1.0)	(1.0)	(1.0)	(0.9)	(1.4)	(1.3)	(1.2)	(1.0)
	180°	3.7	3.7	4.2	3.5	3.6	3.8	3.6	3.8	3.8	4.3	4.0	4.0	3.8
		(1.3)	(1.5)	(1.6)	(1.2)	(1.2)	(1.4)	(1.1)	(1.2)	(1.2)	(1.6)	(1.2)	(1.6)	(1.3)
	Mean	3.0	3.1	3.4	3.1	3.0	3.4	3.3	3.4	3.7	3.5	3.5	3.8	3.4
		(1.1)	(1.3)	(1.5)	(1.1)	(1.2)	(1.5)	(1.2)	(1.4)	(1.6)	(1.5)	(1.2)	(1.5)	(1.4)
		2.8	2.8	3.2	2.8	3.0	3.2	3.1	3.1	3.5	3.4	3.4	3.6	
		(1.0)	(1.1)	(1.4)	(1.0)	(1.2)	(1.3)	(1.1)	(1.3)	(1.5)	(1.3)	(1.2)	(1.4)	
	MEAN		2.9			3.0			3.2			3.5		3.2
			(1.2)			(1.2)			(1.3)			(1.3)		(1.3)

Table 10. Summary of a 2 (resolution) x 3 (clutter) x 4 (no. confusers) x 5 (orientation) ANOVA of Reaction Time for Hits

Source	*df*	*MS*	*F*	*p*
Resolution	1, 9	47.7	5.4	.04
Clutter	2, 18	13.4	44.3	.0001
No. Confusers	3, 27	19.1	23.0	.0001
Orientation	4, 36	81.2	27.5	.0001
Resolution x Clutter	2, 18	0.16	< 1	NS
Resolution x No. Confusers	3, 27	0.5	1.1	NS
Resolution x Orientation	4, 36	4.9	4.0	.04
Clutter x No. Confusers	6, 54	0.2	< 1	NS
Clutter x Orientation	8, 72	3.0	18.1	.0001
No. Confusers x Orientation	12, 108	0.2	1.2	NS
Resolution x Clutter x No. Confusers	6, 54	0.3	1.3	NS
Resolution x Clutter x Orientation	8, 72	0.3	1.7	NS
Resolution x No. Confusers x Orientation	12, 108	1.4	4.2	.003
Clutter x No. Confusers x Orientation	24, 216	1.0	4.0	.0001
Resolution x Clutter x No. Confusers x Orientation	24, 216	1.0	4.2	.0001

With respect to the main effect for resolution, operators were indeed significantly faster at the 2 ft resolution than at 4 ft. Regarding the main effect for clutter, RT tended to be faster in the low (M = 3.0, SD = 0.9) and medium (M = 3.1, SD = 0.9) clutter backgrounds as compared to high clutter (M = 3.4, SD = 1.0). Post hoc testing revealed that both of these backgrounds differed significantly from high clutter ($p < .0001$) but not from each other ($p > .01$). As mentioned earlier, the main effect for number of confusers stemmed from the tendency for RT to increase with the number of confusers present in the image. Post hoc tests indicated that all of the confusers differed significantly from one another at $p < .01$ except zero and one. Finally, with respect to the main effect for orientation, RT was faster at orientations of 45° (M = 2.8, SD = 0.9), 90° (M = 2.7, SD = 0.8), and 135° (M = 2.7, SD = 0.9) as compared to 0° (M = 3.9, SD = 1.2) and 180° (M = 3.6, SD = 1.0). Post hoc tests revealed that all of the orientations differed significantly at $p < .01$ except 0° and 180°, 45° and 90°, and 90° and 135°.

The Resolution x Orientation interaction is portrayed in Figure 24. As can be seen in the figure, the RT for hits at the two image resolutions within each vehicle orientation differed noticeably from each other only when the orientation was 0°. Post hoc correlated t-tests were conducted to determine whether the two resolutions within each orientation differed significantly from each other. None of the differences in means attained significance at the .01 level.

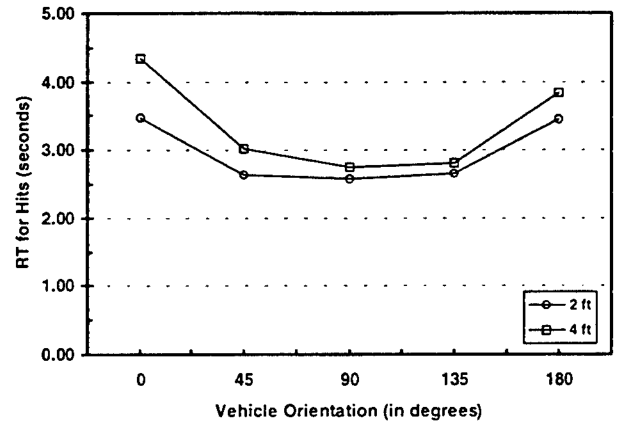


Figure 24: Mean RT for hits as a function of vehicle orientation at the 2 ft and 4 ft resolutions.

The nature of the Clutter x Orientation interaction can be seen in Figure 25. As with resolution, the means for the three levels of clutter within each vehicle orientation differed most noticeably from one another at the 0° orientation. Post hoc testing revealed that all three clutter backgrounds did indeed differ significantly from one another at the 0° orientation ($p < .002$). The RT for hits was highest in the high clutter background and improved progressively as the clutter decreased. Post hoc testing further revealed that the low clutter background differed from medium ($p < .006$) and high ($p < .0004$) at the 135° orientation and that the low and high backgrounds differed when the orientation was 180° ($p < .009$). No other differences were statistically significant ($p > .01$).

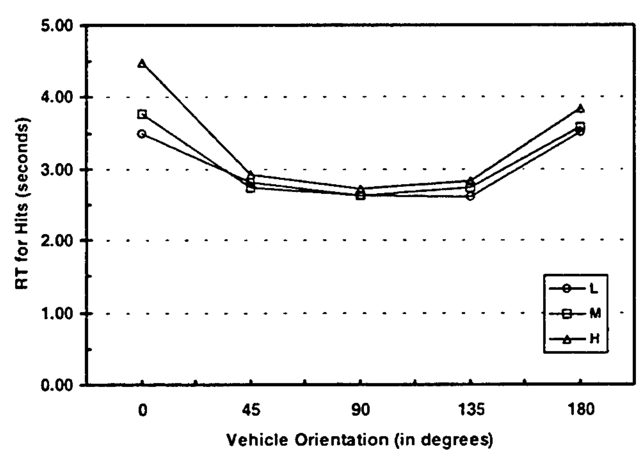
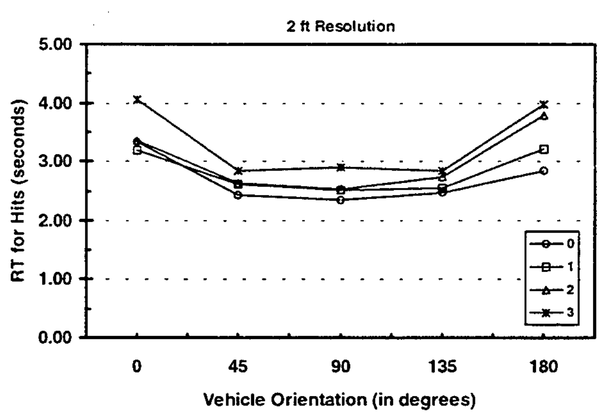


Figure 25: Mean RT for hits as a function of vehicle orientation in the low (L), medium (M), and high (H) clutter backgrounds.

The three-way interaction between resolution, number of confusers, and orientation is depicted in the two plots in Figure 26. The first plot shows mean RT for hits as a function of vehicle orientation for each number of confusers at the 2 ft resolution. The second plot shows the same relationship at the 4 ft resolution. Inspection of the two plots in Figure 26 reveals some variation in RT for hits among the four numbers of confusers within each orientation at both the 2 ft and 4 ft resolutions. In particular, the RT was obviously higher when three confusers were present as compared to zero at each orientation. Follow-up testing of the means within each orientation and resolution produced the following results. With respect to the 2 ft resolution, the RT for three confusers was higher than the RT for zero, one, or two confusers at the 0° orientation ($p < .0004$). At 45°, only zero and three confusers differed from each other ($p < .005$). At 90°, three confusers differed significantly from zero ($p < .0007$), one ($p < .002$), and two ($p < .004$) confusers. At 135°, zero confusers differed from two and three ($p < .007$) and one confuser differed from three ($p < .002$). At 180°, zero confusers differed significantly from one, two, and three ($p < .004$) as did one versus three confusers ($p < .001$). With respect to the 4 ft resolution, none of the differences was statistically significant at orientations of 0° and 180°. At 45° and 90°, zero confusers differed from two and three ($p < .006$). Finally, at 135°, zero confusers differed from two and three ($p < .007$) as did one versus three confusers ($p < .003$).



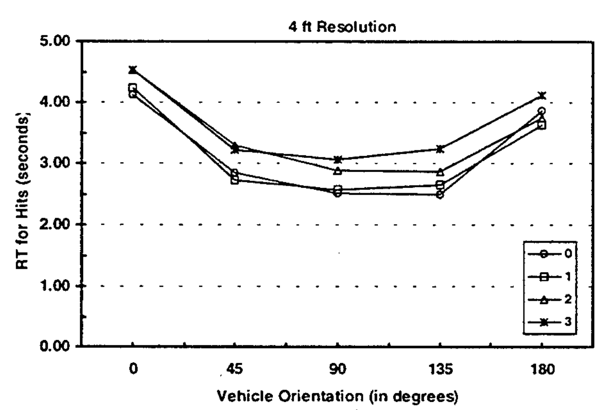


Figure 26: Mean RT for hits as a function of vehicle orientation for each number of confusers at the 2 ft (left) and 4 ft (right) resolutions.

The Clutter x Number of Confusers x Orientation interaction is portrayed in the three plots of Figure 27. The first plot shows mean RT for hits as a function of vehicle orientation for the four numbers of confusers in the low clutter background. The second plot shows the same relationship in the medium clutter background, and the third plot depicts the high clutter background. In the low clutter background, RT for hits appeared to be higher for two and three confusers as compared to zero and one at an orientation of 0°. In addition, at 180°, the RT associated with three confusers was noticeably higher than the RT for all other levels of confusers. In the medium clutter scenes, there was a clear discrepancy between zero and three confusers within all vehicle orientations, though this difference was smallest at 0°. Finally, in the high clutter background, the least variation among the levels of confusers occurred at 45°. At 0°, 90°, and 135°, RT associated with three confusers tended to be elevated; at 180°, it was the RT for two confusers that stood out. The entries in Table 11 show which of these observations were statistically significant during post hoc testing.

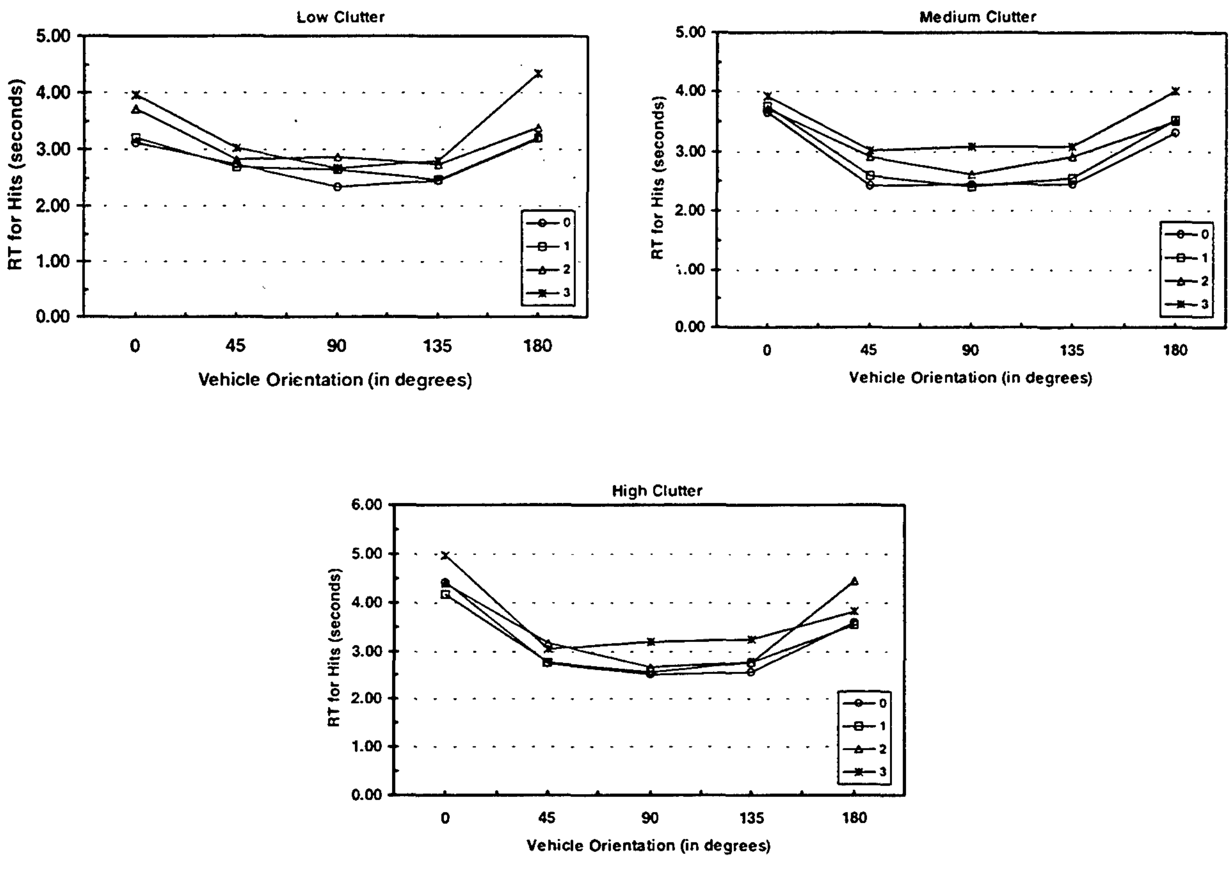


Figure 27: Mean RT for hits as a function of vehicle orientation for each number of confusers in the low (left), medium (right), and high (bottom center) clutter backgrounds.

Table 11. Results of Post Hoc Tests for the Clutter x Number of Confusers x Orientation Interaction in the Analysis of RT for Hits.

		0°			45°			90°			135°			180°		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
L	0	NS	*	*	NS	NS	NS	NS	*	NS	NS	*	NS	NS	NS	*
	1	--	NS	*	--	NS	NS	--	NS	NS	--	*	NS	--	NS	*
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	*
M	0	NS	NS	NS	NS	*	*	NS	NS	*	NS	*	*	NS	NS	NS
	1	--	NS	NS	--	NS	NS	--	*	*	--	*	*	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	*
H	0	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS	*	NS	*	NS
	1	--	NS	NS	--	*	NS	--	NS	NS	--	NS	NS	--	*	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	*	--	--	NS

* $p < .01$; NS = not significant, $p > .01$

Finally, the ANOVA of RT for hits revealed a significant four-way interaction, which is depicted in the six plots of Figure 28. The first three plots show mean RT for hits as a function of vehicle orientation for the four numbers of confusers in low, medium, and high clutter backgrounds, respectively, at the 2 ft resolution. The last three plots show the same relationships in the low, medium, and high clutter backgrounds at the 4 ft resolution. As can be seen in the figure, the interaction stems from the fact that the variation among the four levels of confusers within each orientation differed at each resolution and background. For example, in the low clutter background at the 2 ft resolution, there was a noticeable discrepancy between the RT for three confusers and the RT associated with zero, one, and two confusers at an orientation of 180°. This relationship was not evident in the remaining five plots. The results of post hoc testing are summarized in Table 12 (2 ft resolution) and Table 13 (4 ft resolution). Inspection of the two tables reveals that 23 of the 90 comparisons were statistically significant at the 2 ft resolution, whereas only 14 reached significance at the 4 ft resolution. Further, at the 4 ft resolution, all of the significant differences but one occurred at orientations of 45°, 90°, and 135°. At the 2 ft resolution, on the other hand, the majority of the significant differences occurred at orientations of 0° and 180°.

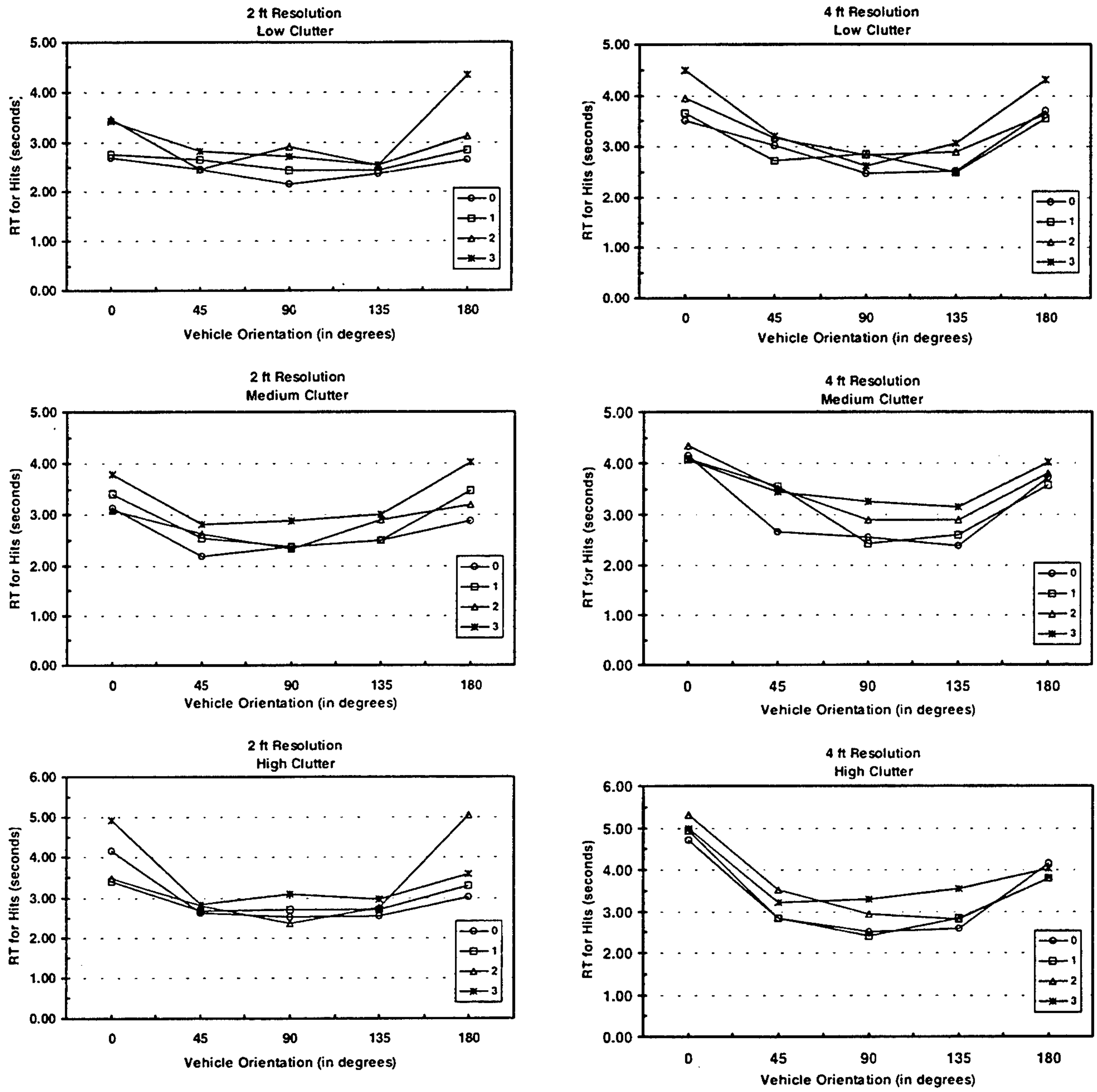


Figure 28: Mean RT for hits as a function of vehicle orientation for each number of confusers at each image resolution and clutter level.

Table 12. Results of Post Hoc Tests for the Resolution x Clutter x Number of Confusers x Orientation Interaction in the Analysis of RT for Hits (2 ft Resolution).

		0°			45°			90°			135°			180°		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
L	0	NS	*	*	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	*
	1	--	*	*	--	NS	NS	--	NS	NS	--	NS	NS	--	NS	*
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	*
M	0	NS	NS	NS	NS	*	*	NS	NS	NS	NS	*	*	*	NS	*
	1	--	NS	NS	--	NS	NS	--	NS	NS	--	NS	*	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	*
H	0	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS
	1	--	NS	*	--	NS	NS	--	NS	NS	--	NS	NS	--	*	NS
	2	--	--	*	--	--	NS	--	--	*	--	--	NS	--	--	*

* $p < .01$; NS = not significant, $p > .01$

Table 13. Results of Post Hoc Tests for the Resolution x Clutter x Number of Confusers x Orientation Interaction in the Analysis of RT for Hits (4 ft Resolution).

		0°			45°			90°			135°			180°		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
L	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	1	--	NS	*	--	NS	NS	--	NS	NS	--	NS	NS	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	NS
M	0	NS	NS	NS	NS	NS	*	NS	NS	*	NS	*	NS	NS	NS	NS
	1	--	NS	NS	--	NS	NS	--	*	*	--	NS	NS	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	NS
H	0	NS	NS	NS	NS	*	*	NS	*	NS	*	NS	*	NS	NS	NS
	1	--	NS	NS	--	*	NS	--	NS	NS	--	NS	*	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	*	--	--	NS

* $p < .01$; NS = not significant, $p > .01$

RT for Correct Rejections.

Mean reaction times for correct rejections in each condition of resolution, clutter, number of confusers, and orientation are presented in Table 14. The overall mean of 4.1 seconds indicates that the operators took slightly longer to make a correct response to nontargets than to targets (where the mean was 3.2 seconds). The RT for correct rejections was noticeably higher at the 4 ft resolution as compared to the 2 ft resolution. There was a slight tendency for RT to increase as the number of confusers increased. Within each resolution, the RT associated with orientations of 0° and 180° tended to be higher than the RT for the remaining three orientations. A summary of the ANOVA of the means in Table 14 appears in Table 15. All four of the main effects were statistically significant.

Table 14. Mean Reaction Time (seconds) for Correct Rejections (Standard Deviations in Parentheses) in Each Condition.

		NUMBER OF CONFUSERS												
		0			1			2			3			
		BACKGROUND CLUTTER												
RES	ORIENT	L	M	H	L	M	H	L	M	H	L	M	H	MEAN
2 ft	0°	3.3 (1.1)	3.8 (1.3)	4.9 (2.1)	3.3 (1.1)	3.8 (1.5)	4.6 (1.9)	3.6 (1.2)	3.7 (1.2)	4.6 (1.7)	3.8 (1.5)	4.1 (1.4)	5.3 (1.6)	4.1 (1.5)
	45°	2.9 (0.6)	3.2 (1.0)	4.1 (1.5)	3.0 (0.7)	3.4 (1.1)	4.1 (1.5)	2.9 (0.6)	3.4 (1.1)	4.2 (1.6)	3.0 (0.8)	3.5 (1.0)	4.2 (1.6)	3.5 (1.2)
	90°	2.7 (0.7)	3.2 (0.9)	3.9 (1.3)	2.8 (0.7)	3.1 (0.9)	4.0 (1.3)	3.1 (0.8)	3.1 (0.8)	3.9 (1.2)	3.0 (0.7)	3.3 (1.1)	4.2 (1.2)	3.4 (1.1)
	135°	2.9 (0.8)	3.5 (1.3)	4.4 (1.7)	2.9 (0.8)	3.6 (1.2)	4.5 (1.7)	3.0 (0.8)	3.7 (1.4)	4.5 (1.7)	3.0 (0.8)	3.8 (1.3)	4.6 (1.6)	3.7 (1.4)
	180°	2.9 (1.0)	3.4 (1.0)	4.6 (2.0)	3.1 (1.0)	3.7 (1.1)	4.5 (1.7)	3.2 (1.0)	3.6 (1.1)	5.6 (2.4)	3.9 (1.2)	4.0 (1.1)	4.7 (1.9)	3.9 (1.6)
	Mean	2.9 (0.8)	3.4 (1.1)	4.4 (1.7)	3.0 (0.9)	3.5 (1.2)	4.3 (1.6)	3.2 (0.9)	3.5 (1.1)	4.5 (1.8)	3.4 (1.1)	3.7 (1.2)	4.6 (1.6)	3.7 (1.4)
4 ft	0°	4.0 (1.4)	5.0 (1.8)	5.7 (2.2)	4.1 (1.5)	4.8 (1.7)	5.9 (2.3)	4.2 (1.7)	5.0 (2.0)	6.2 (2.5)	4.6 (1.7)	4.8 (1.7)	5.9 (2.1)	5.0 (2.0)
	45°	3.7 (1.1)	4.0 (1.6)	5.0 (2.2)	3.5 (1.2)	4.0 (1.6)	5.1 (2.2)	3.8 (1.3)	4.2 (1.6)	5.4 (2.4)	3.8 (1.3)	4.3 (1.6)	5.2 (2.2)	4.3 (1.8)
	90°	3.6 (1.2)	3.8 (1.5)	4.8 (1.8)	3.8 (1.2)	3.8 (1.6)	4.7 (1.8)	3.8 (1.2)	4.0 (1.6)	5.0 (1.8)	3.7 (1.1)	4.2 (1.5)	5.1 (1.7)	4.2 (1.5)
	135°	3.4 (1.0)	3.6 (1.3)	4.8 (1.8)	3.4 (1.1)	3.7 (1.3)	4.9 (1.8)	3.6 (1.1)	3.9 (1.4)	4.9 (1.8)	3.7 (1.2)	4.0 (1.4)	5.3 (1.8)	4.1 (1.5)
	180°	3.9 (1.5)	4.2 (1.5)	5.4 (2.4)	4.0 (1.7)	4.2 (1.7)	5.1 (2.3)	3.9 (1.4)	4.2 (1.6)	5.1 (2.2)	4.2 (1.5)	4.4 (1.6)	5.4 (2.1)	4.5 (1.8)
	Mean	3.7 (1.2)	4.1 (1.6)	5.1 (2.0)	3.8 (1.3)	4.1 (1.6)	5.2 (2.1)	3.9 (1.3)	4.3 (1.6)	5.3 (2.1)	4.0 (1.4)	4.3 (1.5)	5.4 (1.9)	4.4 (1.8)
		3.3 (1.1)	3.8 (1.4)	4.8 (1.9)	3.4 (1.2)	3.8 (1.4)	4.7 (1.9)	3.5 (1.2)	3.9 (1.4)	4.9 (2.0)	3.7 (1.3)	4.0 (1.4)	5.0 (1.8)	
	MEAN		4.0 (1.6)			4.0 (1.6)			4.1 (1.7)			4.2 (1.6)		4.1 (1.6)

Table 15. Summary of a 2 (resolution) x 3 (clutter) x 4 (no. confusers) x 5 (orientation) ANOVA of Reaction Time for Correct Rejections.

Source	*df*	*MS*	*F*	*p*
Resolution	1, 9	157.2	19.0	.002
Clutter	2, 18	202.6	22.2	.0009
No. Confusers	3, 27	5.2	17.4	.0001
Orientation	4, 36	22.9	9.5	.0006
Resolution x Clutter	2, 18	0.3	< 1	NS
Resolution x No. Confusers	3, 27	0.1	< 1	NS
Resolution x Orientation	4, 36	2.8	3.5	.02
Clutter x No. Confusers	6, 54	0.1	< 1	NS
Clutter x Orientation	8, 72	0.6	1.1	NS
No. Confusers x Orientation	12, 108	0.1	1.4	NS
Resolution x Clutter x No. Confusers	6, 54	0.1	2.1	NS
Resolution x Clutter x Orientation	8, 72	0.6	1.9	NS
Resolution x No. Confusers x Orientation	12, 108	0.4	4.2	.003
Clutter x No. Confusers x Orientation	24, 216	0.2	3.7	.0001
Resolution x Clutter x No. Confusers x Orientation	24, 216	0.3	5.4	.0001

With respect to the main effect for resolution, the RT for correct rejections was indeed significantly elevated at the 4 ft resolution as compared to 2 ft. The main effect for clutter arose from the progressive increase in RT as the clutter increased from low (M = 3.5, SD = 1.0) to medium (M = 3.9, SD = 1.3) to high (M = 4.9, SD = 1.8). Post hoc correlated t-tests indicated that the RT for correct rejections was significantly higher in the high clutter background as compared to low ($p < .0012$) and medium ($p < .0004$). As was observed in Table 14, the main effect for confusers was a result of the slight tendency for RT to increase as the number of confusers in the scene increased. Follow-up testing revealed that the RT for zero or one confusers was significantly faster than for two or three confusers ($p < .004$ for all four comparisons). No other comparisons were statistically significant ($p > .01$). Finally, with respect to the main effect for vehicle orientation, the RT was elevated at 0° (M = 4.5, SD = 1.6) and 180° (M = 4.2, SD = 1.5) as compared to 45° (M = 3.9, SD = 1.3), 90° (M = 3.8, SD = 1.2), and 135° (M = 3.9, SD = 1.3). Post hoc testing indicated that the RT at 0° was significantly higher when compared to 45° ($p < .001$), 90° ($p < .006$), and 135° ($p < .003$). No other differences were statistically significant ($p > .01$).

The Resolution x Orientation interaction is portrayed graphically in Figure 29. As can be seen in the figure, mean RT for correct rejections at the 4 ft resolution was elevated in comparison to the 2 ft resolution, though the difference tended to decrease as the vehicle orientation increased from 0° to 180°.

The results of post hoc correlated t-tests indicated that the two resolutions differed ($p < .004$) at all orientations except 180°.

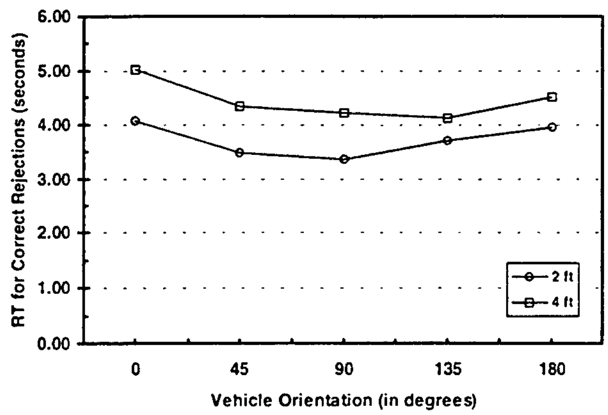


Figure 29: Mean RT for correct rejections as a function of vehicle orientation at the 2 ft and 4 ft resolutions.

The Resolution x Confusers x Orientation interaction is depicted in the two plots of Figure 30. The first plot shows mean RT for correct rejections as a function of vehicle orientation for each number of confusers at the 2 ft resolution. The second plot shows the same relationship at the 4 ft resolution. Inspection of the two plots reveals that there was very little variation among the four numbers of confusers within each orientation at the 4 ft resolution. However, at the 2 ft resolution, there were some noticeable differences at 0° and 180°. Follow-up testing indicated that at the 2 ft resolution, the RT was significantly higher for three confusers as compared to zero, one, and two at orientations of 0° ($p < .0008$) and 90° ($p < .003$). At 45°, only zero and three confusers differed ($p < .0043$). At both 135° and at 180°, zero confusers differed from two and three ($p < .007$), and one confuser differed from three ($p < .009$). Turning to the 4 ft resolution, none of the differences was statistically significant at either 0° or 180°. At 45°, zero confusers differed from two and three ($p < .004$), and one differed from two ($p < .008$). At 90°, zero confusers differed from two and three ($p < .004$). Finally, at 135°, zero confusers differed from two ($p < .01$) and three ($p < .001$), and one confuser differed from three ($p < .002$).

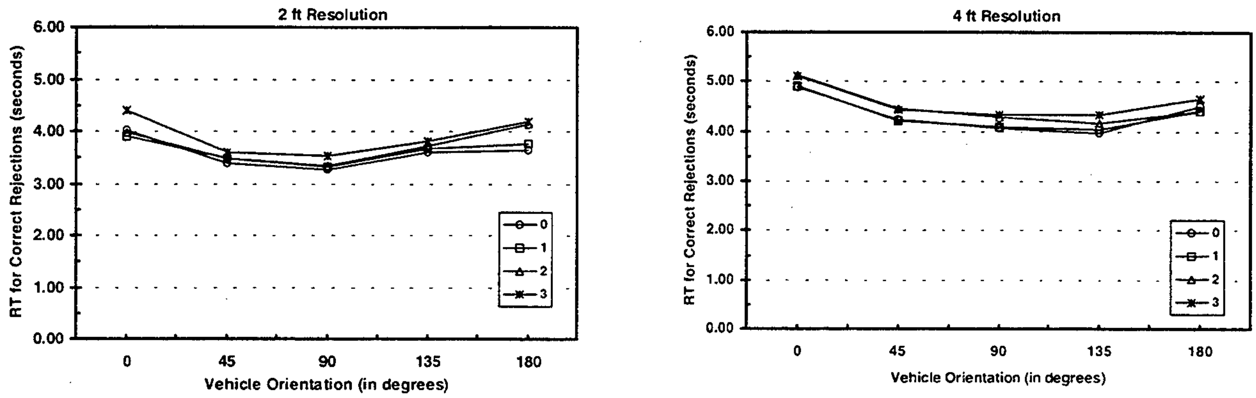
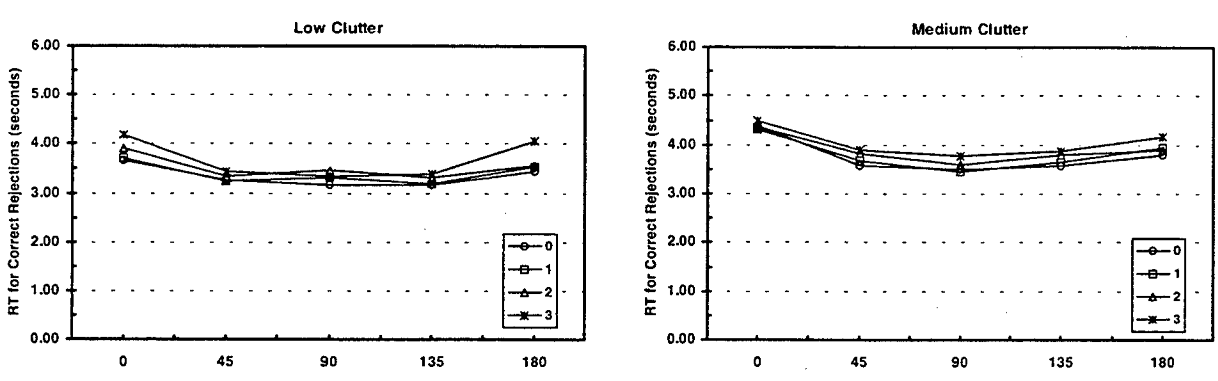


Figure 30: Mean RT for correct rejections as a function of vehicle orientation for each number of confusers at the 2 ft (left) and 4 ft (right) resolutions.

The interaction between clutter, number of confusers, and orientation is portrayed in the three plots of Figure 31. The first plot shows mean RT for correct rejections as a function of vehicle orientation for each number of confusers in the low clutter background. The second plot shows the same relationship in the medium clutter background, and the third plot depicts high clutter. Inspection of the three plots indicates that the RTs for the four numbers of confusers within each orientation were most similar in the medium clutter background. In low clutter, the RT for three confusers was noticeably elevated at 0° and at 180°. In high clutter, the RT for two confusers was inexplicably higher at 180°. A summary of the results of post hoc testing for RT for correct rejections is presented in Table 16. The entries in the table reveal that 20 of the 90 comparisons were statistically significant. Of those, 14 represented significant differences between zero, one, or two confusers versus three confusers, implying that increases in RT for correct rejections will become most widespread when the number of confusers increases to three.



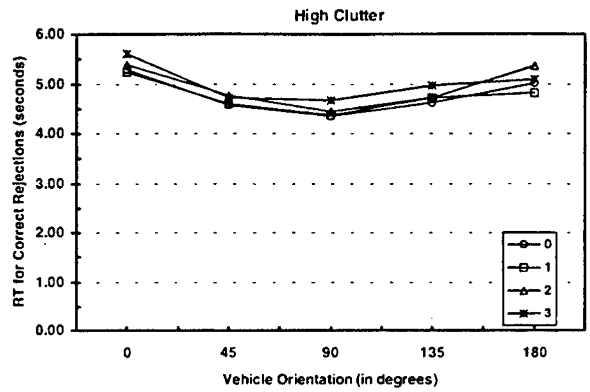


Figure 31: Mean RT for correct rejections as a function of vehicle orientation for each number of confusers in the low (left), medium (right), and high (bottom) clutter backgrounds.

Table 16. Results of Post Hoc Tests for the Clutter x Number of Confusers x Orientation Interaction in the Analysis of RT for Correct Rejections.

		0°			45°			90°			135°			180°		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
L	0	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	*
	1	--	NS	*	--	NS	NS	--	NS	NS	--	*	NS	--	NS	*
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	*
M	0	NS	NS	NS	NS	*	*	NS	NS	*	NS	*	*	NS	NS	*
	1	--	NS	NS	--	NS	NS	--	NS	*	--	*	*	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	*	--	--	NS	--	--	*
H	0	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS	NS
	1	--	NS	NS	--	NS	NS	--	NS	NS	--	NS	NS	--	*	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	NS

* $p < .01$; NS = not significant, $p > .01$

Finally, the ANOVA of RT for correct rejections revealed a significant four-way interaction between resolution, clutter, number of confusers, and orientation. The nature of this interaction can be seen in the six plots of Figure 32. The first three plots show mean RT for correct rejections as a function of vehicle orientation for the four numbers of confusers in the low, medium, and high clutter backgrounds at the 2 ft resolution. The remaining three plots show the same relationships in the low, medium, and high clutter backgrounds at the 4 ft resolution. A summary of the results of post hoc tests for this interaction appear in Table 17 (2 ft resolution) and Table 18 (4 ft resolution). As with the significant four-way interaction in the analysis of RT for hits, most of the significant comparisons occurred at the 2 ft resolution (23 of 90) as opposed to 4 ft (only 13 of 90). Further, at the 4 ft resolution, there were no significant differences at orientations of 0° and 180°. By comparison, at the 2 ft resolution, the significant differences spanned all levels of vehicle orientation.

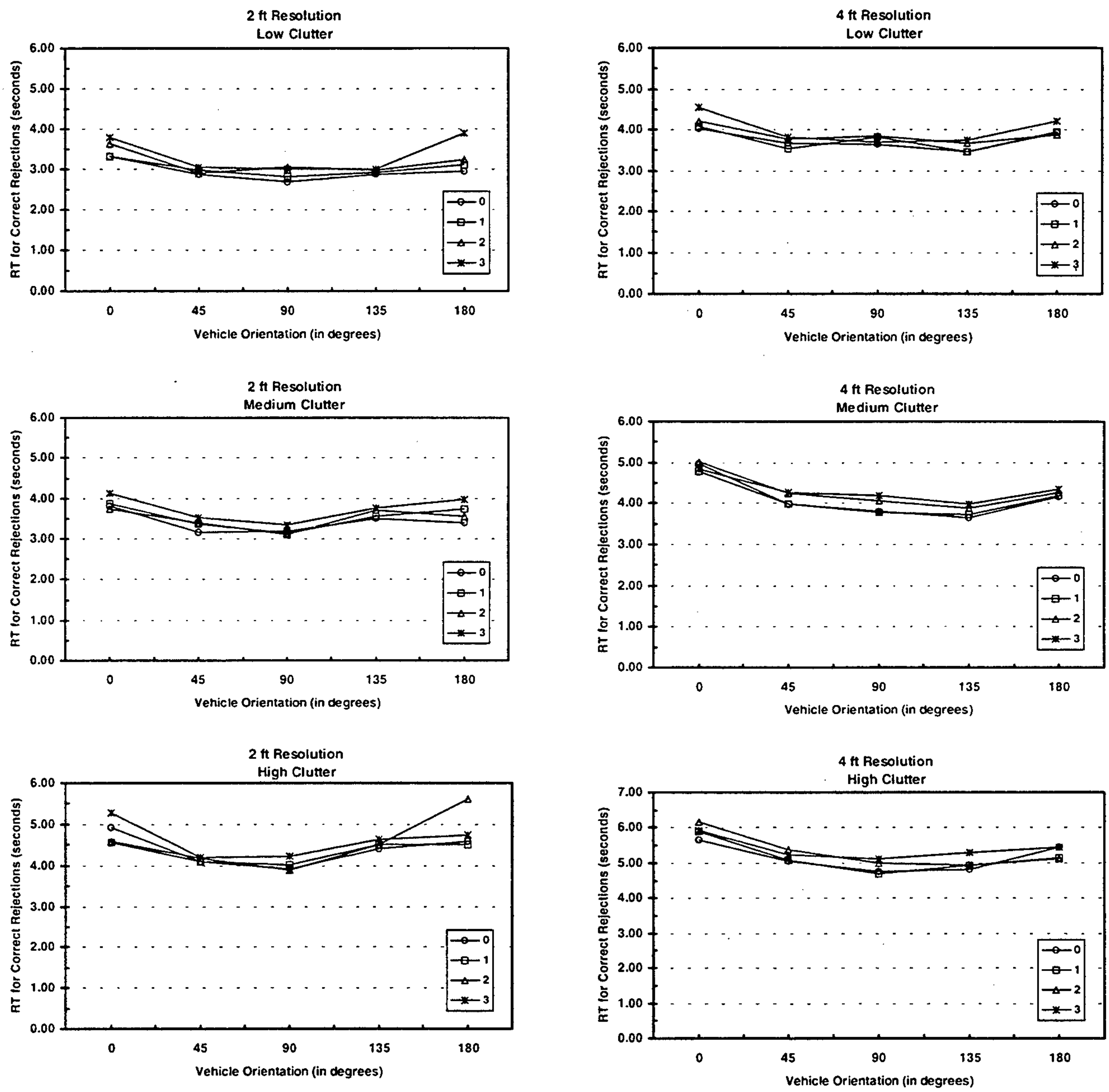


Figure 32: Mean RT for hits as a function of vehicle orientation for each number of confusers at each image resolution and clutter level.

Table 17. Results of Post Hoc Tests for the Resolution x Clutter x Number of Confusers x Orientation Interaction in the Analysis of RT for Correct Rejections (2 ft Resolution).

		0°			45°			90°			135°			180°		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
L	0	NS	*	NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	NS	*
	1	--	*	*	--	NS	NS	--	*	NS	--	NS	NS	--	NS	*
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	*
M	0	NS	NS	NS	NS	*	*	NS	NS	NS	NS	*	*	*	NS	*
	1	--	NS	NS	--	NS	NS	--	NS	NS	--	NS	*	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	*
H	0	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS
	1	--	NS	*	--	NS	NS	--	NS	NS	--	NS	NS	--	*	NS
	2	--	--	*	--	--	NS	--	--	*	--	--	NS	--	--	NS

* $p < .01$; NS = not significant, $p > .01$

Table 18. Results of Post Hoc Tests for the Resolution x Clutter x Number of Confusers x Orientation Interaction in the Analysis of RT for Correct Rejections (4 ft Resolution).

		0°			45°			90°			135°			180°		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
L	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	1	--	NS	NS	--	NS	NS	--	NS	NS	--	NS	NS	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	NS
M	0	NS	NS	NS	NS	NS	*	NS	NS	*	NS	*	NS	NS	NS	NS
	1	--	NS	NS	--	NS	NS	--	*	*	--	NS	NS	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	NS	--	--	NS
H	0	NS	NS	NS	NS	*	*	NS	*	NS	*	NS	*	NS	NS	NS
	1	--	NS	NS	--	*	NS	--	NS	NS	--	NS	*	--	NS	NS
	2	--	--	NS	--	--	NS	--	--	NS	--	--	*	--	--	NS

* $p < .01$; NS = not significant, $p > .01$

<u>RT for Misses and False Alarms.</u>

Because most of the responses made by the operators in this study tended to be correct (i.e., either hits or correct rejections), there were much fewer incorrect responses (i.e., misses and false alarms) available for analysis. In fact, some operators did not make any mistakes in some of the conditions, which meant that RT data for misses and false alarms were missing entirely. Consequently, because of the presence of missing data in some conditions, full factorial analyses of RT for misses and RT for false alarms could not be completed. Instead, only main effects analyses were conducted for each of the four independent variables. The results of these analyses are presented here.

First, none of the main effects for resolution, clutter, number of confusers, or orientation was statistically significant ($p > .05$) in the analyses of RT for false alarms. Second, in the analyses of RT for misses ($N = 9$), only the main effects for clutter and number of confusers were statistically significant. With respect to the main effect for clutter, $F(2,16) = 5.6$, $p < .015$, the RT for misses was much higher in the high clutter background ($M = 8.1$, $SD = 3.6$) as compared to the low ($M = 5.9$, $SD = 3.0$) and medium ($M = 5.6$, $SD = 2.3$) clutter backgrounds. Post hoc correlated t-tests indicated that the discrepancies between the high versus the low and medium clutter scenes were statistically significant, $p < .01$. Regarding the main effect for number of confusers, $F(3, 24) = 3.6$, $p < .03$, the RT for misses was much higher when three confusers were present ($M = 7.8$, $SD = 4.2$) as compared to zero ($M = 6.4$, $SD = 2.6$), one ($M = 5.7$, $SD = 3.0$), and two ($M = 6.4$, $SD = 2.8$). However, because of the high standard deviations associated with the means, none of the differences was statistically significant, $p > .01$.

Comparison of RT for Hits, Correct Rejections, Misses, and False Alarms.

The final analysis of operators' reaction times constituted a comparison of their RTs for hits, correct rejections, misses, and false alarms. In general, a rank ordering of the RTs typically shows that operators are faster when making correct decisions (hits and correct rejections) as compared to incorrect decisions (misses and false alarms; See & Kuperman, 1995). Figure 33 portrays mean reaction times for hits, correct rejections, misses, and false alarms in the present investigation. As can be seen in the figure, reaction times for correct decisions were indeed faster than those for incorrect decisions in this study. Further, RT for hits tended to be faster than RT for correct rejections and RT for misses tended to be faster than RT for false alarms. A one-way ANOVA of the RTs was statistically significant, $F(3,24) = 10.1$, $p < .004$. Follow-up tests indicated that all of the RTs were significantly different from one another at $p < .01$ except for misses and false alarms.

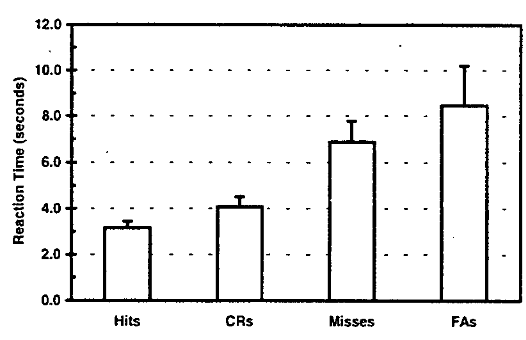


Figure 33: Mean RT for hits, correct rejections, misses, and false alarms.

Operator Confidence Ratings

Although operators were asked to rate their confidence in each target and nontarget decision primarily to provide the data needed to generate ROC curves, we decided to conduct a separate analysis of their ratings to examine the effects of each independent variable on decision confidence alone. When deciding whether or not a TEL was present, operators were asked to respond 1, 2, or 3 if they thought a target was definitely, probably, or possibly not present and 4, 5, or 6 if they thought the TEL was possibly, probably, or definitely present. Hence, their responses represented low, medium, and high levels of confidence in each target and nontarget decision. The target/nontarget confidence ratings were converted to a scale ranging from one (low confidence) to three (high confidence) for subsequent analysis.

Mean confidence ratings in each condition of resolution, clutter, number of confusers, and orientation are presented in Table 19. The overall mean of 2.32 indicates that the operators were somewhat more than moderately confident in their responses. Further, the means in the table reveal that they were more confident when viewing the 2 ft resolution imagery as compared to 4 ft. However, their confidence did not appear to be affected by an increase in the number of confusers present in the scene. Within each level of image resolution, there was a noticeable tendency for the mean confidence rating to be higher at vehicle orientations of 45°, 90°, and 135° as opposed to 0° and 180°. A summary of the ANOVA of the means in Table 19 appears in Table 20. All of the main effects except number of confusers were statistically significant.

Table 19. Mean Confidence Rating (Standard Deviations in Parentheses) in Each Condition.

		NUMBER OF CONFUSERS												
		0			1			2			3			
		BACKGROUND CLUTTER												
RES	ORIENT	L	M	H	L	M	H	L	M	H	L	M	H	MEAN
	0°	1.92	1.84	1.83	2.20	2.16	2.06	1.96	2.01	1.95	1.88	2.01	1.91	1.98
		(0.64)	(0.62)	(0.66)	(0.51)	(0.50)	(0.55)	(0.64)	(0.72)	(0.60)	(0.60)	(0.60)	(0.62)	(0.59)
	45°	2.65	2.65	2.56	2.64	2.58	2.46	2.69	2.67	2.63	2.64	2.63	2.64	2.62
		(0.54)	(0.50)	(0.62)	(0.37)	(0.42)	(0.49)	(0.44)	(0.47)	(0.53)	(0.54)	(0.50)	(0.49)	(0.48)
2 ft	90°	2.86	2.78	2.85	2.76	2.76	2.56	2.84	2.84	2.83	2.85	2.84	2.86	2.80
		(0.29)	(0.35)	(0.31)	(0.36)	(0.36)	(0.44)	(0.31)	(0.34)	(0.34)	(0.31)	(0.37)	(0.31)	(0.34)
	135°	2.69	2.65	2.60	2.68	2.62	2.42	2.67	2.73	2.65	2.67	2.64	2.63	2.64
		(0.47)	(0.51)	(0.54)	(0.36)	(0.44)	(0.52)	(0.49)	(0.44)	(0.48)	(0.50)	(0.54)	(0.49)	(0.47)
	180°	1.97	1.99	1.90	2.34	2.19	2.04	1.95	1.99	1.71	1.99	1.98	1.97	2.00
		(0.60)	(0.61)	(0.66)	(0.42)	(0.46)	(0.54)	(0.63)	(0.63)	(0.49)	(0.64)	(0.58)	(0.64)	(0.57)
	Mean	2.42	2.38	2.35	2.53	2.46	2.31	2.42	2.45	2.35	2.41	2.42	2.40	2.41
		(0.64)	(0.64)	(0.68)	(0.45))	(0.48)	(0.53)	(0.63)	(0.63)	(0.65)	(0.64)	(0.62)	(0.64)	(0.60)
	0°	1.53	1.39	1.43	1.92	1.78	1.63	1.50	1.55	1.46	1.62	1.55	1.54	1.57
		(0.53)	(0.29)	(0.47)	(0.38)	(0.38)	(0.31)	(0.55)	(0.46)	(0.47)	(0.44)	(0.47)	(0.46)	(0.44)
	45°	2.56	2.58	2.57	2.60	2.45	2.36	2.62	2.60	2.51	2.61	2.64	2.61	2.56
		(0.54)	(0.62)	(0.61)	(0.41)	(0.40)	(0.47)	(0.55)	(0.60)	(0.64)	(0.53)	(0.56)	(0.54)	(0.52)
4 ft	90°	2.86	2.82	2.77	2.66	2.64	2.50	2.82	2.81	2.75	2.80	2.79	2.79	2.75
		(0.37)	(0.40)	(0.41)	(0.26)	(0.29)	(0.47)	(0.38)	(0.44)	(0.39)	(0.41)	(0.43)	(0.42)	(0.39)
	135°	2.66	2.61	2.65	2.56	2.51	2.36	2.70	2.62	2.62	2.70	2.64	2.59	2.60
		(0.53)	(0.59)	(0.54)	(0.38)	(0.38)	(0.48)	(0.49)	(0.57)	(0.58)	(0.52)	(0.50)	(0.60)	(0.50)
	180°	1.52	1.50	1.51	2.08	2.04	1.84	1.78	1.70	1.58	1.71	1.74	1.71	1.72
		(0.52)	(0.50)	(0.53)	(0.43)	(0.44)	(0.40)	(0.58)	(0.48)	(0.48)	(0.49)	(0.49)	(0.56)	(0.50)
	Mean	2.23	2.18	2.19	2.37	2.28	2.14	2.28	2.26	2.18	2.29	2.27	2.25	2.24
		(0.76)	(0.77)	(0.77)	(0.47)	(0.49)	(0.54)	(0.73)	(0.72)	(0.74)	(0.69)	(0.70)	(0.72)	(0.68)
		2.32	2.28	2.27	2.45	2.37	2.22	2.35	2.35	2.27	2.35	2.35	2.32	
		(0.70)	(0.71)	(0.73)	(0.47)	(0.49)	(0.54)	(0.68)	(0.68)	(0.70)	(0.67)	(0.66)	(0.68)	
	MEAN		2.29			2.35			2.32			2.34		2.32
			(0.71)			(0.51)			(0.69)			(0.67)		(0.65)

Table 20. Summary of a 2 (resolution) x 3 (clutter) x 4 (no. confusers) x 5 (orientation) ANOVA of Operator Confidence Ratings.

Source	*df*	*MS*	*F*	*p*
Resolution	1, 9	8.2	17.5	.002
Clutter	2, 18	0.97	15.8	.001
No. Confusers	3, 27	0.20	1.1	NS
Orientation	4, 36	52.5	36.5	.0001
Resolution x Clutter	2, 18	0.02	3.3	NS
Resolution x No. Confusers	3, 27	0.03	<1	NS
Resolution x Orientation	4, 36	1.6	9.6	.003
Clutter x No. Confusers	6, 54	0.22	6.0	.006
Clutter x Orientation	8, 72	0.02	1.5	NS
No. Confusers x Orientation	12, 108	0.78	18.3	.0001
Resolution x Clutter x No. Confusers	6, 54	0.01	<1	NS
Resolution x Clutter x Orientation	8, 72	0.01	1.5	NS
Resolution x No. Confusers x Orientation	12, 108	0.07	4.2	.0006
Clutter x No. Confusers x Orientation	24, 216	0.02	1.6	NS
Resolution x Clutter x No. Confusers x Orientation	24, 216	0.01	1.2	NS

With respect to the main effect for resolution, operator confidence was indeed significantly higher at the 2 ft resolution as compared to 4 ft. The main effect for background clutter revealed that confidence tended to be higher in low ($M = 2.37$, $SD = 0.40$) and medium clutter ($M = 2.34$, $SD = 0.40$) as compared to high ($M = 2.27$, $SD = 0.43$). The results of post-hoc correlated t-tests indicated that both low and medium clutter differed significantly from high clutter, $p < .003$. Finally, the main effect for orientation could be seen in lower confidence at orientations of 0° ($M = 1.78$, $SD = 0.48$) and 180° ($M = 1.86$, $SD = 0.50$) as compared to 45° ($M = 2.59$, $SD = 0.50$), 90° ($M = 2.78$, $SD = 0.35$), and 135° ($M = 2.62$, $SD = 0.48$). Post hoc testing revealed that confidence at 0° and 180° did indeed differ significantly from operator confidence at the oblique and broadside orientations, $p < .0003$ in each case. No other differences were statistically significant.

The Resolution x Orientation interaction is portrayed in Figure 34. As can be seen in the figure, operator confidence was nearly identical at the 2 ft and 4 ft resolutions when vehicle orientation was 45°, 90°, or 135°. However, at orientations of 0° and 180°, operator confidence was noticeably higher at the 2 ft resolution. In fact, follow-up testing indicated that the two levels of image resolution within each orientation differed significantly only at the head-on and tail-on orientations, $p < .006$.

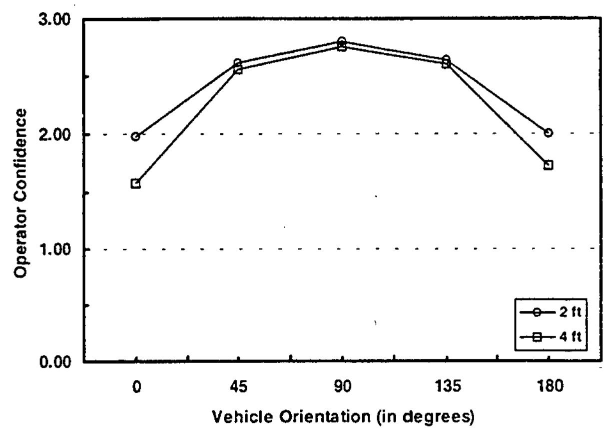


Figure 34: Mean operator confidence as a function of vehicle orientation at the 2 ft and 4 ft resolutions.

The interaction between clutter and number of confusers is portrayed in Figure 35, which shows that confidence did not vary in the low, medium, and high clutter backgrounds when zero or three confusers were present. On the other hand, when one confuser was present, confidence appeared to be higher in the low and medium clutter backgrounds as compared to high. A similar situation occurred when two confusers were present, though the difference was smaller. The results of post-hoc correlated *t*-tests indicated that operator confidence was indeed significantly higher in the low and medium clutter backgrounds as opposed to high clutter when one or two confusers were present, $p < .008$ in each case. No other differences were statistically significant.

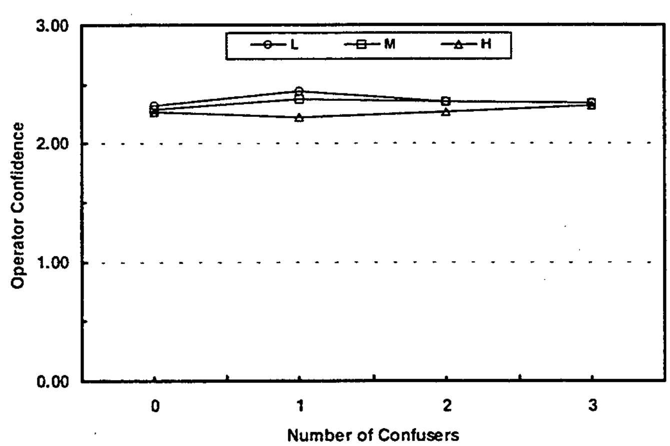


Figure 35: Mean operator confidence as a function of number of confusers for the low (L), medium (M), and high (H) clutter backgrounds.

The Number of Confusers x Orientation interaction is depicted in Figure 36. The plot in Figure 36 shows that operator confidence was highest when one confuser was present at vehicle orientations of 0° and 180°. However, at the remaining three orientations, confidence was lowest when one confuser was present. Follow-up testing revealed no significant differences among the four numbers of confusers at orientations of 45° and 135°. At 0°, the zero-one ($p < .0004$), zero-two ($p < .0052$), and one-two ($p < .0059$) differences were significant. At 90°, the zero-one ($p < .0034$), one-two ($p < .0075$), and one-three ($p < .0045$) differences were significant. And at 180°, the zero-one ($p < .0005$) and one-two ($p < .0036$) differences were significant.

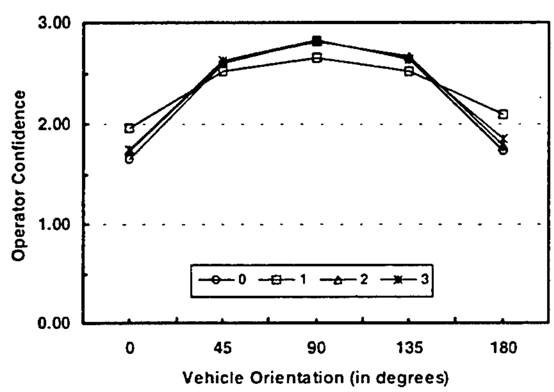
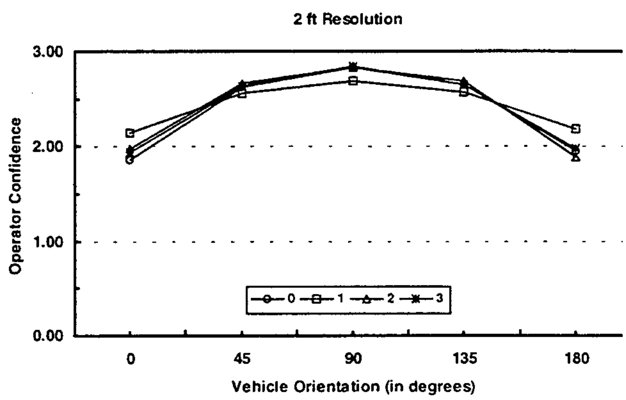


Figure 36: Mean operator confidence as a function of vehicle orientation for each number of confusers.

The three-way interaction between resolution, number of confusers, and orientation is portrayed in the two plots of Figure 37. The first plot shows mean operator confidence as a function of vehicle orientation for each number of confusers at the 2 ft resolution. The second plot shows the same relationship at the 4 ft resolution. In general, the two plots show that confidence tended to be highest when one confuser was present at orientations of 0° and 180°. At the remaining three orientations, confidence was lowest when one confuser was present. This trend appeared at both the 2 ft and 4 ft resolutions, but was more pronounced at 4 ft. The results of post-hoc correlated t-tests showed that at the 2 ft resolution and an orientation of 0°, the zero-one ($p < .0086$) and zero-two ($p < .0024$) differences were significant; at 180°, only the one-two difference attained significance ($p < .0018$). No other differences were statistically significant at the 2 ft resolution. At the 4 ft resolution, the zero-one, one-two, and one-three differences were significant at orientations of 0° and 90° ($p < .01$ in each case). At 180°, one confuser differed significantly from zero ($p < .0001$) and two ($p < .0097$).



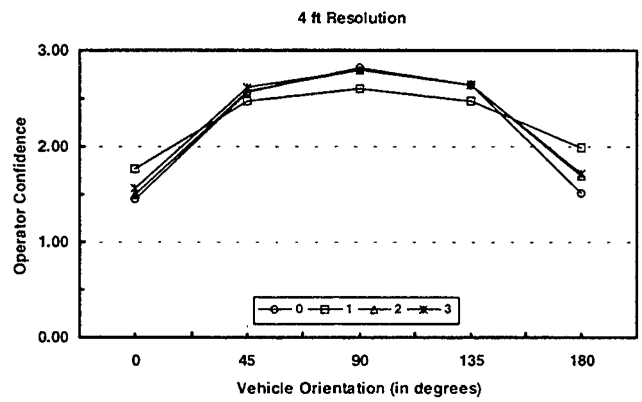


Figure 37: Mean operator confidence as a function of vehicle orientation for each number of confusers at the 2 ft (left) and 4 ft (right) resolutions.

Receiver Operating Characteristic Curves

To portray the tradeoffs between hits and false alarms as operator response bias shifts from conservative to lenient, ROC curves were generated from operators' confidence rating data in the present study. In doing so, the original six-point rating scale was retained to provide five operating characteristic points on each curve. Because these are continuous curves that begin at hit/false alarm proportions of (0,0) and end at (1,1), they are particularly useful for estimating tradeoffs beyond what actually occurred in the empirical investigation. In this section, ROC curves for resolution, clutter, number of confusers, and orientation are depicted. Additional curves for each two-way, three-way, and four-way interaction can be found in the appendices.

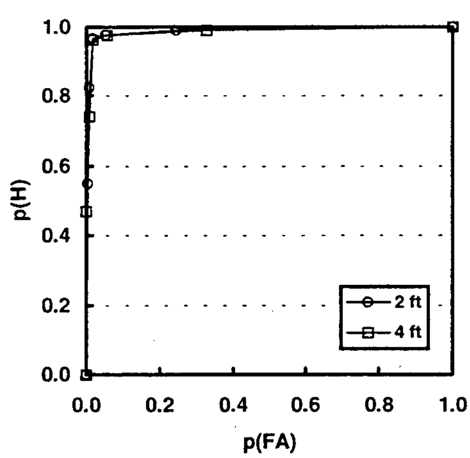


Figure 38: ROC curves for resolution.

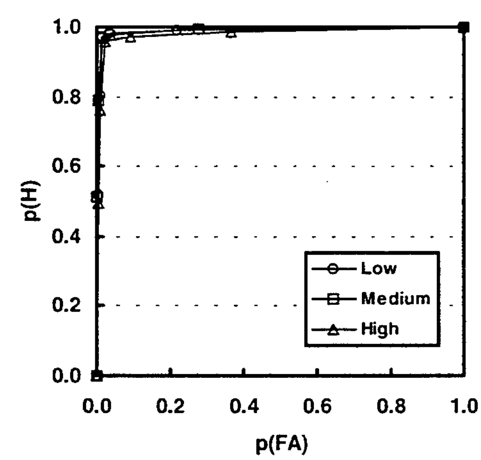


Figure 39: ROC curves for background clutter.

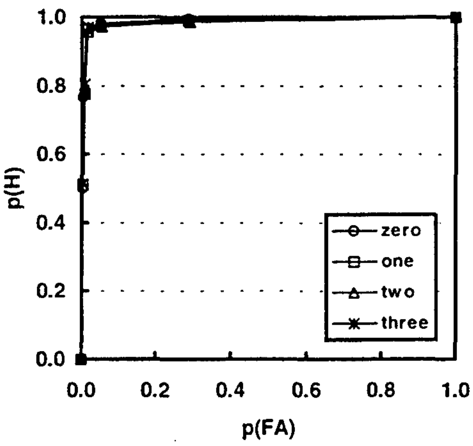


Figure 40: ROC curves for number of confusers.

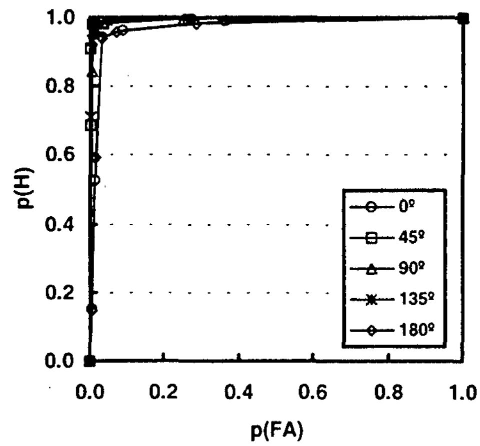


Figure 41: ROC curves for vehicle orientation.

As can be seen by examining the ROC curves for each main effect, overall performance was quite good. All of the curves were located in the upper left corner of the ROC space, signifying high d' scores at all levels of each independent variable. In particular, the ROC curves for resolution show that the 2 ft and 4 ft resolutions were virtually indistinguishable from each other (Figure 38). A similar situation can be seen in the ROC curves for number of confusers (Figure 40). With respect to background clutter, on the other hand, there was a slight difference between the curves for low and high clutter (Figure 39). The curve for low clutter was positioned slightly higher in the upper left corner than the curve for high clutter, implying that operator sensitivity was somewhat greater in the low clutter scenes. Finally, the ROC curves for orientation in Figure 41 show that the curves for 45°, 90°, and 135° were located above the curves representing 0° and 180°. This relationship signifies that the task of target detection was relatively easier when the vehicle was positioned broadside or obliquely as opposed to either head-on or tail-on. It should be emphasized, however, that even the differences associated with background clutter and vehicle orientation were exceedingly small. For example, when the orientation was 0°, a false alarm rate of 5% was accompanied by a hit rate of about 95%. When the orientation was 90°, the same false alarm rate was accompanied by a higher hit rate of 99%.

Summary of Results

In summary, the effects of resolution, clutter, number of confusers, and vehicle orientation on operators' hits, false alarms, sensitivity, bias, RT for hits, RT for correct rejections, and decision-making confidence were assessed by means of four-way repeated-measures ANOVAs and post-hoc correlated t-

tests. The outcomes of these statistical analyses indicated first that image resolution affected decision-making time and confidence only and not performance accuracy per se. Specifically, the RT for both hits and correct rejections was elevated and confidence was poorer at the 4 ft resolution as compared to 2 ft. However, there were no statistically significant differences in hits, false alarms, sensitivity, or response bias between the two resolutions. Second, the effects of background clutter could be seen in operators' sensitivity to TEL target detection and localization, their RT for both hits and correct rejections, and their decision-making confidence. Sensitivity was significantly poorer in the high clutter background than in low clutter, and RT was slower and confidence was lower in high clutter as compared to low and medium. Third, with respect to the independent variable of primary interest in this study, the number of confusers did not impact operator performance accuracy or confidence; however, the RT for hits and correct rejections was affected. Namely, for both dependent variables, the RT was slower when two or three confusers were present as opposed to when only zero or one appeared in the scene. Fourth, vehicle orientation affected perceptual sensitivity, RT for hits, RT for correct rejections, and confidence. In general, performance accuracy, reaction time, and confidence tended to be poorer at orientations of 0° and 180°; sensitivity was significantly reduced at 0° and 180° as compared to 45° and 135°; the RT for hits was slower at 0° and 180° as compared to 45°, 90°, and 135°; the RT for correct rejections was worse at 0° as compared to 45°, 90°, and 135°; and confidence was significantly lower at orientations of 0° and 180° as compared to 45°, 90°, and 135°.

Finally, three of the eleven interactions are worth mentioning. The Clutter x Orientation interaction was statistically significant in all analyses except the RT for correct rejections and operator confidence. The interactions stemmed from a tendency for performance to deteriorate in the high clutter background at vehicle orientations of 0° and 180°. For example, false alarms were higher and operator sensitivity was significantly lower in high clutter as compared to low and medium at a vehicle orientation of 180°. At an orientation of 0°, the proportion of hits was lower in high clutter as opposed to low and the RT for hits increased progressively as the background clutter increased.

The Resolution x Number of Confusers x Orientation interaction was statistically significant in all analyses except response bias. For hits, false alarms, and sensitivity, the interactions resulted from differences among the number of confusers at the 2 ft resolution when the vehicle orientation was 180°. For instance, in this condition, false alarms were higher when two confusers were present as compared to zero, one, and three; and sensitivity was greater for zero confusers as compared to two. Both hits and sensitivity were also inexplicably higher when three confusers were present as compared to two. With respect to RT for hits and correct rejections, the interactions involved differences among the number of confusers within each orientation at both the 2 ft and 4 ft resolutions. When significant differences occurred, they always revealed a slower reaction time for the higher number of confusers. The three-way interaction was somewhat unique with regard to operator confidence. In general, for both the 2 ft and 4 ft resolutions, operator confidence tended to be highest when one confuser was present at orientations of 0° and 180°.

And, last, the Clutter x Number of Confusers x Orientation interaction was significant in all of the analyses except confidence. For hits, false alarms, sensitivity, and response bias, the interactions occurred as a result of performance in the high clutter background at a vehicle orientation of 180°. In this condition, performance tended to be worst when two confusers were present: both hits and sensitivity were lower for two confusers as compared to one and three; false alarms were higher for two confusers as compared to zero and three; and bias was more conservative for two confusers as opposed to three. For the RT variables, on the other hand, the interactions stemmed from variations among the number of confusers within each orientation in all of the backgrounds. Again, when significant differences occurred, they always indicated that reaction time was slower for the higher number of confusers.

DISCUSSION

As described in the Introduction, the purpose of the present study was to quantify the effects of the presence of confusers on TEL target detection and localization performance with SAR imagery, primarily in terms of the signal detection theory measures of sensitivity and bias. A secondary goal was to examine the impact of TEL orientation on performance effectiveness. Finally, the effects of background clutter and image resolution were also studied. We expected that performance effectiveness would decline 1) as the number of confusers in the scene increased, 2) as the orientation deviated from a 90° broadside view of the TEL, 3) as the background clutter increased, and 4) as the resolution deteriorated from 2 ft to 4 ft.

Effects of Confusers on TEL Target Detection and Localization Performance.

With respect to the primary independent variable of interest, the results indicated that the number of confusers did not impact operator hits, false alarms, sensitivity, bias, or decision-making confidence. The effects of number of confusers could be seen only in operators' reaction times to the images. Specifically, both RT for hits and RT for correct rejections were slower when two or three confusers were present in a scene as opposed to when only zero or one appeared. This outcome in and of itself does not necessarily imply a detrimental effect of confusers on performance since reaction time naturally increases as the number of objects to be inspected increases, regardless of whether or not they are confusers. Hence, the slower reaction times when two or more confusers were present may be attributable solely to the need to examine more objects before reaching a decision as opposed to requiring additional time to decide which object was the TEL target. Along these lines, it is noteworthy that decision-making time did not differ between target-only scenes (zero confusers) and target-plus-one-confuser scenes. When only a single confuser was present in a target scene, operators were still able to determine quickly which object was the TEL (i.e., the presence of the confuser did not significantly increase total reaction time and operators apparently did not need more time to reach a target/nontarget decision when the confuser was present). It was only when two or more confusers were present that RT increased, most likely as a consequence of the simple need to examine more objects. Thus, our hypothesis that performance effectiveness would decline as the number of confusers increased was only partially supported by the results.

Recall that previous literature has shown that the time to acquire a target increases and performance accuracy deteriorates as the number of confusers increases (Greening, 1974). The results of the present study concur in terms of the increase in reaction time but not with regard to performance accuracy. The reasons for this apparent discrepancy may lie in the very definition of what is and what is not a confuser. First, according to Greening (1974), a confuser can be thought of as an object that resembles the target to a greater or lesser degree. He further indicates that the distinction between clutter and confusers is not always clear-cut in the real world. In general, he regards clutter as more or less homogeneous aspects of the background that can readily be dismissed as nontargets. A confuser is any part of the background that resembles the target closely enough to warrant further examination. With this in mind, the M-548 cargo truck can indeed be considered a confuser rather than clutter because it did resemble the target to some degree, though this degree was lesser rather than greater. As noted in the Results, when operators believed a target to be present in the image, they correctly selected the TEL 99.3% of the time and incorrectly chose the confuser only 0.5% of the time. Hence, it would seem that the absence of an effect of number of confusers on performance accuracy was due in part to only a very slight resemblance of the confuser to the target. That is, while the M-548 was a confuser vehicle, it was not particularly confusing.

Further evidence along these lines comes from a more structured analysis of the similarity between the TEL and the M-548 cargo truck akin to the type conducted by O'Kane, Biederman, Cooper, and Nystrom (1997). As discussed earlier, their investigations indicated that a similarity metric based on the magnitude and number of viewpoint-invariant part differences (e.g., wheeled versus tracked; presence or absence of a cargo bed; presence or absence of a gun) between a pair of vehicles was significantly related to performance effectiveness. If we examine the number of viewpoint-invariant part differences between the TEL and M-548, we see that the two vehicles were actually not very similar at all. First and foremost, the TEL is wheeled whereas the M-548 is tracked. This alone would place the vehicles on opposite sides of the trunk in O'Kane et al.'s (1997) similarity tree (making them more dissimilar than similar). Further, the TEL has a missile on the back of the vehicle and the M-548 has a gun at the front. Finally, the M-548 has a cargo bed and the TEL does not. Thus, according to O'Kane et al.'s analysis, these are two vehicles that are not very likely to be confused because they are rather far apart on the similarity tree.

Of course, the efficacy of this similarity metric is based on the premise that the distinguishing characteristics between the two vehicles are prominent in the imagery. It may be the case that the imagery is so poor (e.g., the 4 ft resolution) that only size and shape are apparent. If this happens, operators would have to depend not on the viewpoint-invariant parts but on the less reliable metric properties of the vehicles. In this regard even, the two vehicles were more dissimilar than similar; the TEL is approximately 13 m long whereas the M-548 is only about 6 m long. We should note that the M-548 was selected as the confuser vehicle because it was explicitly designated as a TEL confuser in the MSTAR database and is also frequently regarded as such in the ATR community. However, as was evidenced in the present study, the TEL was actually easily distinguishable from the M-548 confuser vehicle (except possibly at tail-on or head-on orientations).

Effects of Vehicle Orientation on TEL Target Detection and Localization Performance.

In fact, the results did indicate that TEL target detection and localization performance was most problematic at orientations of 0° (head-on) and 180° (tail-on) as opposed to 45°, 90°, and 135°. Operator sensitivity was significantly reduced at 0° and 180° as compared to 45° and 135°; the RT for hits was slower at 0° and 180° as compared to 45°, 90°, and 135°; the RT for correct rejections was worse at 0° as compared to 45°, 90°, and 135°; and confidence was significantly lower at orientations of 0° and 180° as compared to 45°, 90°, and 135°. Further, in the significant interactions involving vehicle orientation, 0° and 180° invariably emerged as the orientations associated with the worst performance. The relative difficulty of the task at the head-on and tail-on orientations most likely resulted from the fact that the features distinguishing the TEL from the M-548 were more difficult to discern at 0° and 180°. In the broadside and oblique views of the TEL, the size difference was more readily apparent as was the difference in the radar returns of the two vehicles. Specifically, the machine gun mounted on the top of the M-548's cab produced a noticeable "tail" in its return, which was completely different from the TEL's radar return. This "tail" was least visible when the M-548 was oriented at 0° or 180°, which made it more difficult to distinguish between the TEL and the confuser at those orientations and thereby produced somewhat poorer performance.

These outcomes are noteworthy because they provide the first empirical evidence of the effects of orientation on TEL target detection and localization performance. As described in the Introduction, studies of orientation to date have focused on ship recognition rather than ground targets. While the outcomes of ship recognition studies may generalize to some extent to studies of target acquisition with land vehicles, the results of the present study indicate that they may not wholly apply. For example, the maritime studies demonstrated a clear advantage for a 90° ship orientation over orientations ranging from 10° off bow up to 90° (Mocharnuk, Gaudio, & Suwe, 1981; Whitehurst, 1976). Although the broadside view of the TEL was superior to head-on and tail-on views in the present investigation, it was not superior to the oblique orientations of 45° and 135°. In general, performance effectiveness did not differ significantly among orientations of 45°, 90°, and 135°. The difference in outcomes between the present study and those of the ship recognition studies may also have been due in part to the different types of imagery used in each investigation. Mocharnuk, Gaudio, and Suwe (1981) used simulated IR imagery and Whitehurst (1976) used television imagery, whereas we used simulated SAR imagery. Due to geometry and viewing angle, there was relatively less information in the IR and television imagery as the targets deviated from a broadside view than would be true for SAR imagery. Because SAR imagery provides a "plan view" (Toomay, 1998), it always displayed the imaged area as if viewed from directly overhead. As vehicle orientation changed, the SAR imagery changed due to radar reflecting off different surfaces; hence, what could not be seen due to occlusion with IR or television imagery was marked with a shadow in radar. In sum, both differences in the type of imagery (i.e., SAR, IR, television) and the type of vehicles (i.e., land versus sea) used may have contributed to the discrepancies in outcomes between our study and previous examinations of vehicle orientation.

Effects of Resolution and Background Clutter on TEL Target Detection and Localization Performance.

Finally, in addition to the effects of number of confusers and vehicle orientation, the impact of image resolution and background clutter on TEL target acquisition was also examined in the current study. Image resolution affected operators' reaction times to the imagery and their decision-making confidence only and not their ability to detect and locate the TEL itself. Operators took slightly longer to reach a decision at the 4 ft image resolution as compared to 2 ft, and they had less confidence in that decision. While this outcome is not unexpected, it only partially supports our hypothesis since we also expected to see some variations in hits, false alarms, or sensitivity. As described earlier, previous studies have demonstrated that performance accuracy typically improves along with improvements in the resolution (Davis, See, Shacklett, & Kuperman, 1996; Kuperman, Wilson, & Davis, 1993; Kuperman, Wilson, & Perez, 1988; See & Kuperman, 1995). In the Davis et al. (1996) study, for example, sensitivity was significantly higher and false alarms were lower at a resolution of 4 ft as compared to 8.5 ft. Comparable outcomes may not have emerged in the present study due to the exceptionally high level of performance accuracy. Overall, the mean proportion of hits was .93 and the mean proportion of false alarms was only .04, indicating that operators were very accurate and made few mistakes. Further, the mean level of sensitivity, $d' = 3.4$, indicated that the task lay within a moderately easy range rather than difficult.

With respect to background clutter, operator sensitivity was significantly poorer in the high clutter background as opposed to low clutter. In addition, both RT for hits and RT for correct rejections were slower and confidence was poorer in high clutter as compared to medium and low. These findings concur with the results of previous investigations, which have demonstrated that performance typically deteriorates as the amount of background clutter in a scene increases (Cole & Hughes, 1984; Davis, See, Shacklett, & Kuperman, 1996; Kuperman, Wilson, & Perez, 1988; See, Davis, & Kuperman, 1997; See & Kuperman, 1995).

We should note here that clutter was defined as the number of trees per image in the present study rather than the number of trees per square mile, as in previous studies (e.g., See & Kuperman, 1995). Thus, increases in background clutter were represented as increments in the number of trees from 15 (low) to 45 (medium) to 135 (high). Hence, as the number of trees increased, the image appeared to be more cluttered. However, when image resolution is simultaneously taken into account, the low, medium, and high levels of clutter may not have been comparable between the 2 ft and 4 ft resolutions, precisely because clutter was defined as the number of trees per image. Since image size remained constant, the image covered a much larger area as the resolution worsened from 2 ft to 4 ft. Thus, the same number of trees appeared to occupy much less space, creating more open expanses in the image. This effect was particularly visible at the highest clutter level. At the 2 ft resolution, 135 trees occupied most of the image, making it appear extremely cluttered. At the 4 ft resolution, however, the amount of open space was relatively greater, potentially making it easier to detect any vehicles that might be present. In fact, there was a tendency for hits and sensitivity to be higher at the 4 ft resolution when clutter was high, though this difference was not significant. In future studies that simultaneously examine both resolution and clutter, background clutter should best be defined in terms of the area covered.

Future Research.

First, future research should seek to examine further the effects of confusers on TEL target acquisition and augment the present findings by using vehicles that are potentially more confusing than the M-548. One candidate is the M-520, a cargo truck whose size (9.8 m long) more closely emulates that of the TEL (13 m long) than is true for the M-548 (6 m long). In addition, the M-520, like the TEL, is a wheeled vehicle. While the present study was being completed, a CAD model of the M-520 became available through the MSTAR database, enabling it to be used in future examinations of TEL confusers.

Second, future work should test the ideas of Duncan and Humphreys (1989) for applicability to real-world tasks such as TEL target acquisition in the presence of more than one type of confuser. As described in the Introduction, Duncan and Humphreys demonstrated that the effects of both T/NT similarity and NT/NT similarity must be taken into account when assessing the effects of confusers on target detection performance. Specifically, they showed that search difficulty increased as T/NT similarity increased and as NT/NT similarity decreased. Further, the most rapid search times occurred when the target and nontargets were dissimilar and all of the nontargets were similar. Because only one type of confuser was used in the current study, the direct applicability of these outcomes could not be evaluated with regard to TEL target acquisition. The effects of confuser *orientation* similarity could have been explored had we had sufficient imagery. However, our primary interest was in the effects of TEL orientation on target acquisition performance. The orientations of the confusers, when present, varied randomly; hence, in some images, two or more confusers had the same orientation. In such cases, the spreading suppression proposed by Duncan and Humphreys should presumably be exceptionally strong: the nontargets not only represent the same type of vehicle but also have radar returns that are identical in every way. Unfortunately, there was not enough imagery to study this effect in isolation. Further examination of the effects of NT/NT similarity in terms of both confuser type and confuser orientation could prove to be useful, particularly since it is not known whether Duncan and Humphreys' (1989) results generalize to real-world tasks.

Finally, future work should also examine the effects of TEL confusers on eye gaze behavior, as in studies conducted by Boersema, Zwaga, and Adams (1989) and Boersema and Zwaga (1993). Their investigations showed that observers' scanning patterns were less efficient when confusers were present. Observers took longer to locate a target sign and made more eye fixations as the number of confuser advertisements in the scene increased. However, not all of the extra eye fixations actually fell on the confusers, implying that the extra time was spent not just in looking at the additional confusers but in looking less efficiently at the scene in general. Future endeavors should seek to determine if these notions apply to the acquisition of TEL targets when confusers are present. Subsequent work might then focus on the development of training methods to improve scanning patterns.

CONCLUSIONS

1. In terms of hits, false alarms, perceptual sensitivity, response bias, and operator confidence, TEL target acquisition performance was unaffected as the number of M-548 confusers increased from zero to four.
2. Reaction time was somewhat slower (approximately 300 milliseconds) when two or more M-548 confusers were present as compared to when only zero or one confusers appeared in the scene.
3. TEL target acquisition performance was superior and confidence was higher at vehicle orientations of 45°, 90°, and 135° as opposed to 0° (head-on) and 180° (tail-on).
4. Decision-making time was slower and confidence was poorer at an image resolution of 4 ft as compared to 2 ft.
5. Perceptual sensitivity, reaction time, and confidence were all degraded when the background clutter was high.
6. Future work should examine the effects of confusers on TEL target acquisition by using:
   a) a confuser such as the M-520 that more closely resembles the TEL
   b) more than one type of confuser vehicle to examine the effects of T/NT and NT/NT similarity on TEL target acquisition
   c) equipment to assess eye gaze behavior when confusers are present

REFERENCES

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review, 94,* 115-147.

Birkmire, D. P., Karsh, R., Barnette, B. D., Pillalamarri, R., & Breintenbach, F. W. (1991). *Perceptibility of military vehicle silhouettes* (Technical Memorandum 2-91). Aberdeen Proving Ground, MD: Human Engineering Laboratory.

Boersema, T., & Zwaga, H. J. G. (1985). The influence of advertisements on the conspicuity of routing information. *Applied Ergonomics, 16,* 267-273.

Boersema, T., & Zwaga, H. J. G. (1993). Compatibility of simplified and realistic stimulus fields in visual search. In D. Brogan, A. Gale, & K. Carr (Eds.), *Visual search 2* (pp. 409-417). London: Taylor & Francis.

Boersema, T., Zwaga, H. J. G., & Adams, A. S. (1989). Conspicuity in realistic scenes: an eye-movement measure. *Applied Ergonomics, 20,* 267-273.

Cole, B. L., & Hughes, P. K. (1984). A field trial of attention and search conspicuity. *Human Factors, 26,* 299-313.

Craig, A. (1984). Human engineering: The control of vigilance. In J. S. Warm (Ed.), *Sustained attention in human performance* (pp. 247-291). Chichester, U.K.: Wiley.

Davis, I., See, J. E., Shacklett, S. L., & Kuperman, G. G. (1996). *Unaided target acquisition performance with enhanced APG-70 synthetic aperture radar: A signal detection theory analysis* (Report No. AL/CF-TR-1996-0104). Wright-Patterson Air Force Base, OH: Armstrong Laboratory.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96,* 433-458.

Fulghum, D. A. (1994). Scud hunting may drop under 10-minute mark. *Aviation Week and Space Technology, 140 (8),* 90.

Gescheider, G. A. (1985). *Psychophysics: Method, theory, and application* (2nd ed.). Hillsdale, NJ: Erlbaum.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics.* New York: Wiley.

Greening, C. P. (1974). *Modeling visual target acquisition: Inclusion of certain psychological variables* (Report No. NWC TP 5690). China Lake, CA: Naval Weapons Center.

Hacker, M. J., & Ratcliff, R. (1979). A revised table of d' for M-alternative forced choice. *Perception & Psychophysics, 26,* 168-170.

Holahan, C. J., Culler, R. E., & Wilcox, B. L. (1978). Effects of visual distraction on reaction time in a simulated traffic environment. *Human Factors, 20,* 409-413.

Huynh, H., & Feldt, L. S. (1970). Conditions under which mean square ratios in repeated measurements designs have exact *F*-distributions. *Journal of the American Statistical Association, 65,* 1582-1589.

Huynh, H., & Feldt, L. S. (1976). Estimation of the Box correction for degrees of freedom from sample data in randomized block and split-plot designs. *Journal of Educational Statistics, 1,* 69-82.

Kuperman, G. G., Wilson, D. L., & Davis, I. (1993). *High resolution radar demonstration program: Operator performance study* (Report No. AL-TR-1993-0032). Wright-Patterson Air Force Base, OH: Armstrong Laboratory.

Kuperman, G. G., Wilson, D. L., & Perez, W. A. (1988). *Relocatable target acquisition performance with simulated synthetic aperture radar imagery* (Report No. AAMRL-TR-88-025). Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.

Macmillan, N. A., & Creelman, C. D. (1991). *Detection theory: A user's guide.* Cambridge: Cambridge University Press.

Mocharnuk, J. B., Gaudio, D. F., & Suwe, C. L. (1981). Imaging infrared ship target acquisition studies. *Human Factors, 23,* 561-580.

O'Kane, B. L., Biederman, I., Cooper, E. E., & Nystrom, B. (1997). An account of object identification confusions. *Journal of Experimental Psychology: Applied, 3,* 21-41.

Pashler, H. (1987). Target-distractor discriminability in visual search. *Perception & Psychophysics, 41,* 285-292.

See, J. E., Davis, I., & Kuperman, G. G. (1997). *Automatic target cueing and operator performance with enhanced APG-70 synthetic aperture radar imagery* (Report No. AL/CF-TR-1997-0171). Wright-Patterson Air Force Base, OH: Armstrong Laboratory.

See, J. E., & Kuperman, G. G. (1995). *The effects of resolution and other factors on target acquisition performance using simulated synthetic aperture radar imagery* (Report No. AL/CF-TR-1995-0149). Wright-Patterson Air Force Base, OH: Armstrong Laboratory.

Starr, S. J., Metz, C. E., Lusted, L. B., & Goodenough, D. J. (1975). Visual detection and localization of radiographic images. *Radiology, 116,* 533-538.

SS-1 'Scud' (R-11/8K11, R-11FM (SS-N-1B) and R-17/8K14) (September 1996). *Jane's weapon systems,* Issue 22.

Swensson, R. G., & Judy, P. F. (1981). Detection of noisy visual targets: Models for the effects of spatial uncertainty and signal-to-noise ratio. *Perception & Psychophysics, 29,* 521-534.

Swets, J. A., Pickett, R. M., Whitehead, S. F., Getty, D. J., Schnur, J. A., Swets, J. B., & Freeman, B. A. (1979). Assessment of diagnostic technologies. *Science, 205,* 753-759.

Toms, M. L., & Kuperman, G. G. (1991). *Sensor fusion: A human factors perspective* (Report No. AL-TR-1991-0152). Wright-Patterson Air Force Base, OH: Armstrong Laboratory.

Toomay, J.C. (1998). *Radar principles for the non-specialist* (2nd ed.). Mandham, NJ: SciTech Publishing.

United defense M548 tracked cargo carrier (1996-97). *Jane's military vehicles and logistics.*

Whitehurst, H. O. (1976). *Ship recognition range on television: Effects of sun position, ship orientation, and wake size* (NWC Technical Memorandum 2964). China Lake, CA: Naval Weapons Center.

Wilson, D. L. (1992). *Theory of signal detection and its application to visual target acquisition: A review of the literature* (Report No. AL-TR-1992-0083). Wright-Patterson Air Force Base, OH: Armstrong Laboratory.

APPENDIX A

ROC CURVES FOR TWO-WAY INTERACTIONS

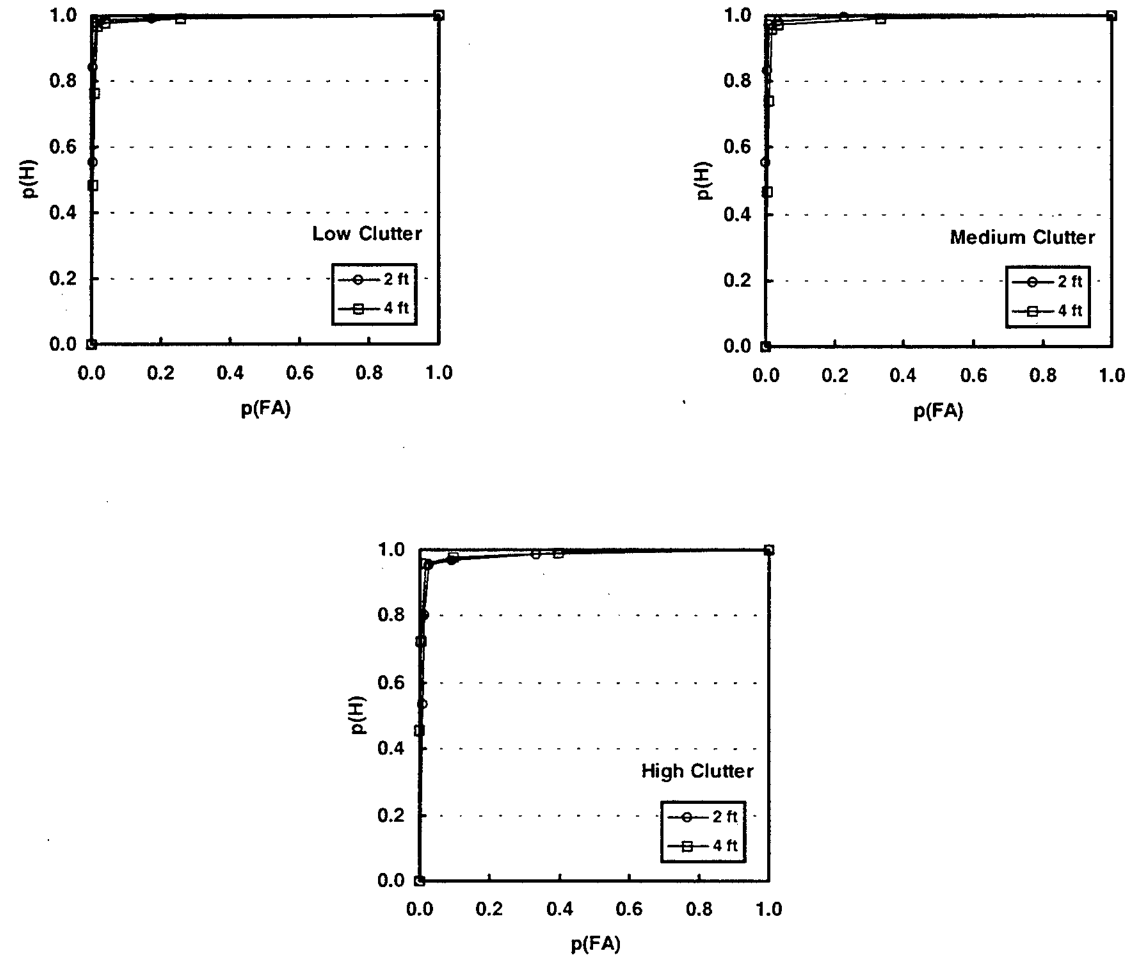


Figure A 1: ROC curves for Clutter x Orientation.

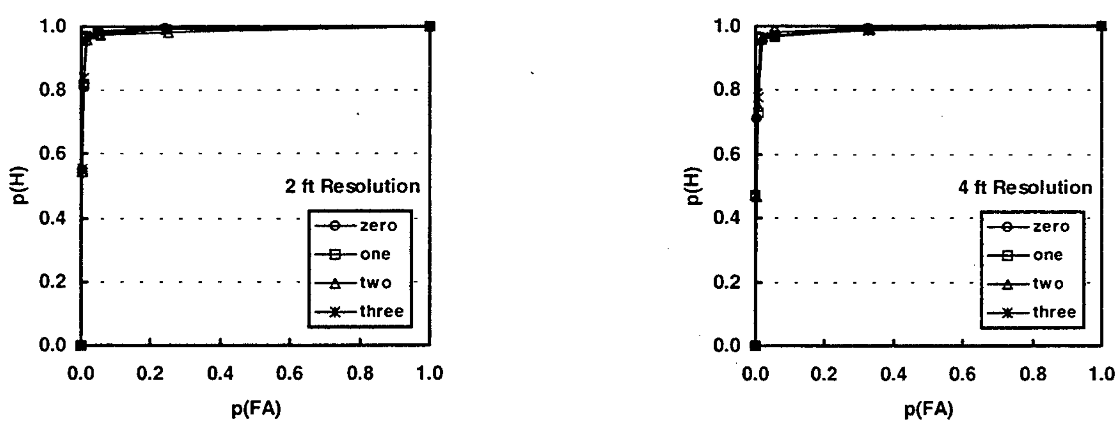


Figure A 2: ROC curves for Resolution x Number of Confusers.

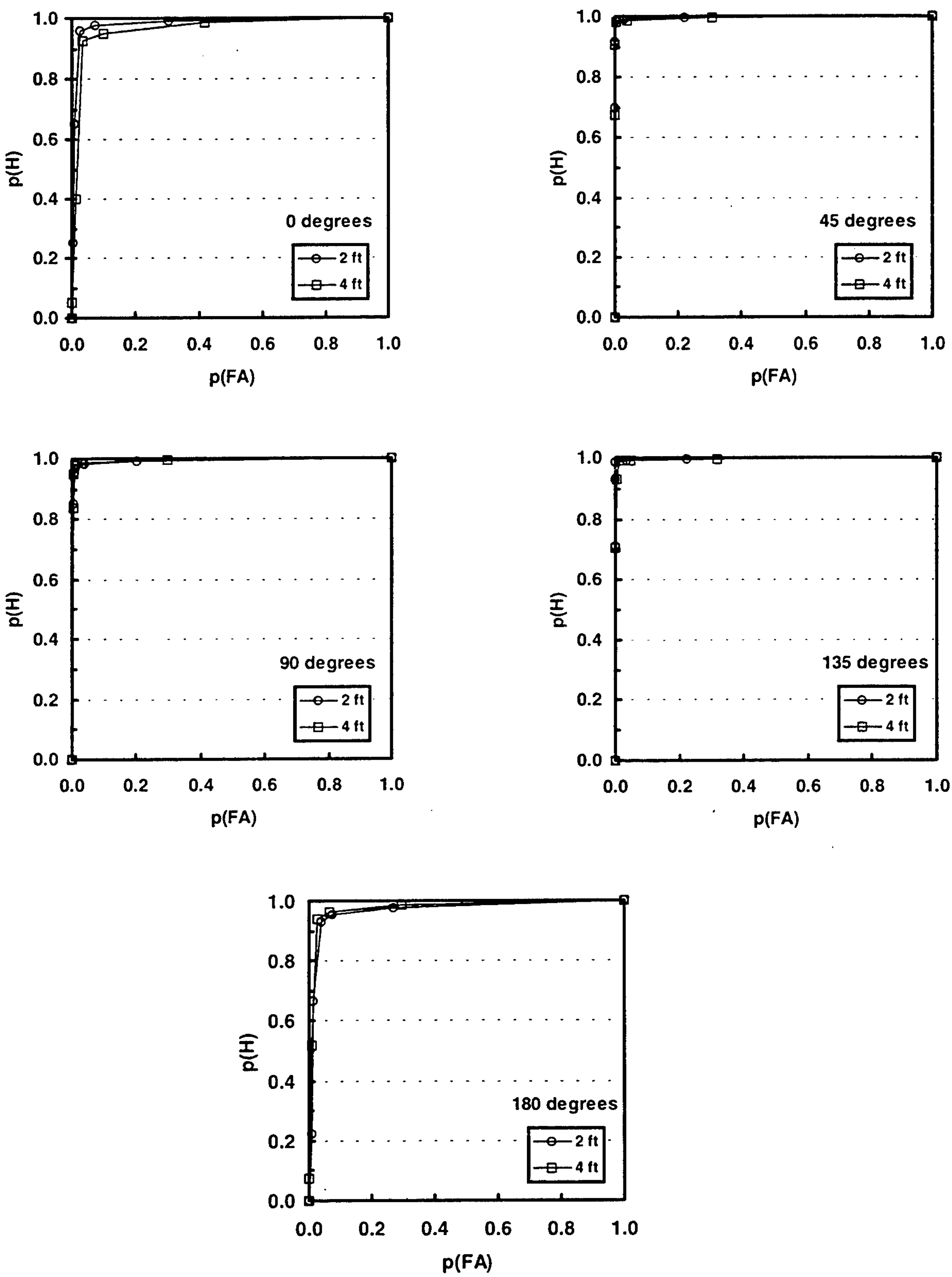


Figure A 3: ROC curves for Resolution x Orientation.

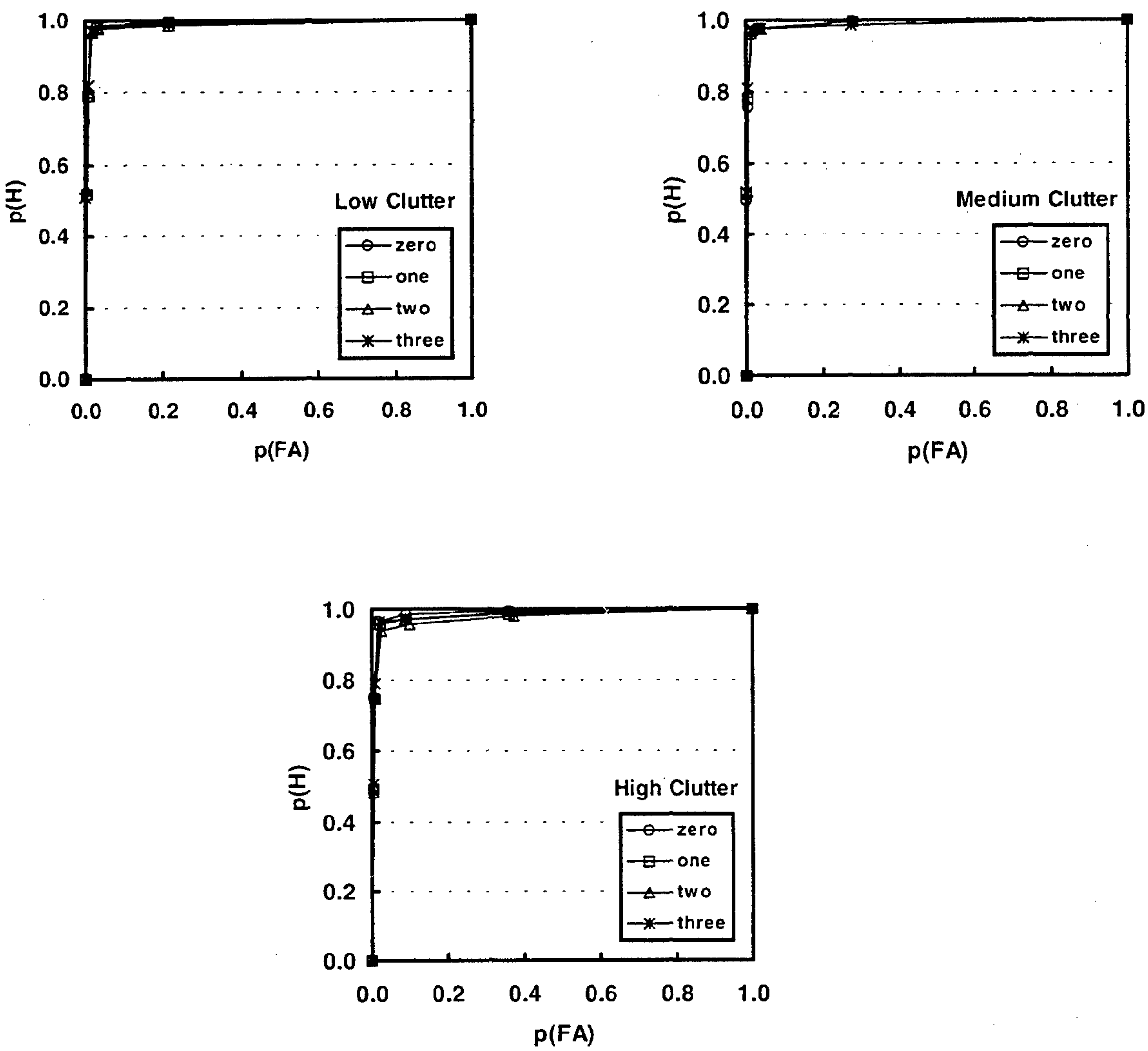


Figure A 4: ROC curves for Clutter x Number of Confusers.

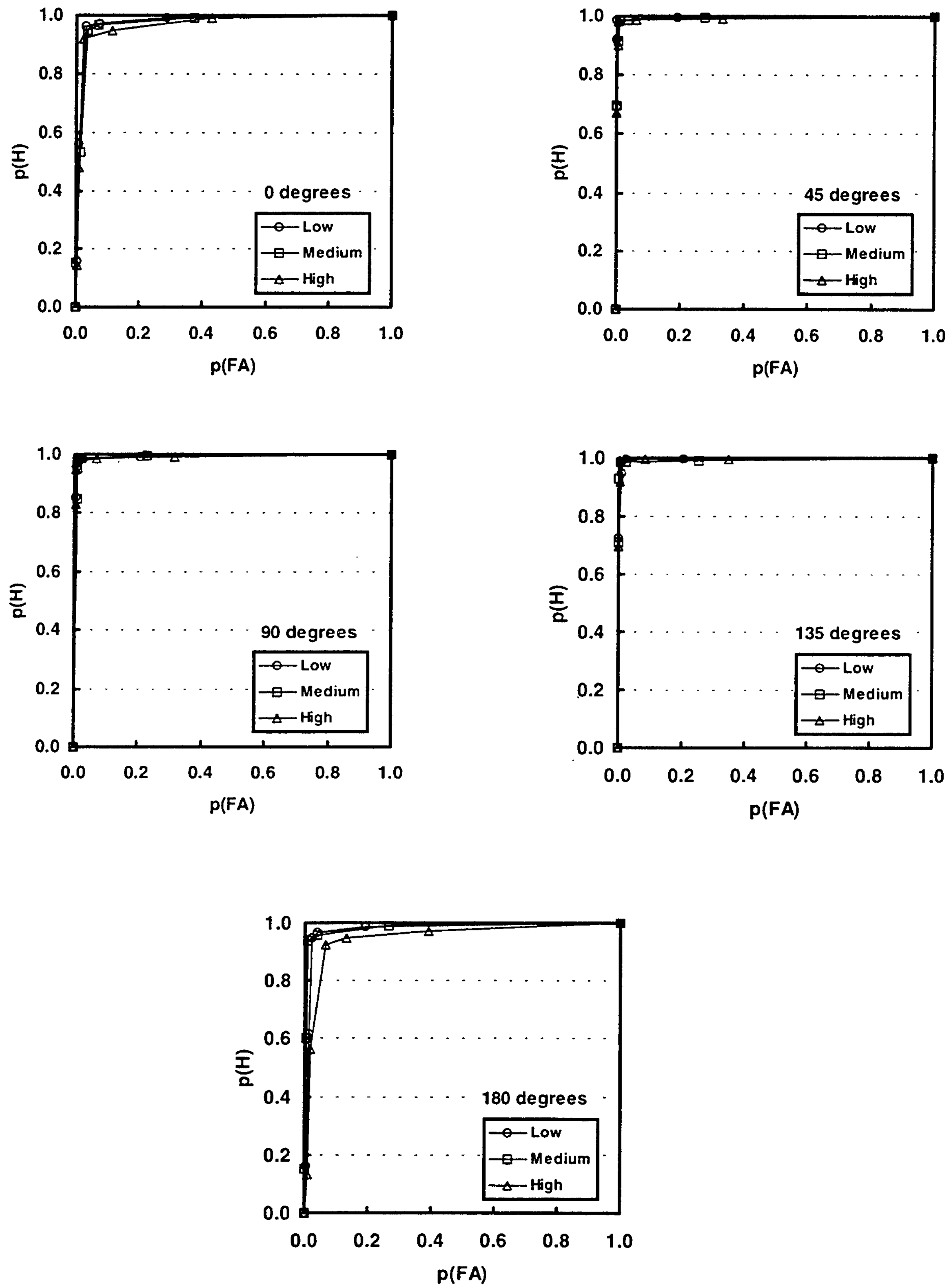


Figure A 5: ROC curves for Clutter x Orientation.

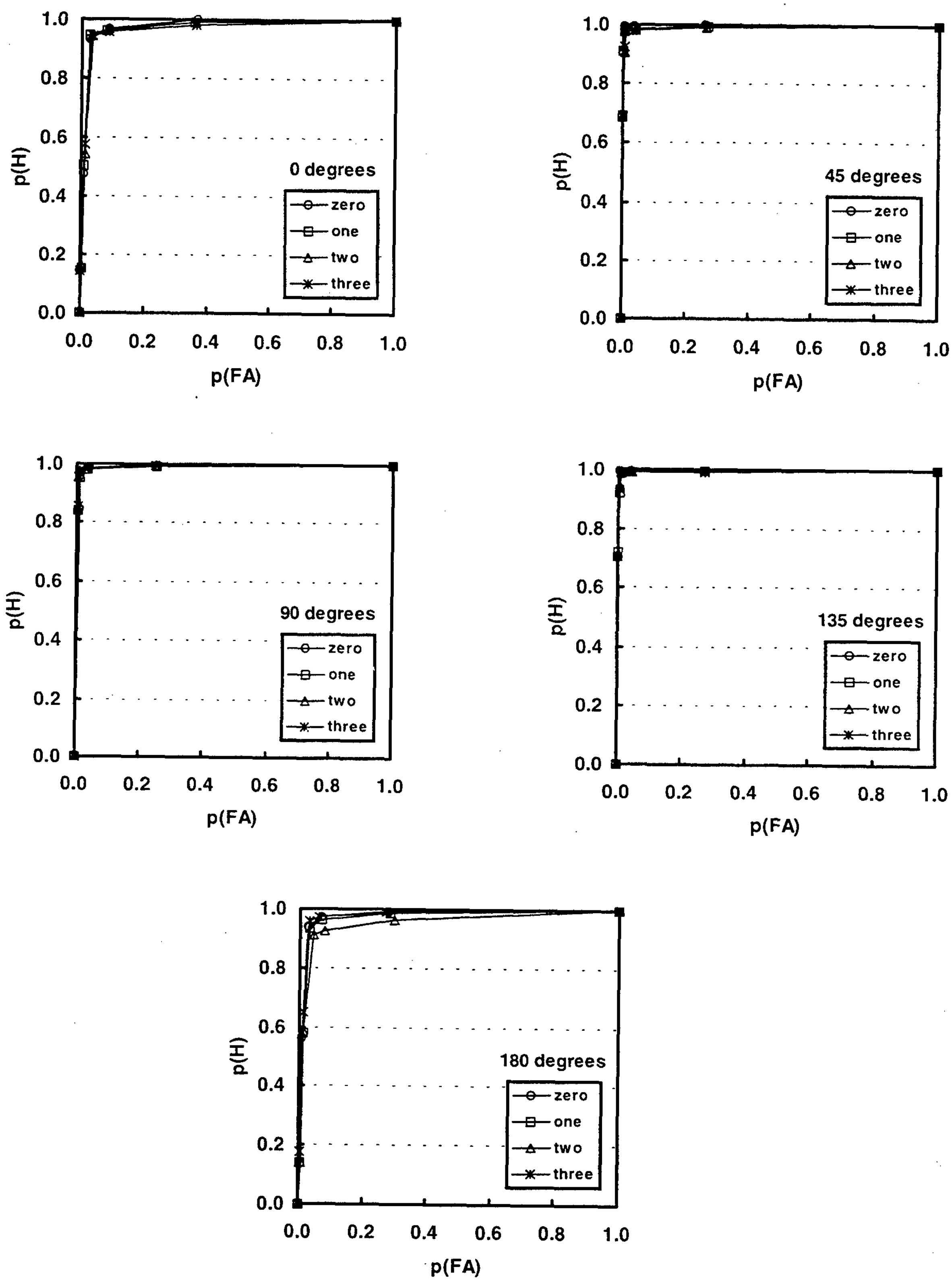


Figure A 6: ROC curves for Number of Confusers x Orientation.

APPENDIX B

ROC CURVES FOR THREE-WAY INTERACTIONS

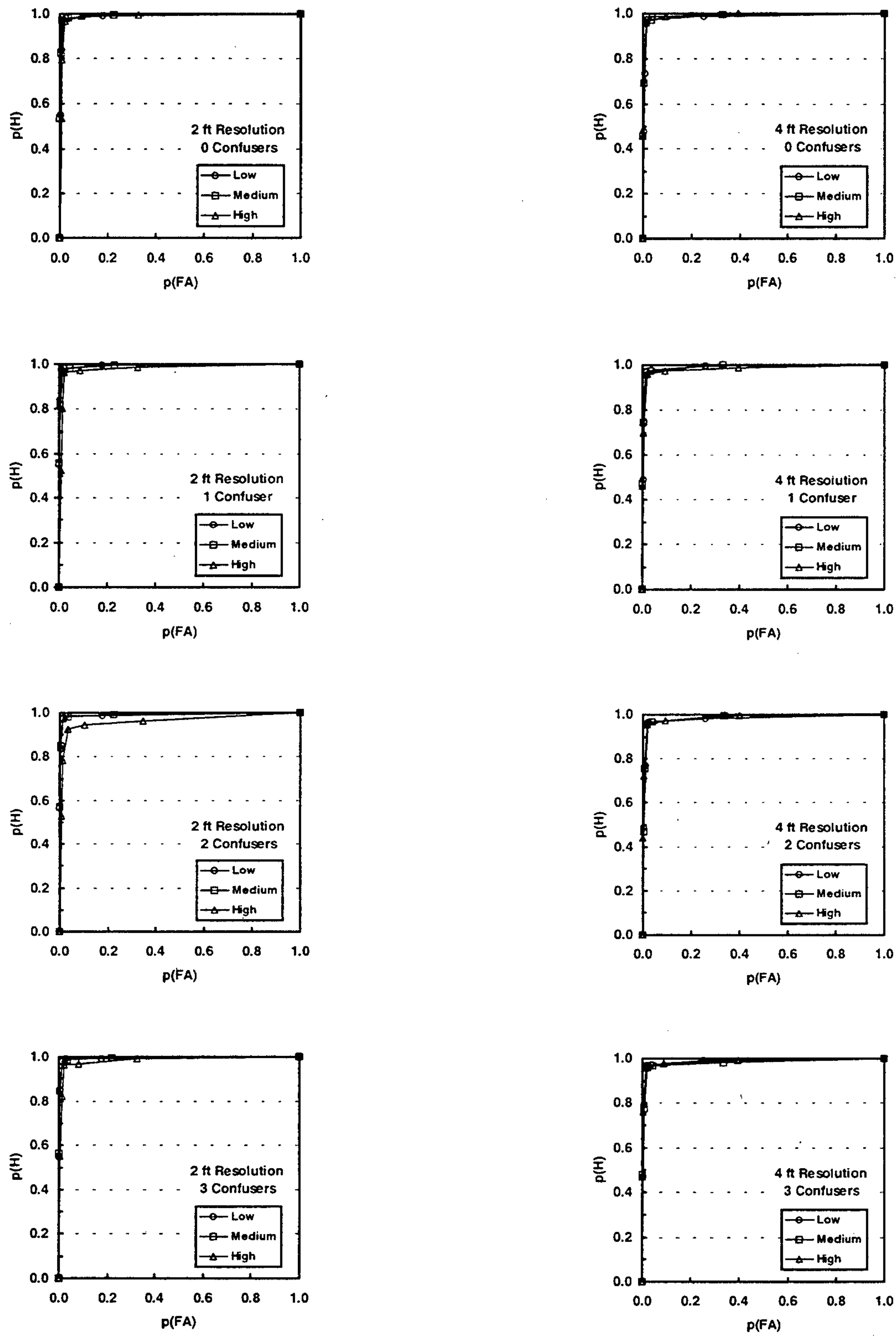


Figure B 1: ROC curves for Resolution x Clutter x Number of Confusers.

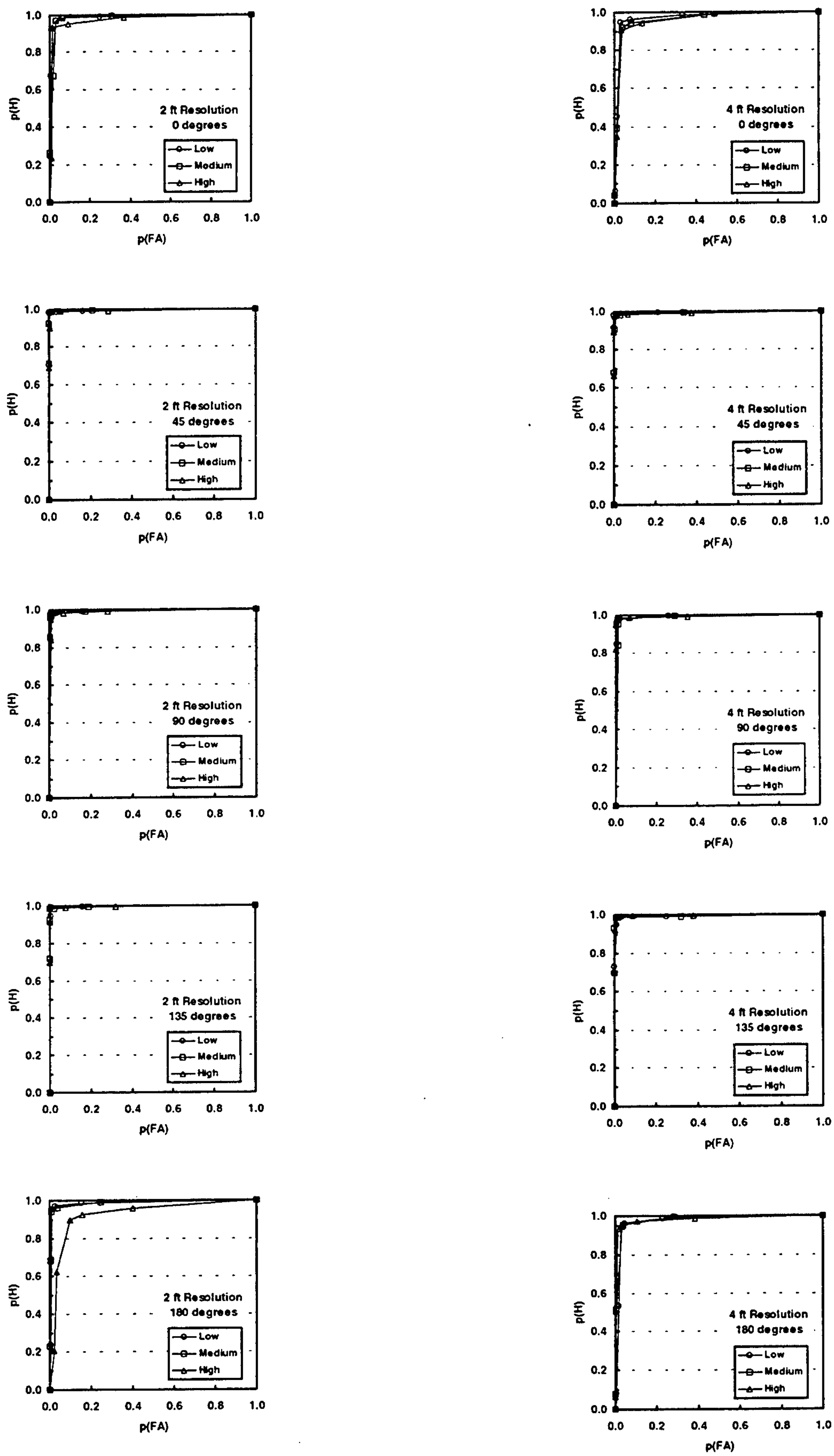


Figure B 2: ROC Curves for Resolution x Clutter x Orientation.

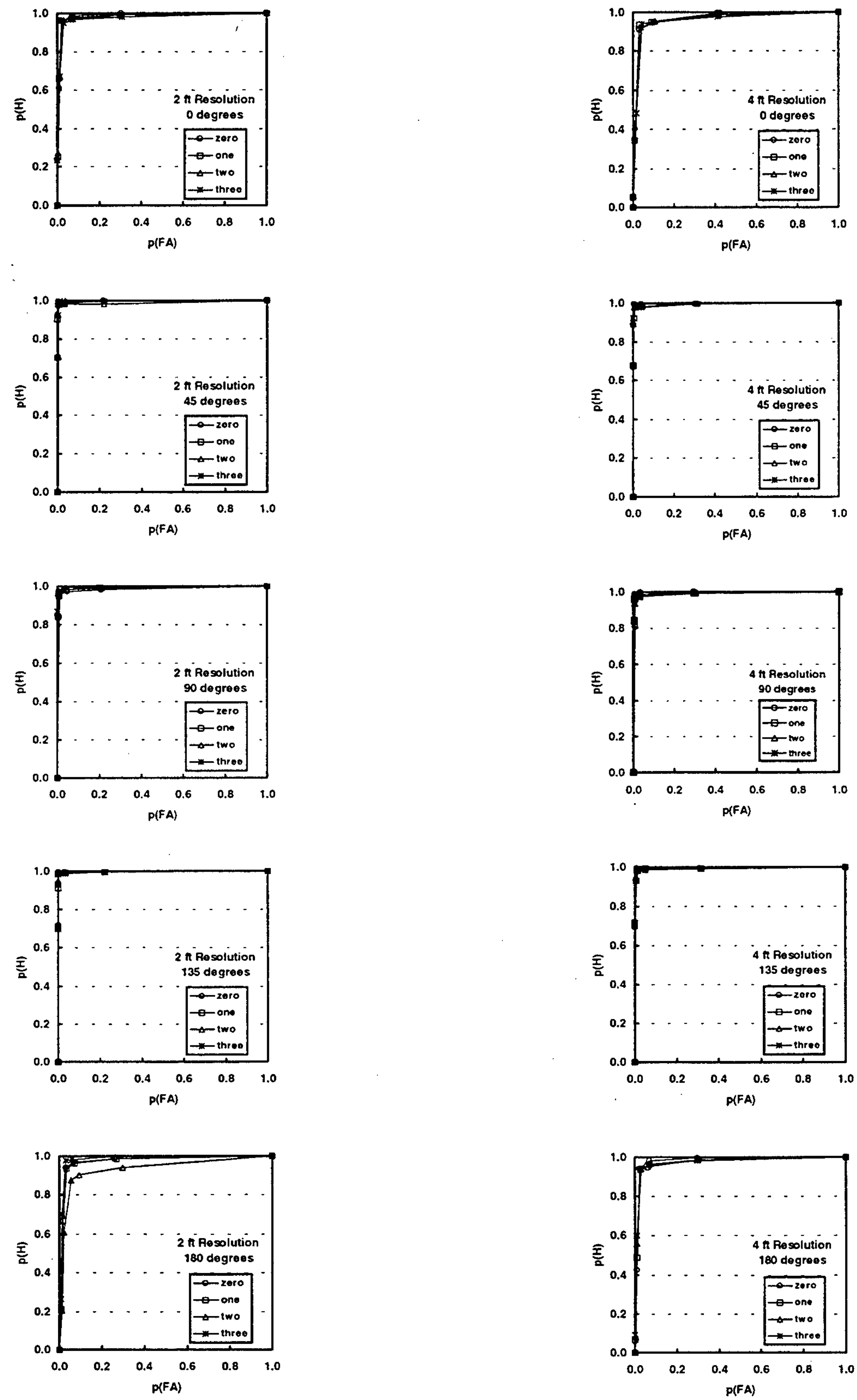


Figure B 3: ROC curves for Resolution x Number of Confusers x Orientation.

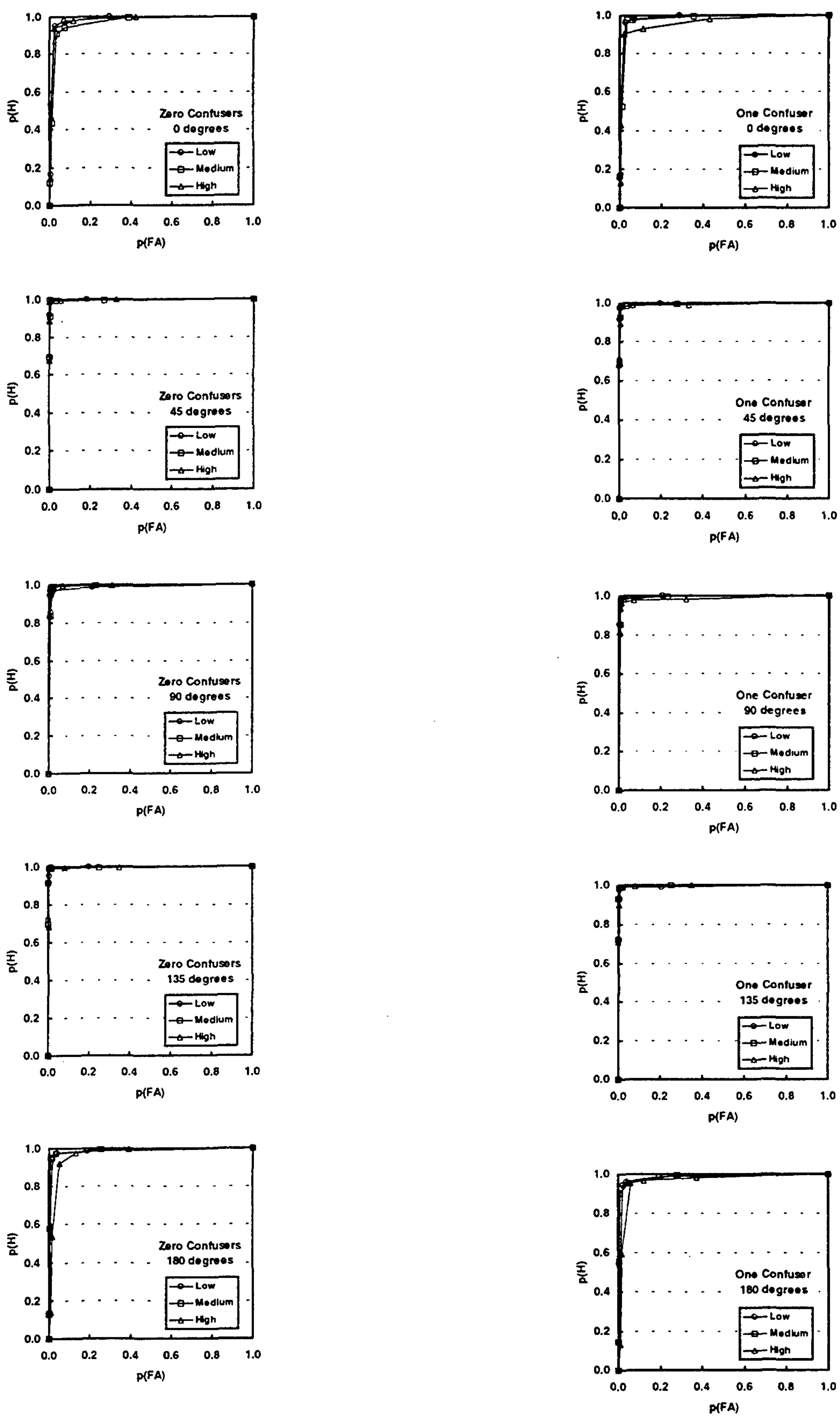


Figure B 4: ROC curves for Clutter x Number of Confusers x Orientation. *(continued in Figure B5)*

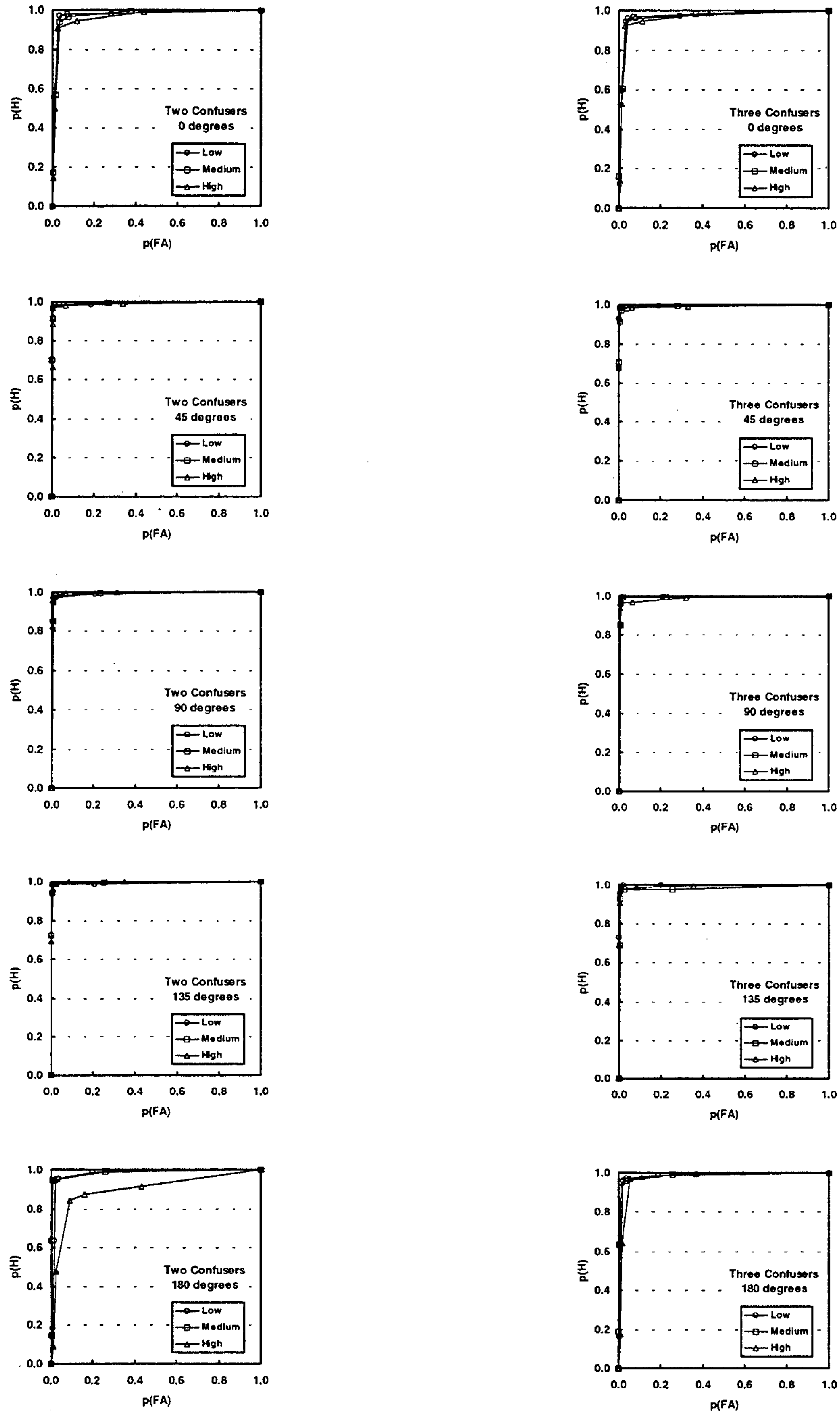


Figure B 5: ROC curves for Clutter x Number of Confusers x Orientation. *(continued from Figure B4).*

APPENDIX C

ROC CURVES FOR FOUR-WAY INTERACTIONS

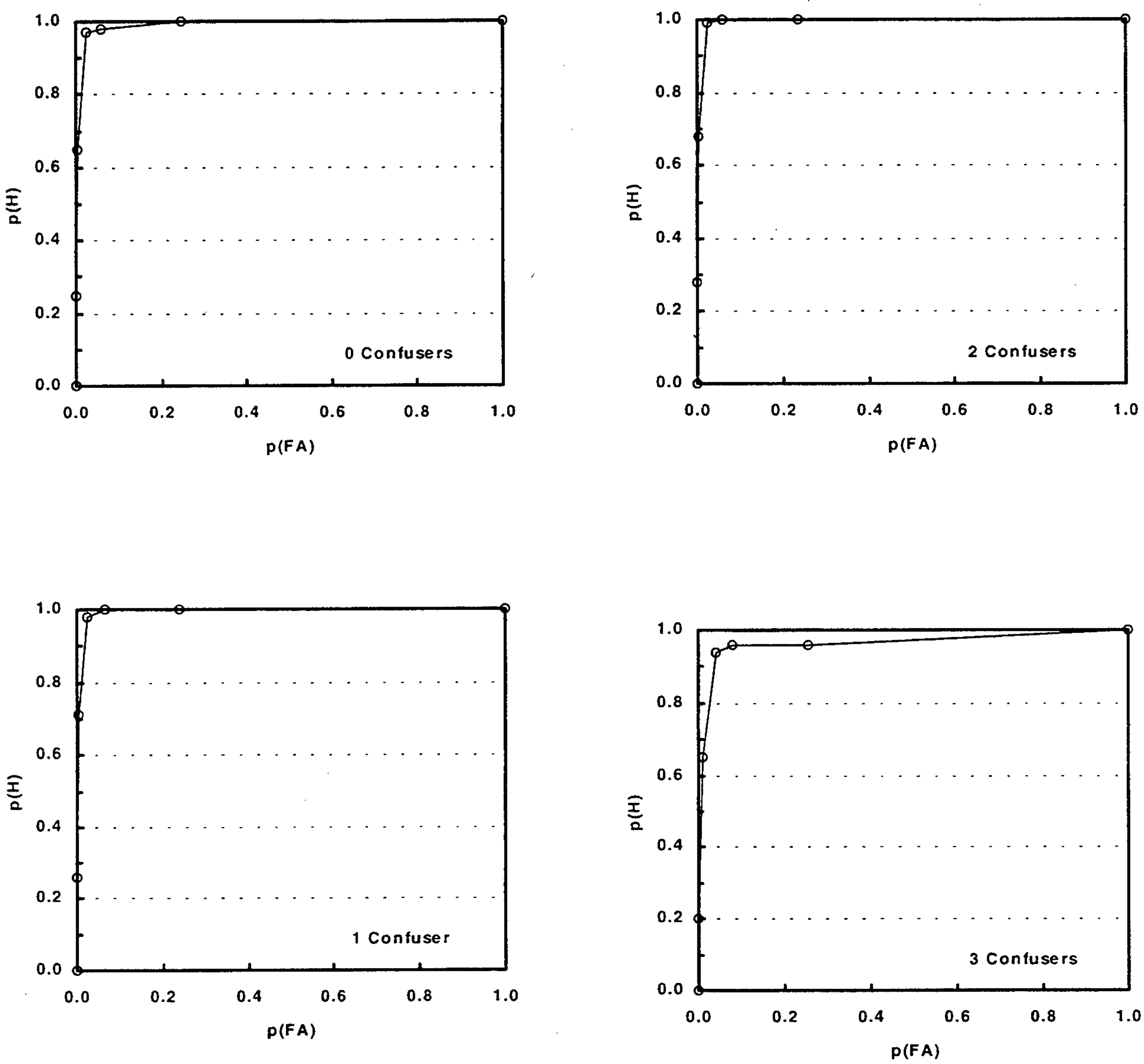


Figure C 1: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, low clutter, 0°.

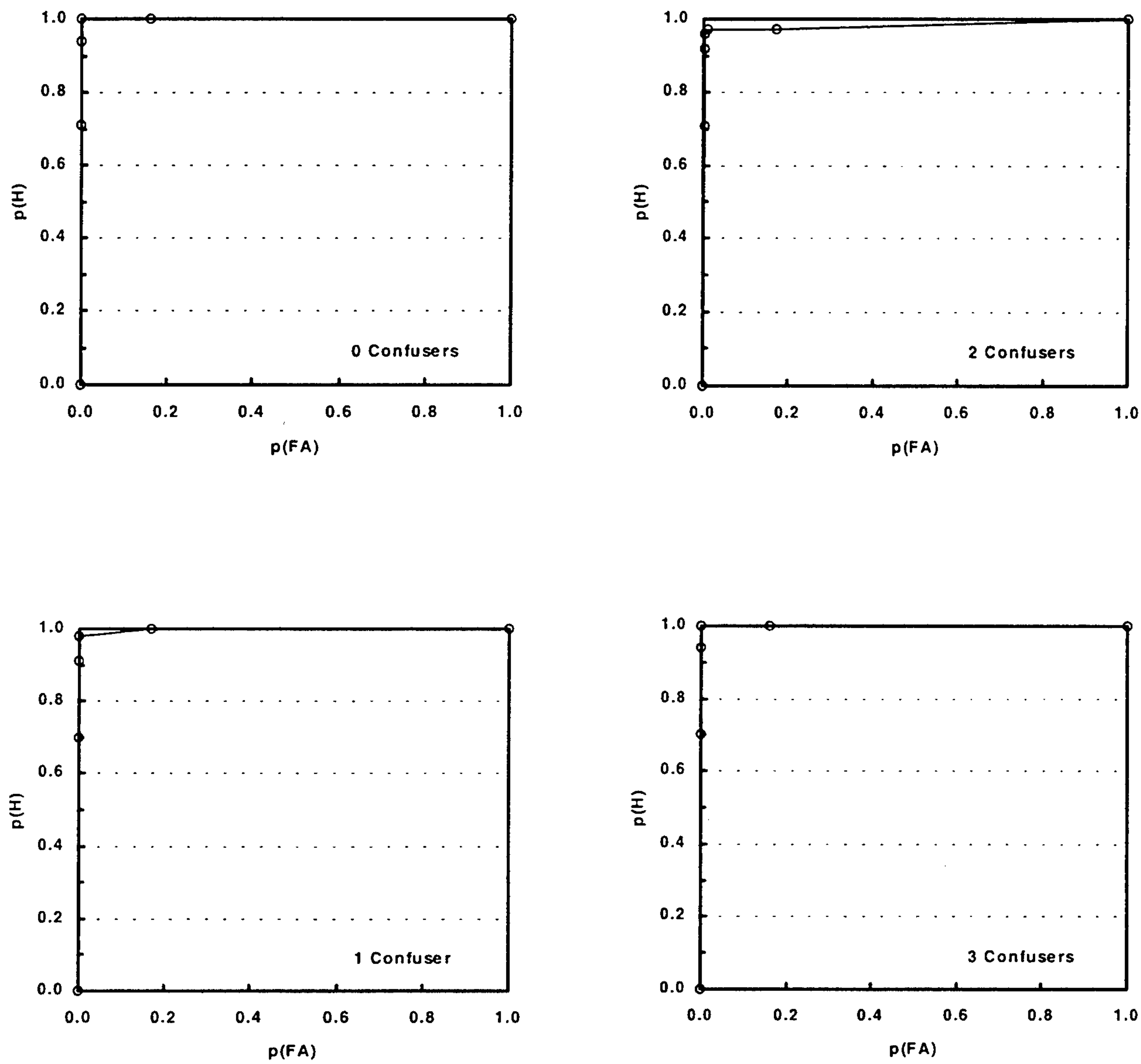


Figure C 2: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, low clutter, 45°.

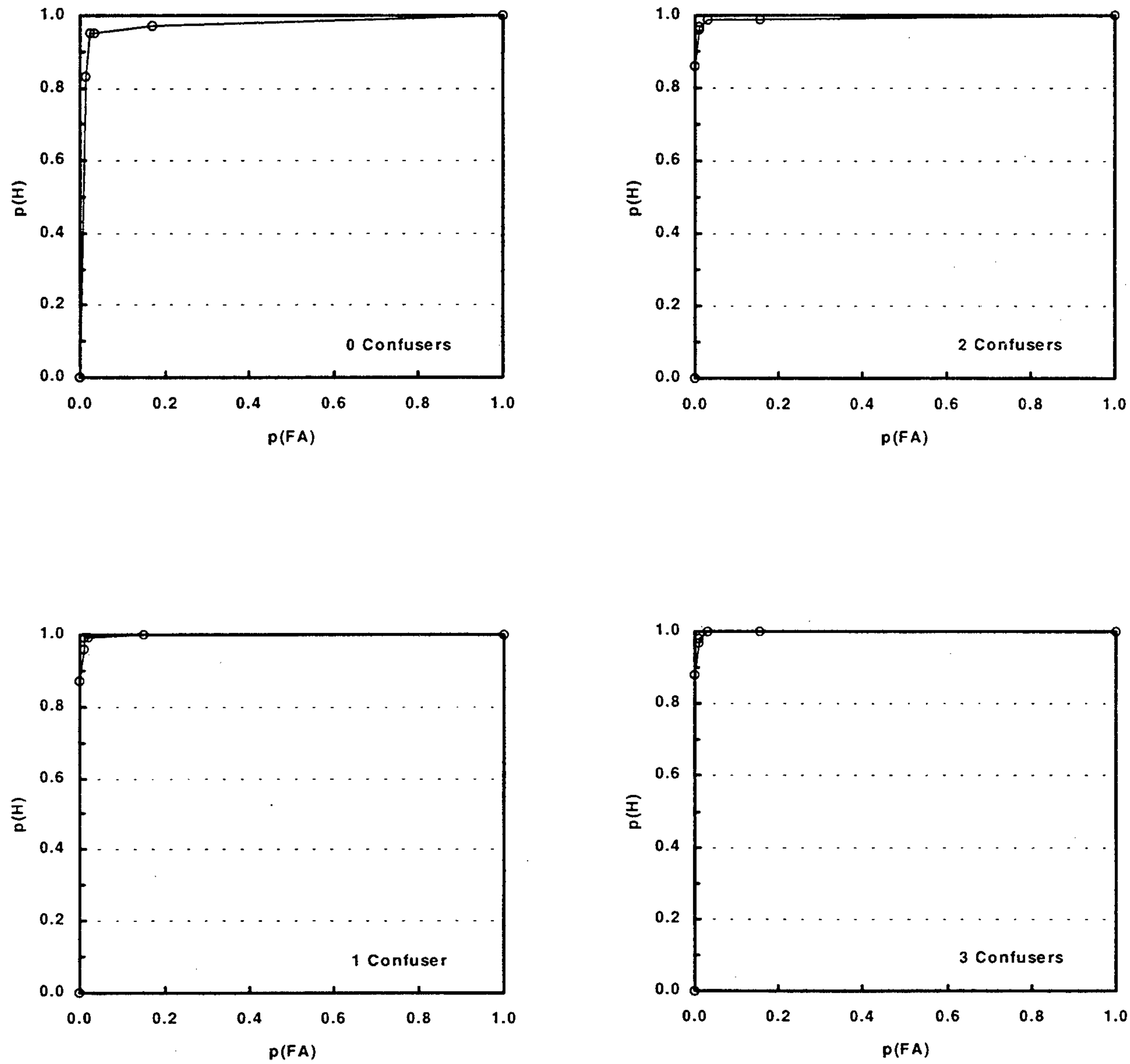


Figure C 3: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, low clutter, 90°.

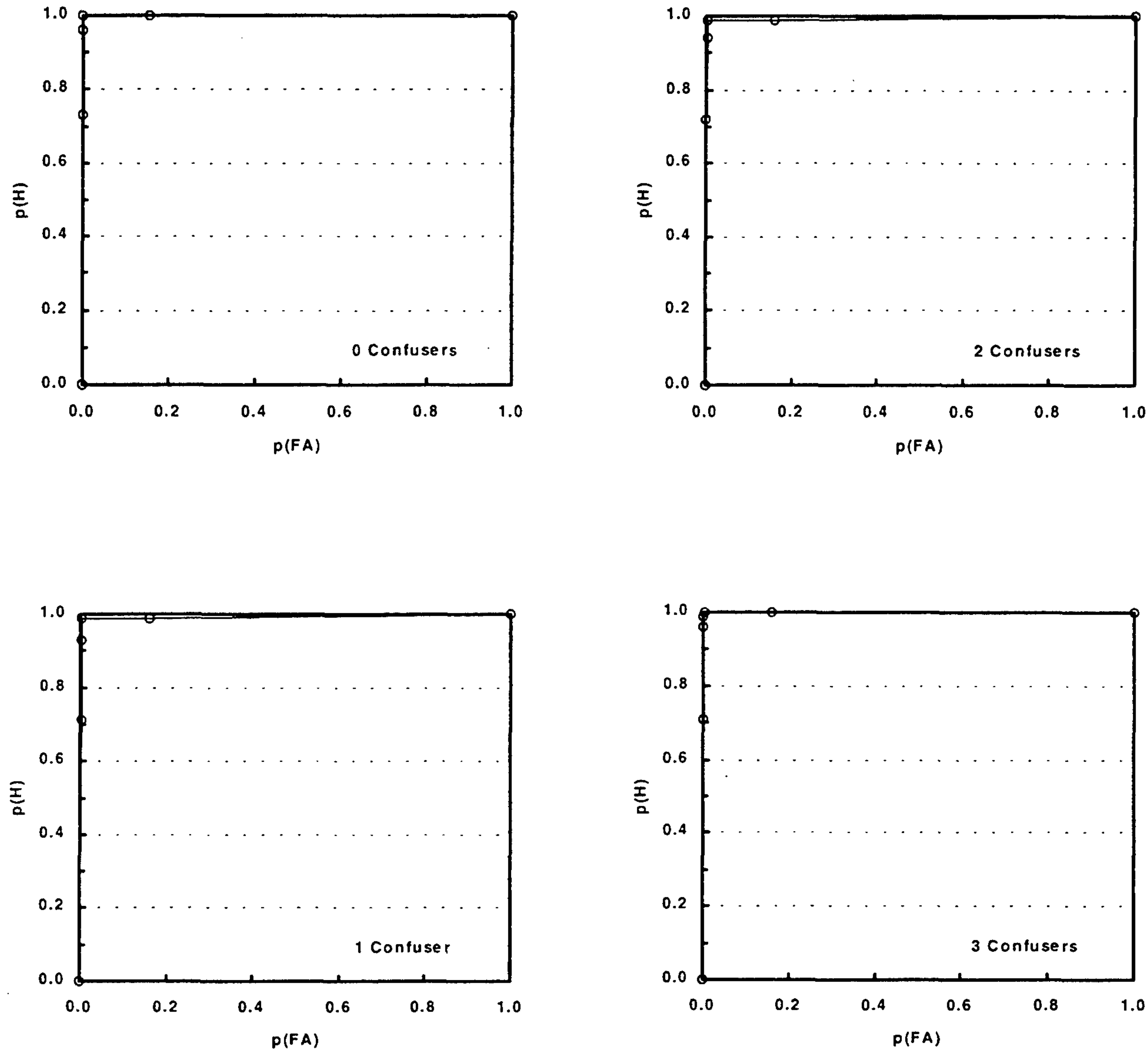


Figure C 4: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, low clutter, 135°.

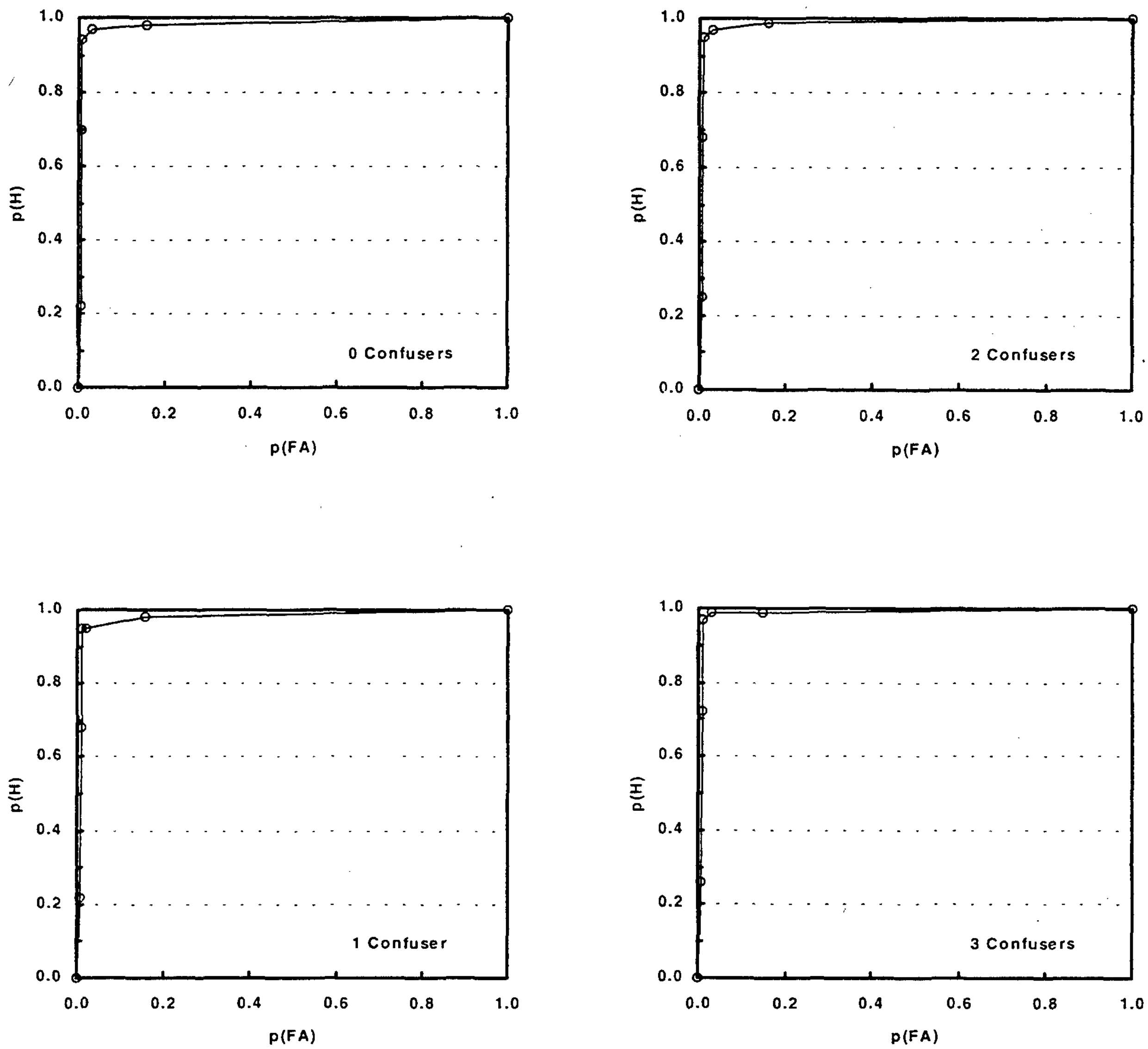


Figure C 5: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, low clutter, 180°.

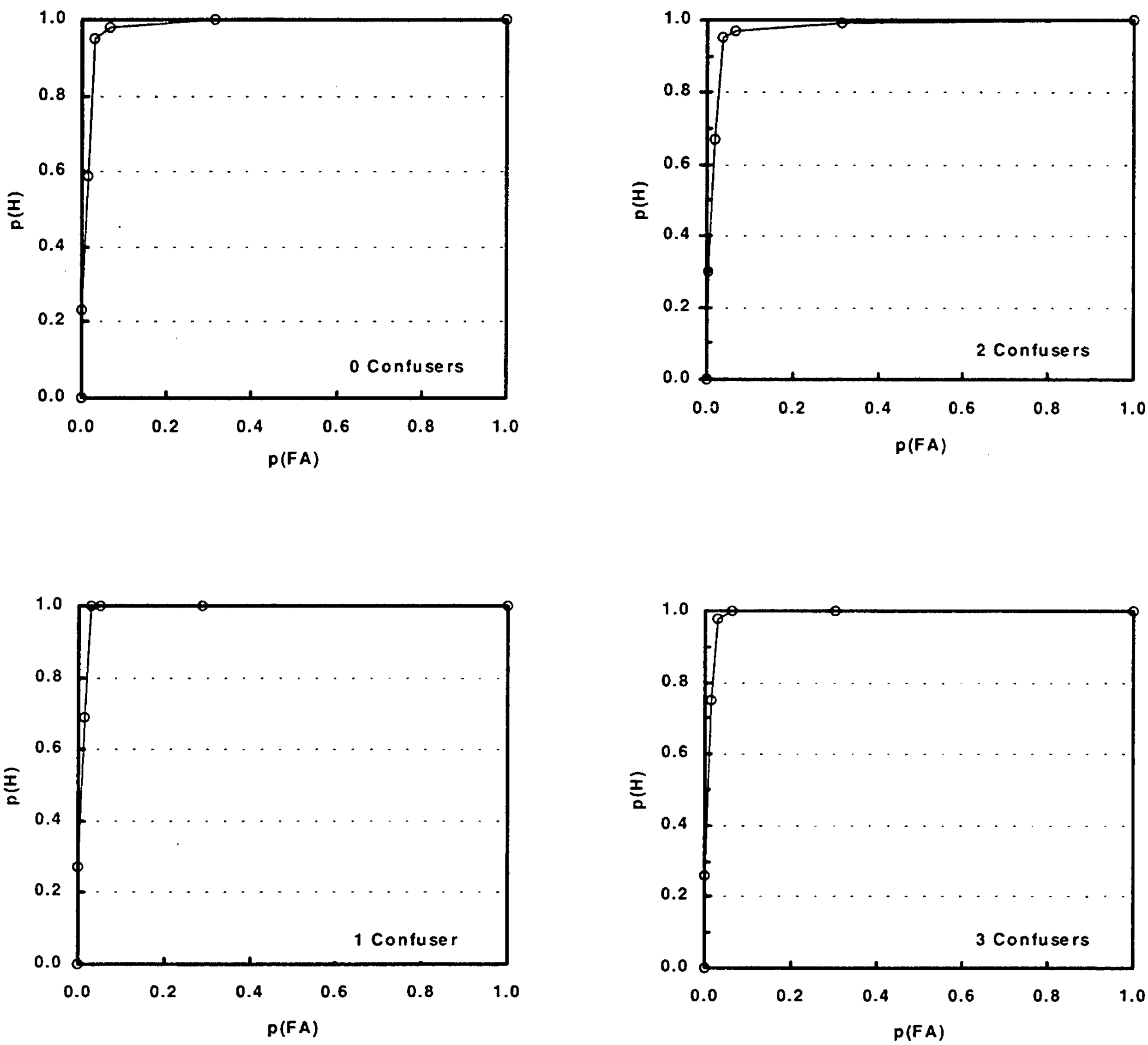


Figure C 6: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, medium clutter, 0°.

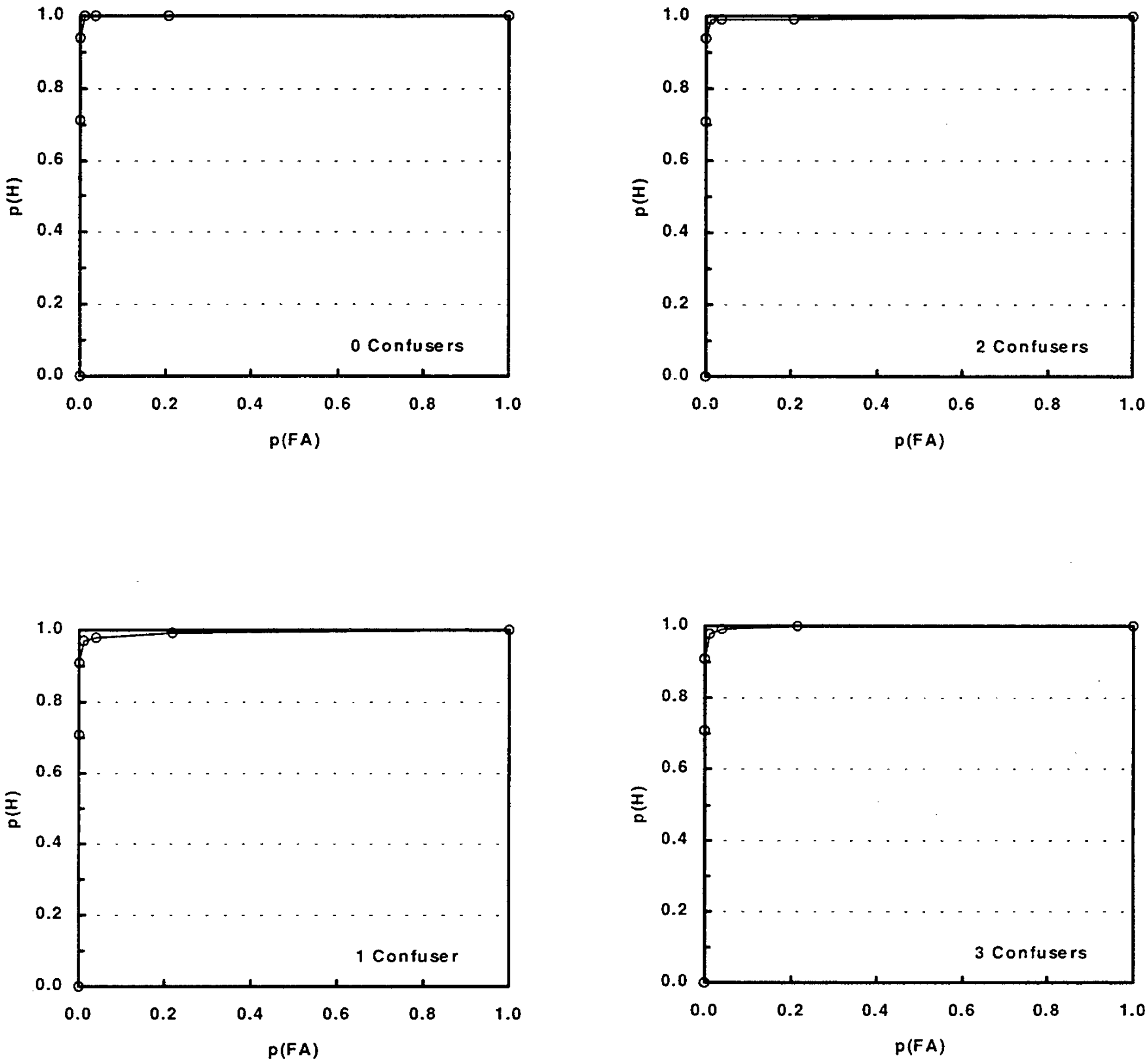


Figure C 7: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, medium clutter, 45°.

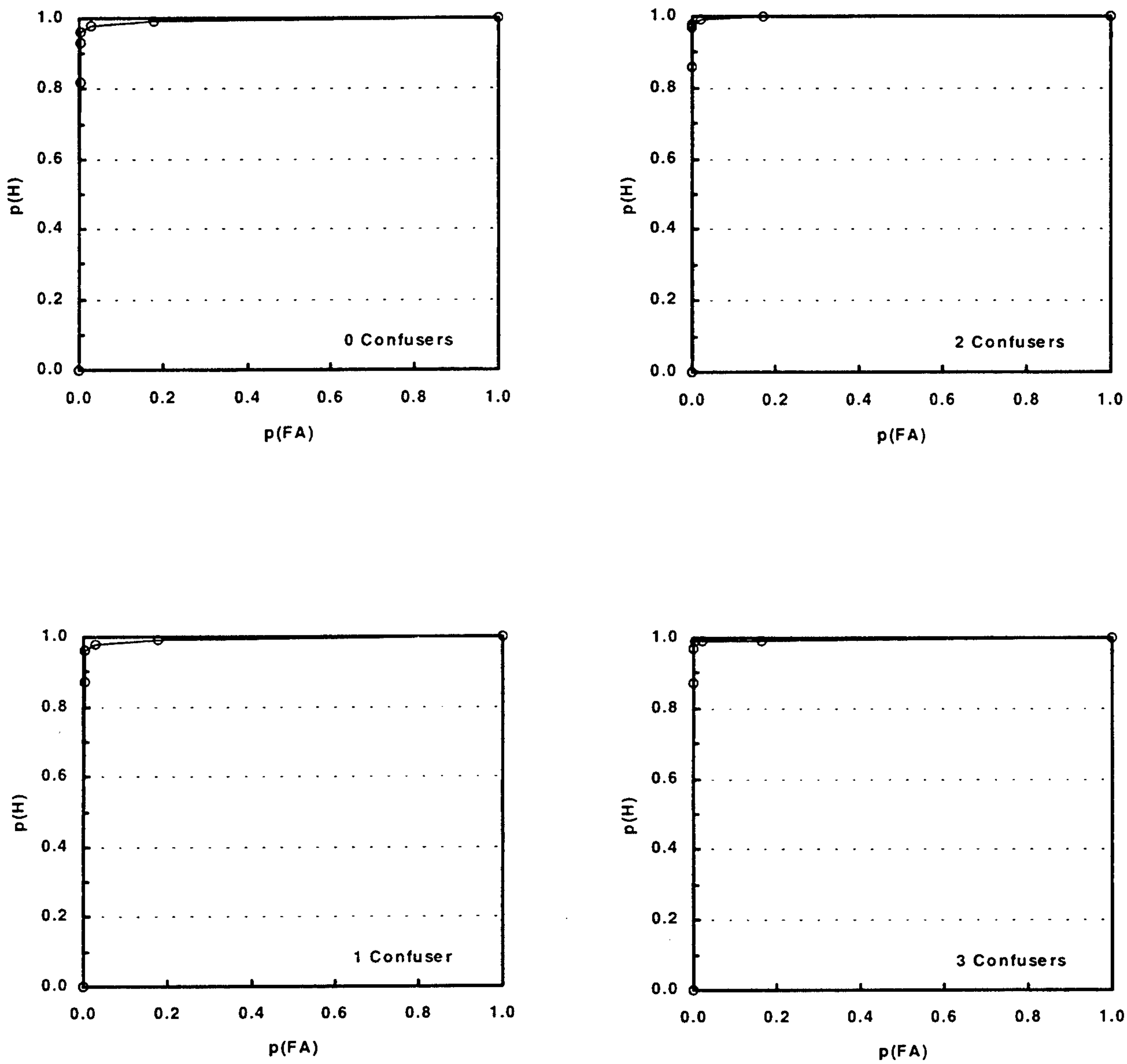


Figure C 8: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, medium clutter, 90°.

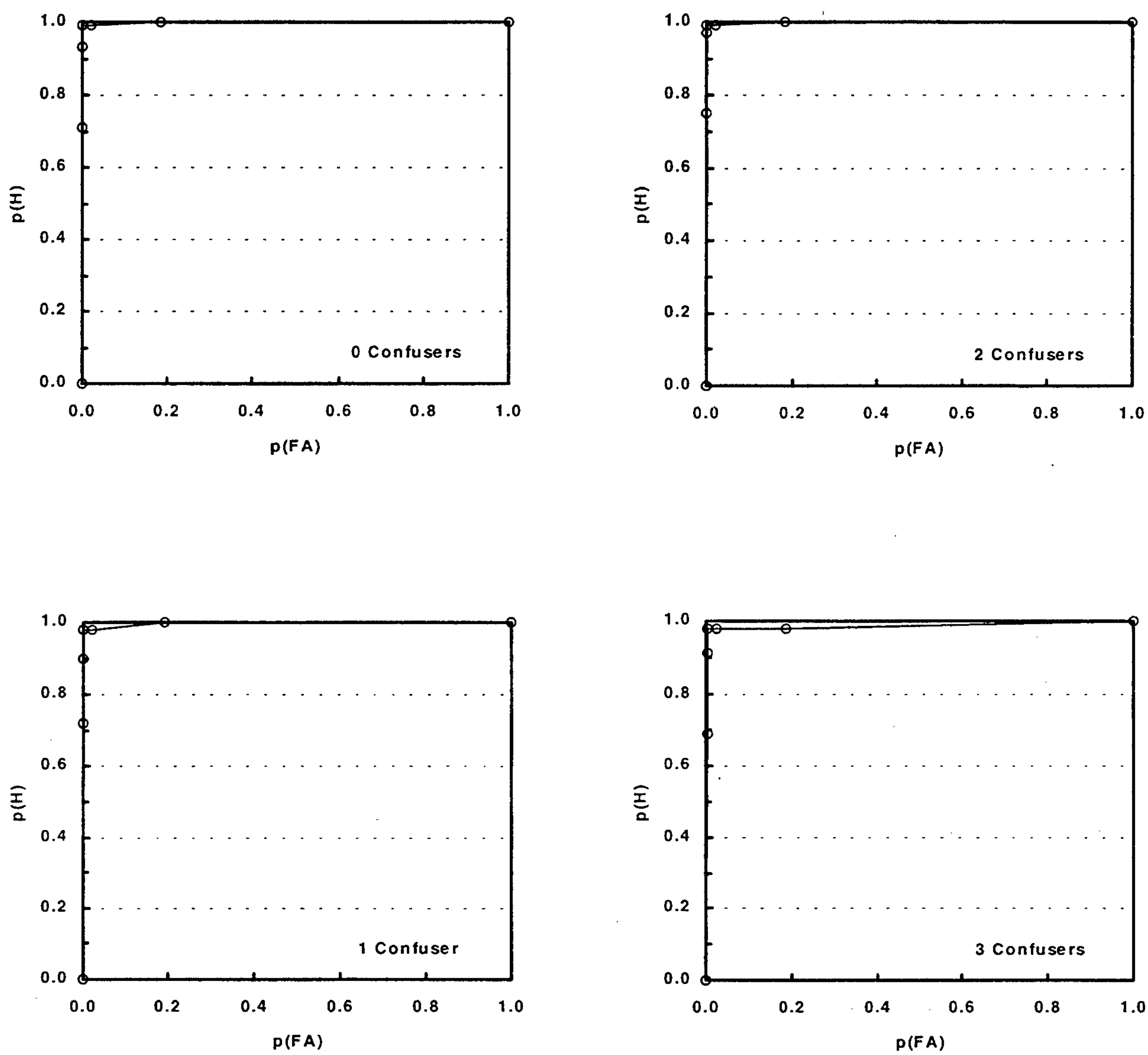


Figure C 9: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, medium clutter, 135°.

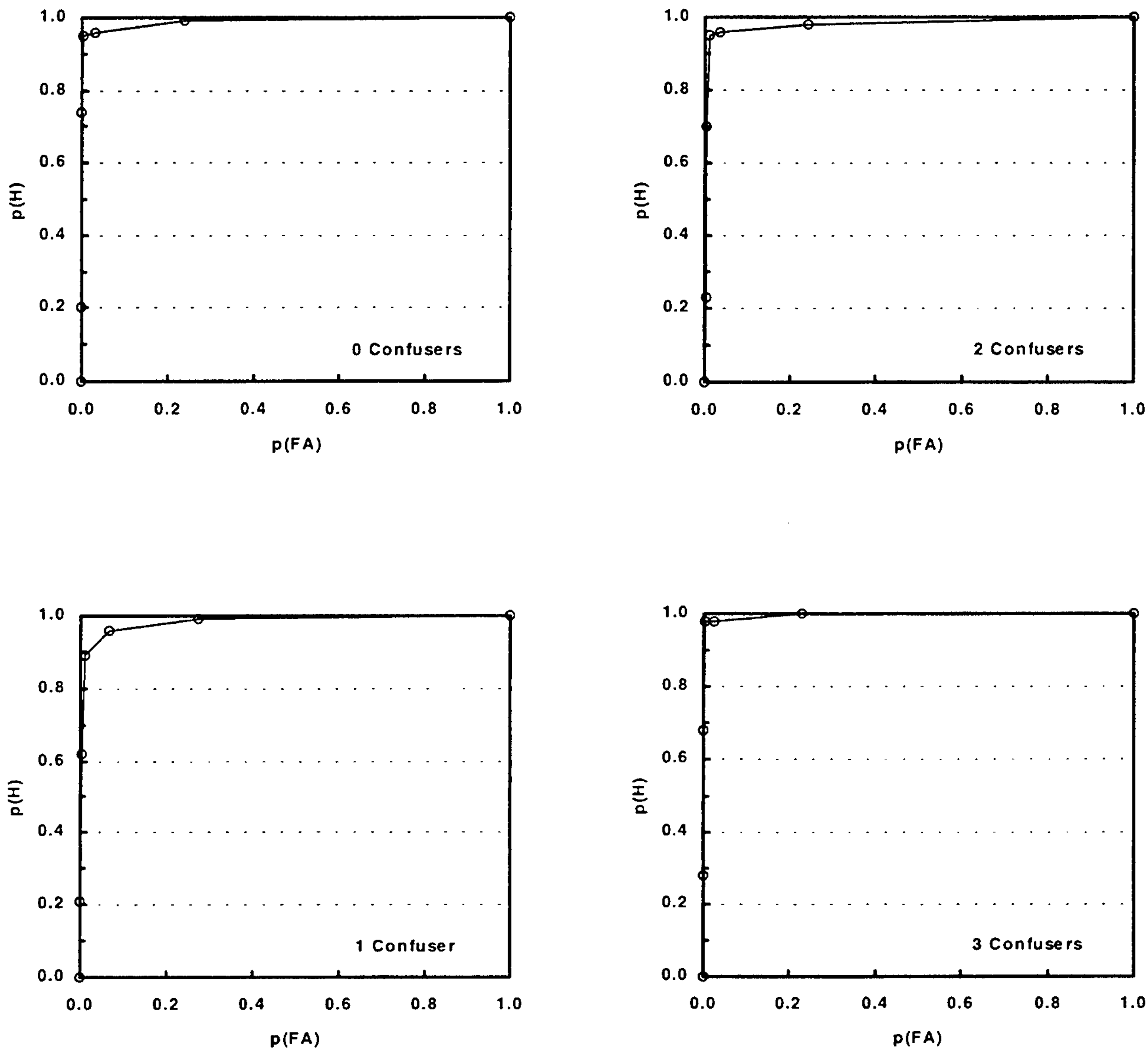


Figure C 10: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, medium clutter, 180°.

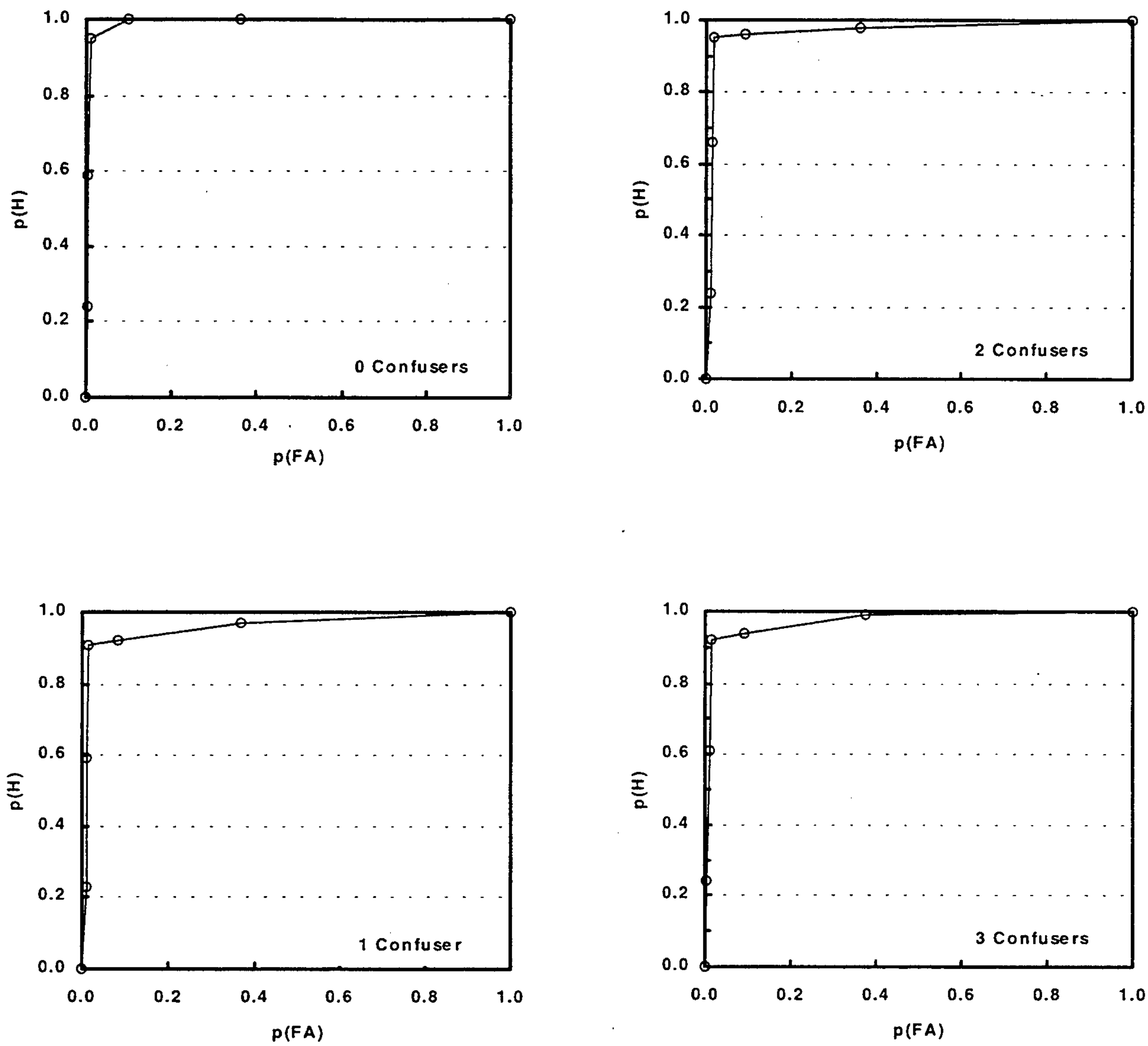


Figure C 11: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, high clutter, 0°.

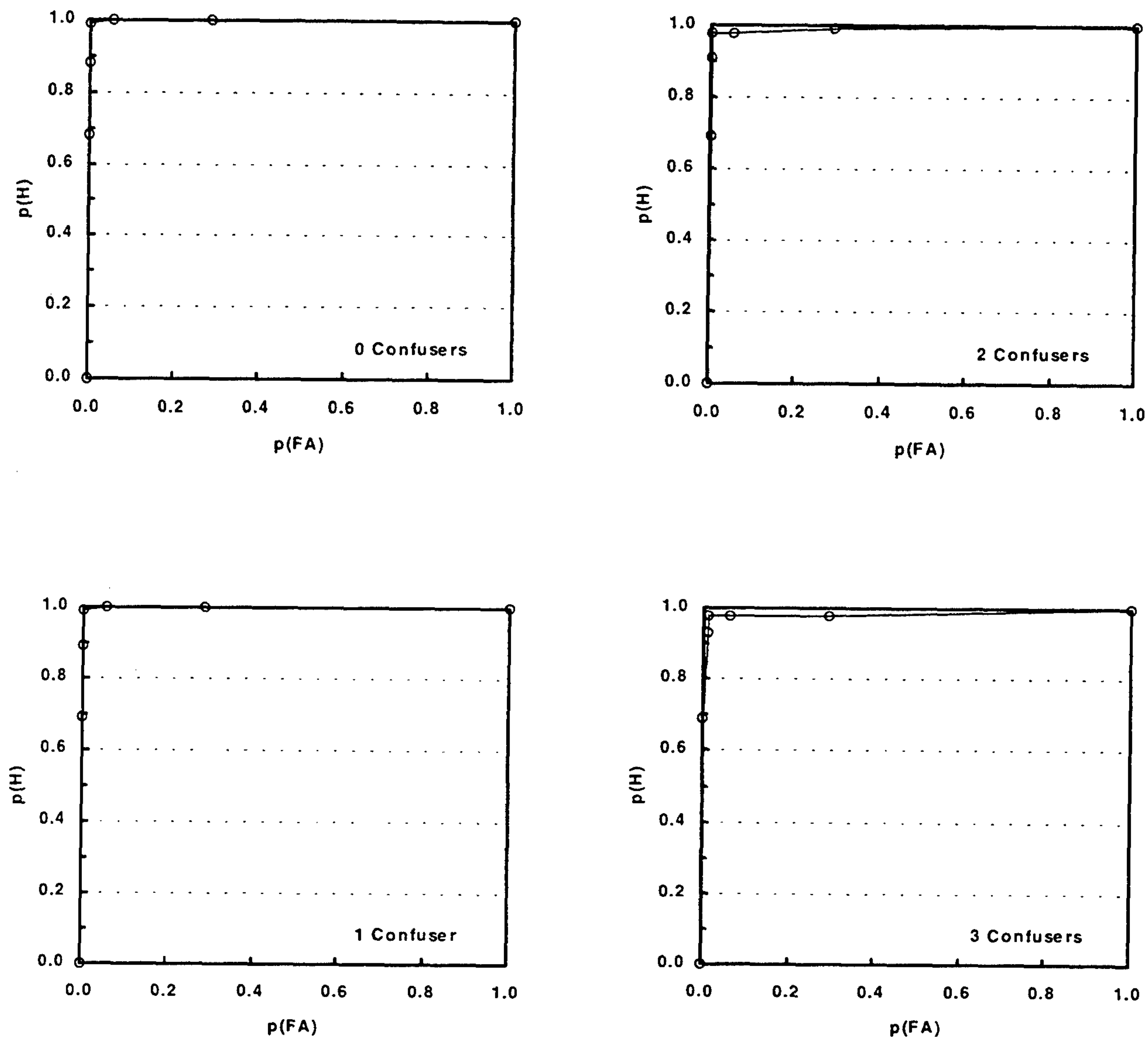


Figure C 12: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, high clutter, 45°.

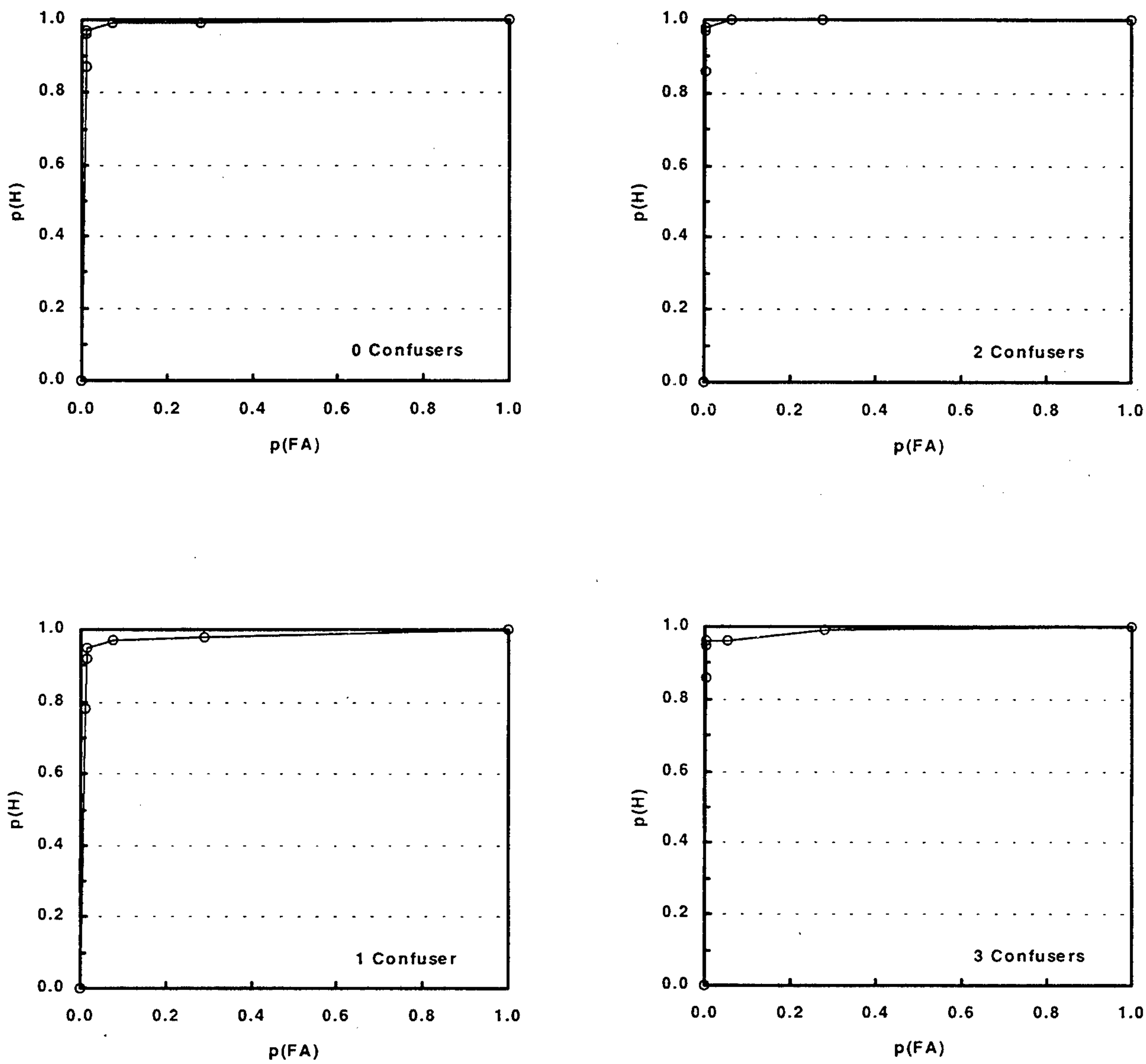


Figure C 13: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, high clutter, 90°.

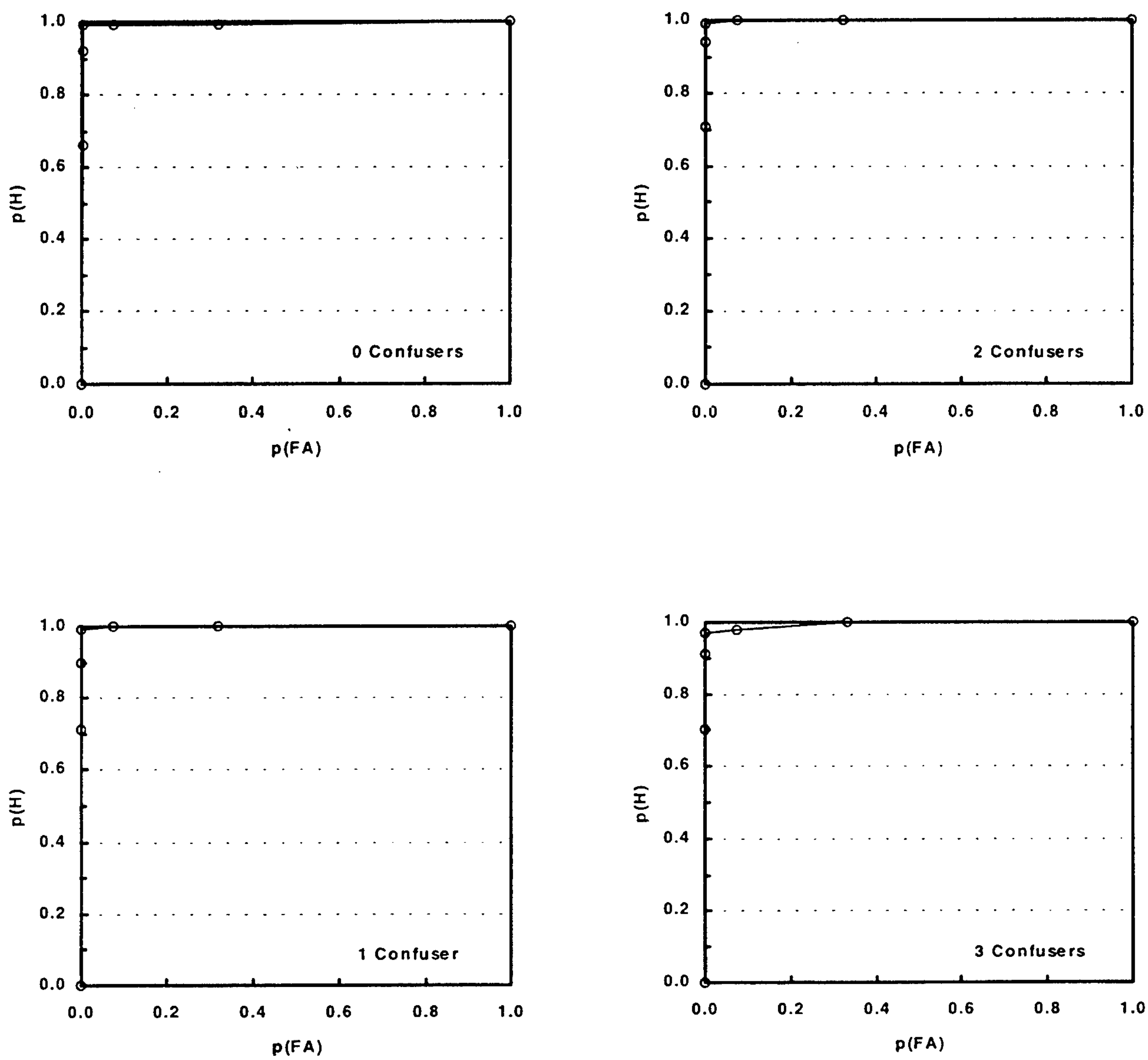


Figure C 14: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, high clutter, 135°.

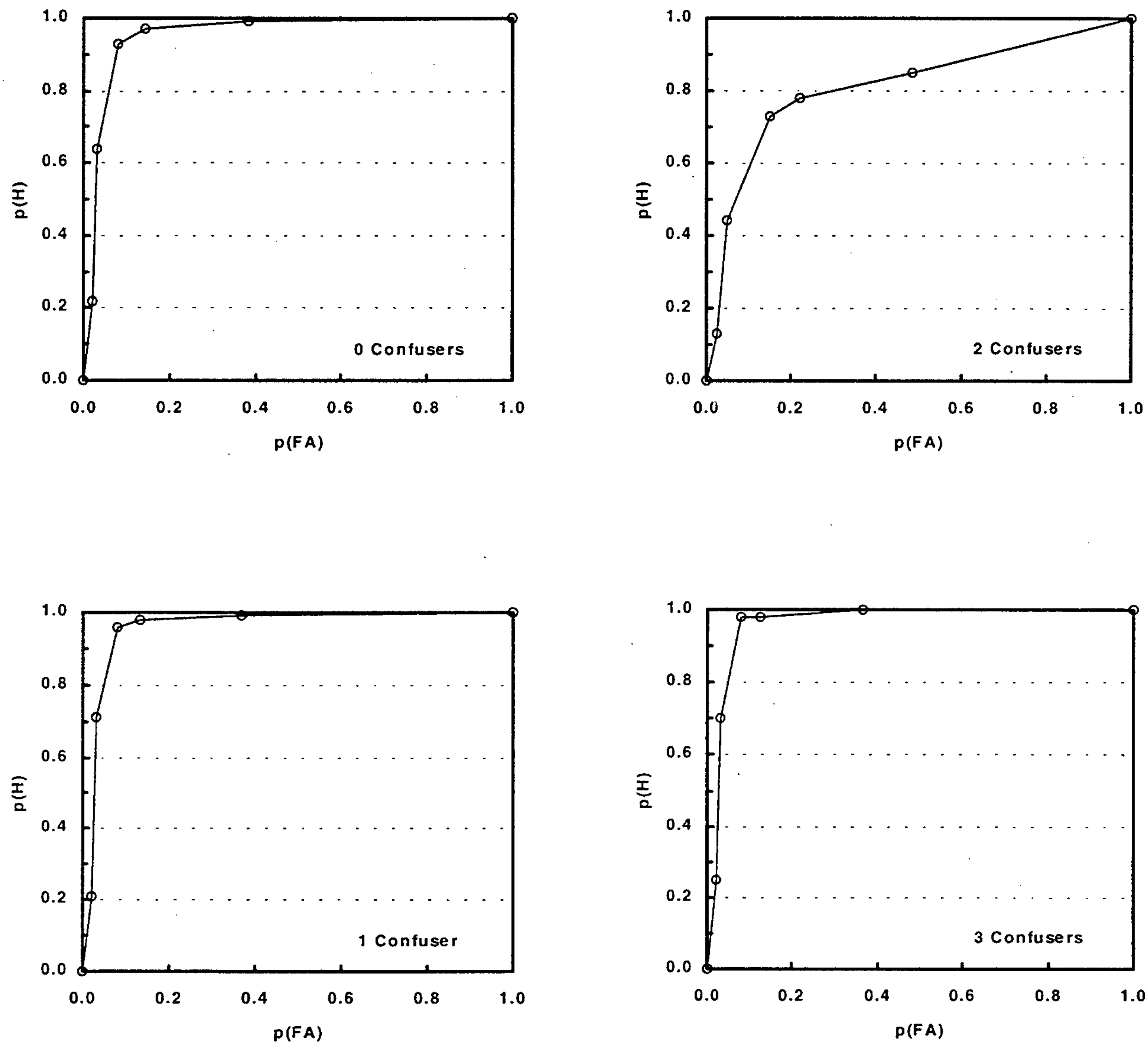


Figure C 15: ROC curves for 0, 1, 2, and 3 confusers at the 2 ft resolution, high clutter, 180°.

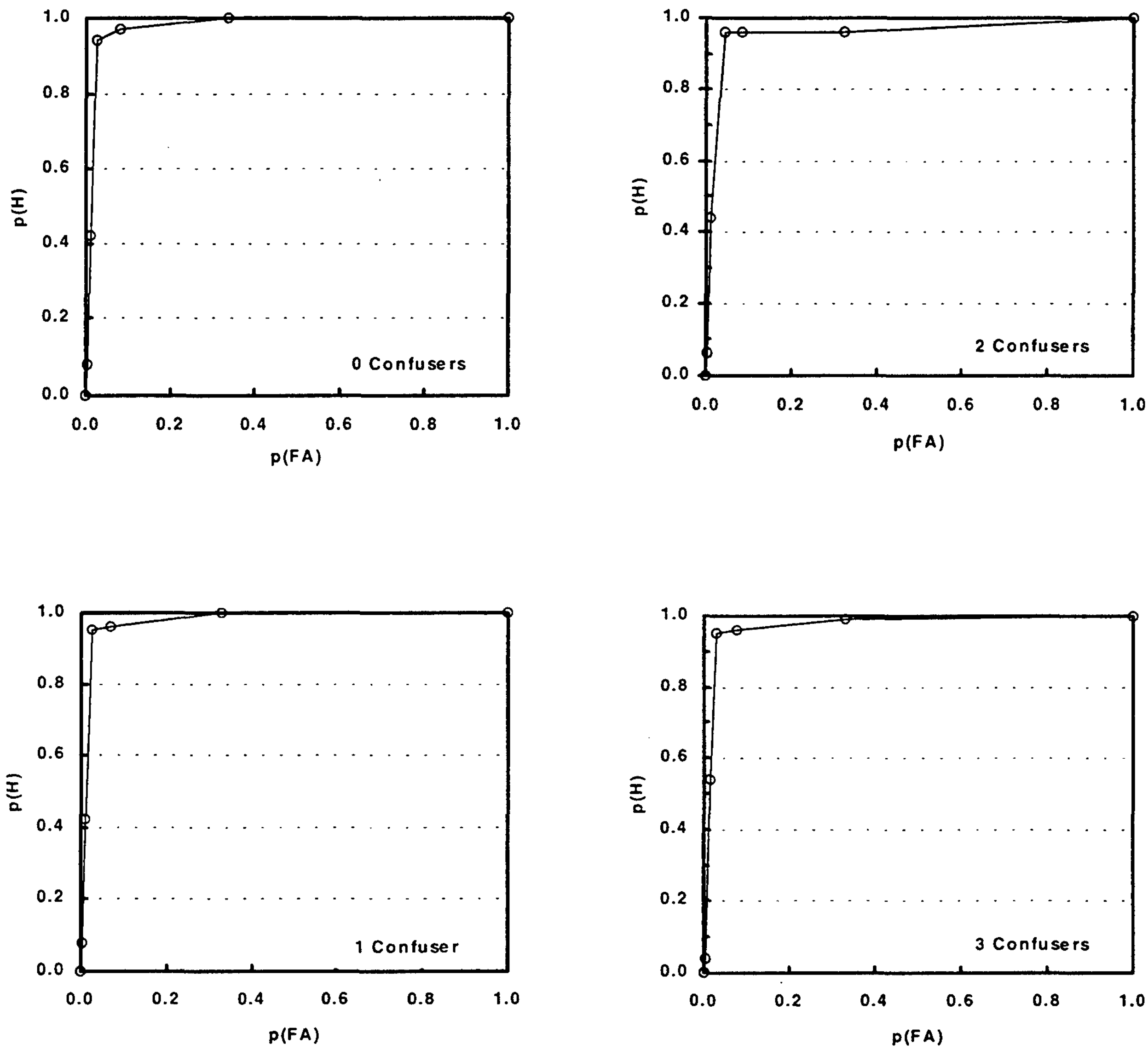


Figure C 16: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, low clutter, 0°.

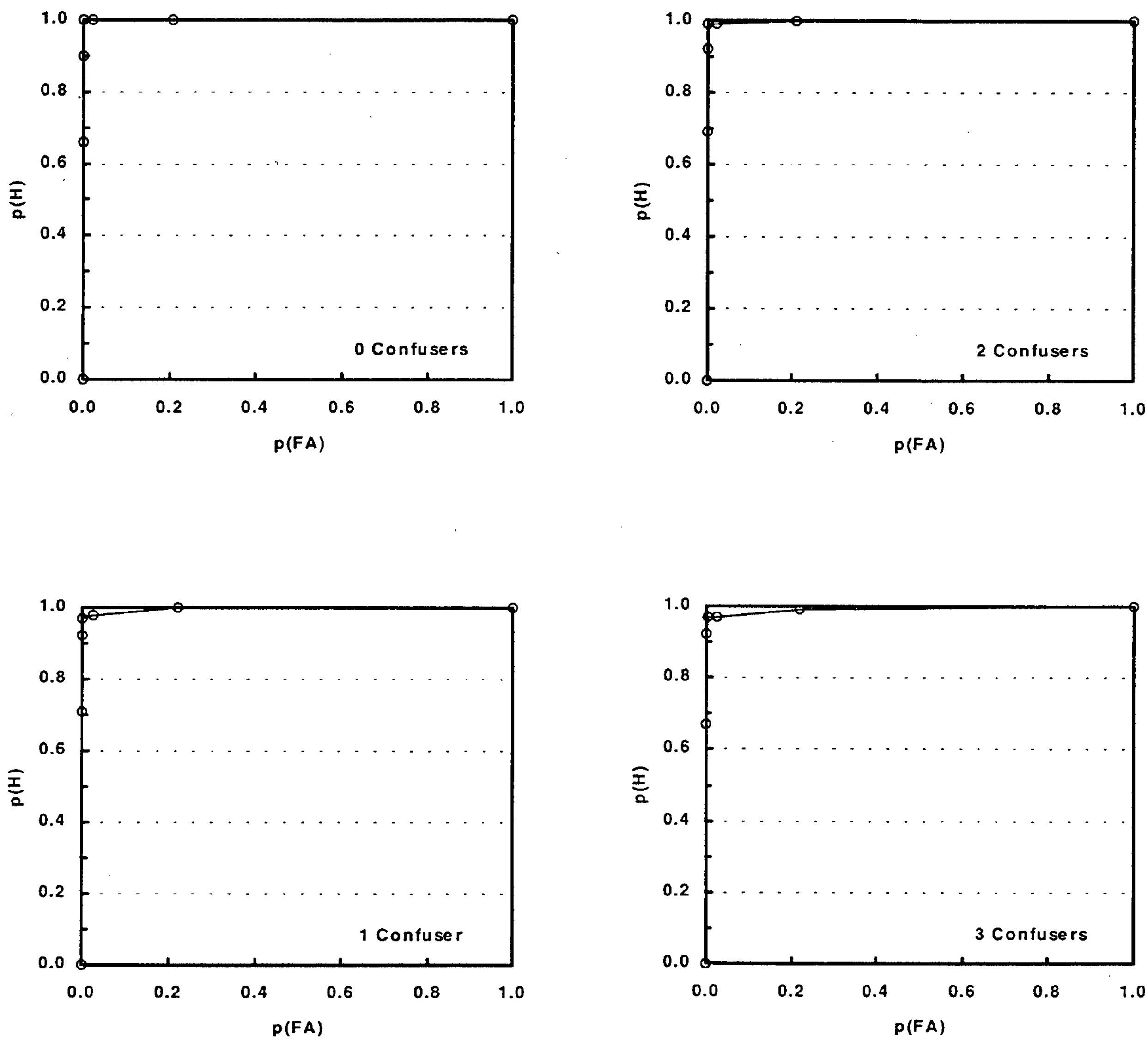


Figure C 17: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, low clutter, 45°.

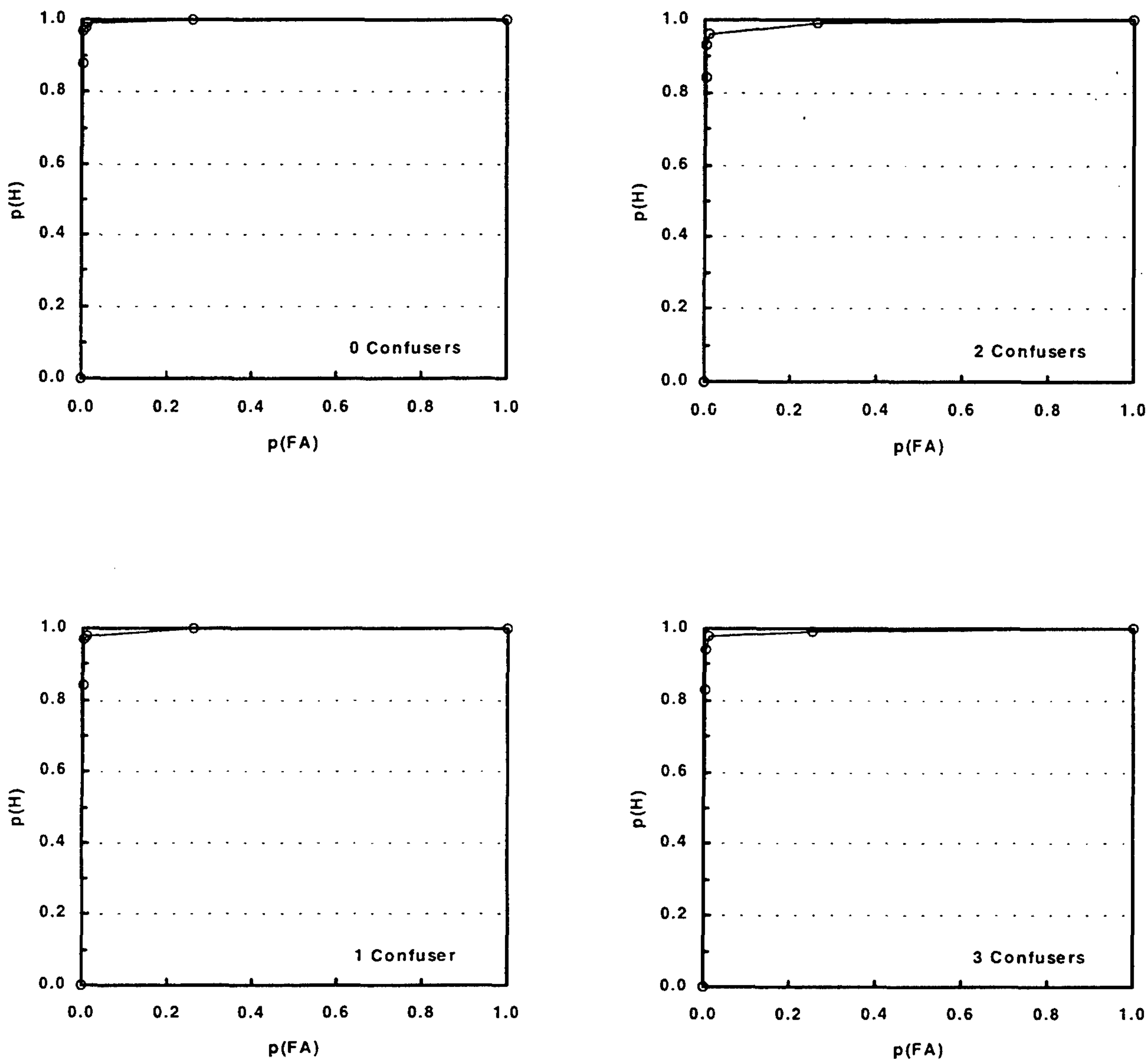


Figure C 18: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, low clutter, 90°.

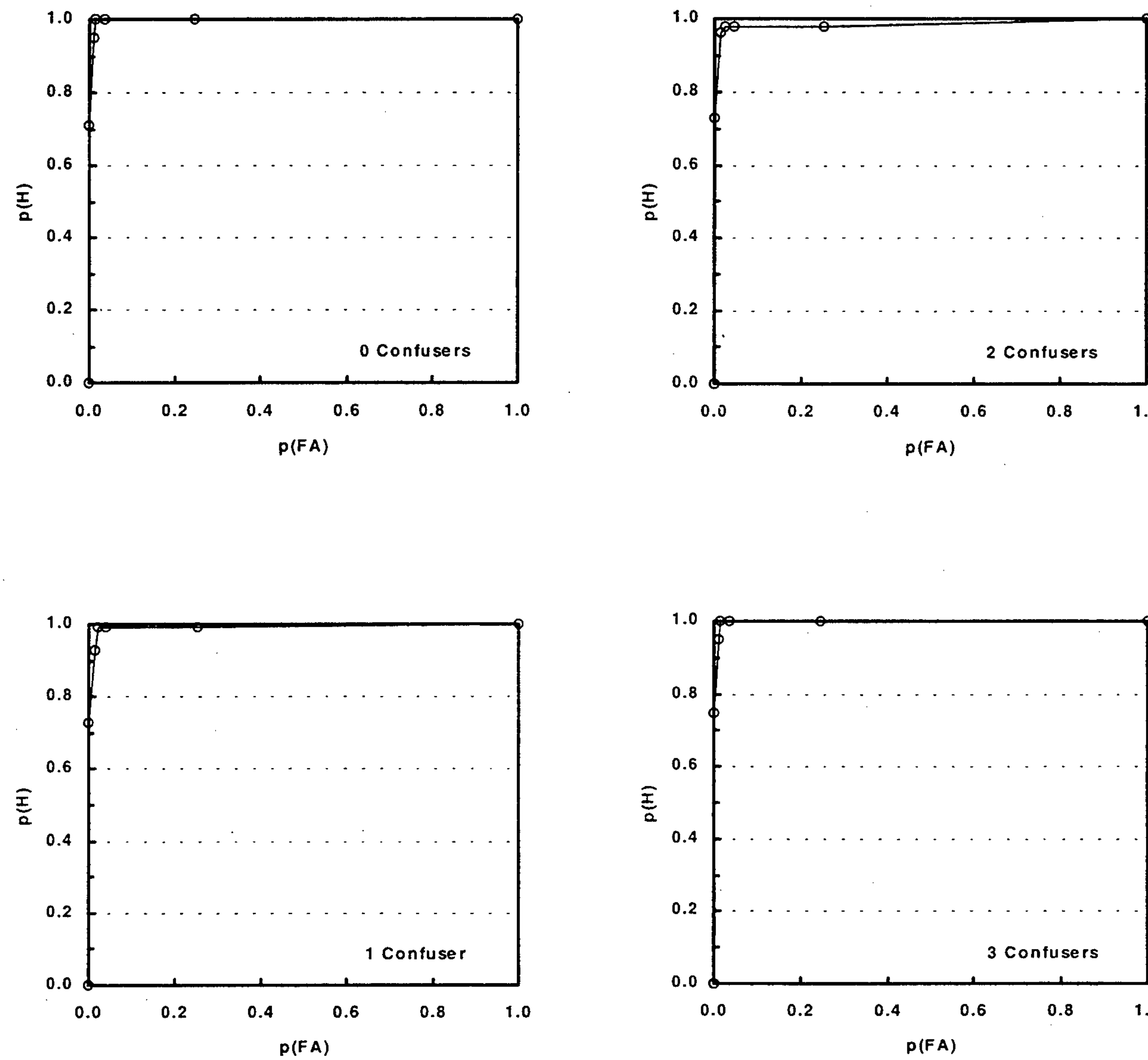


Figure C 19: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, low clutter, 135°.

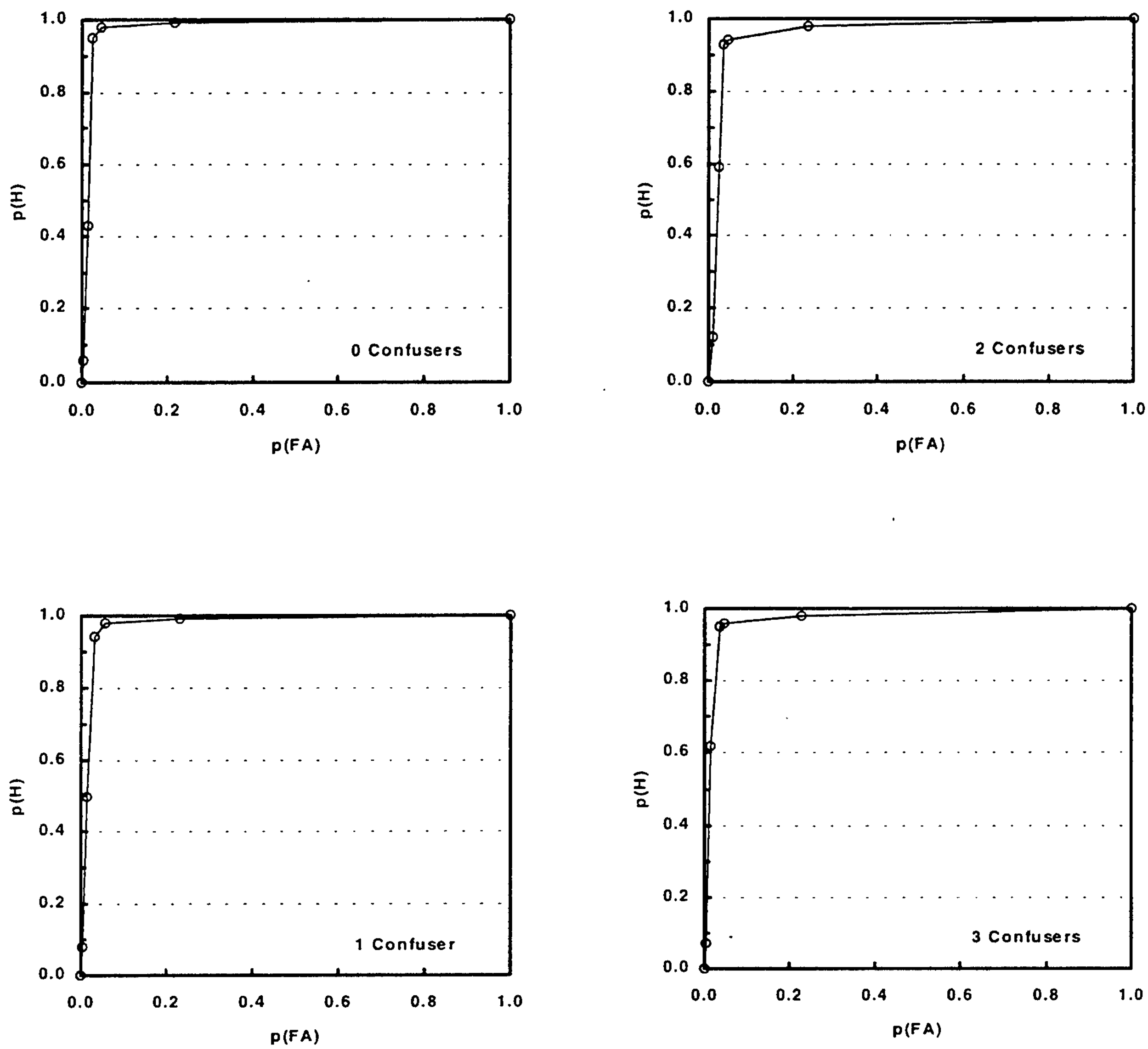


Figure C 20: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, low clutter, 180°.

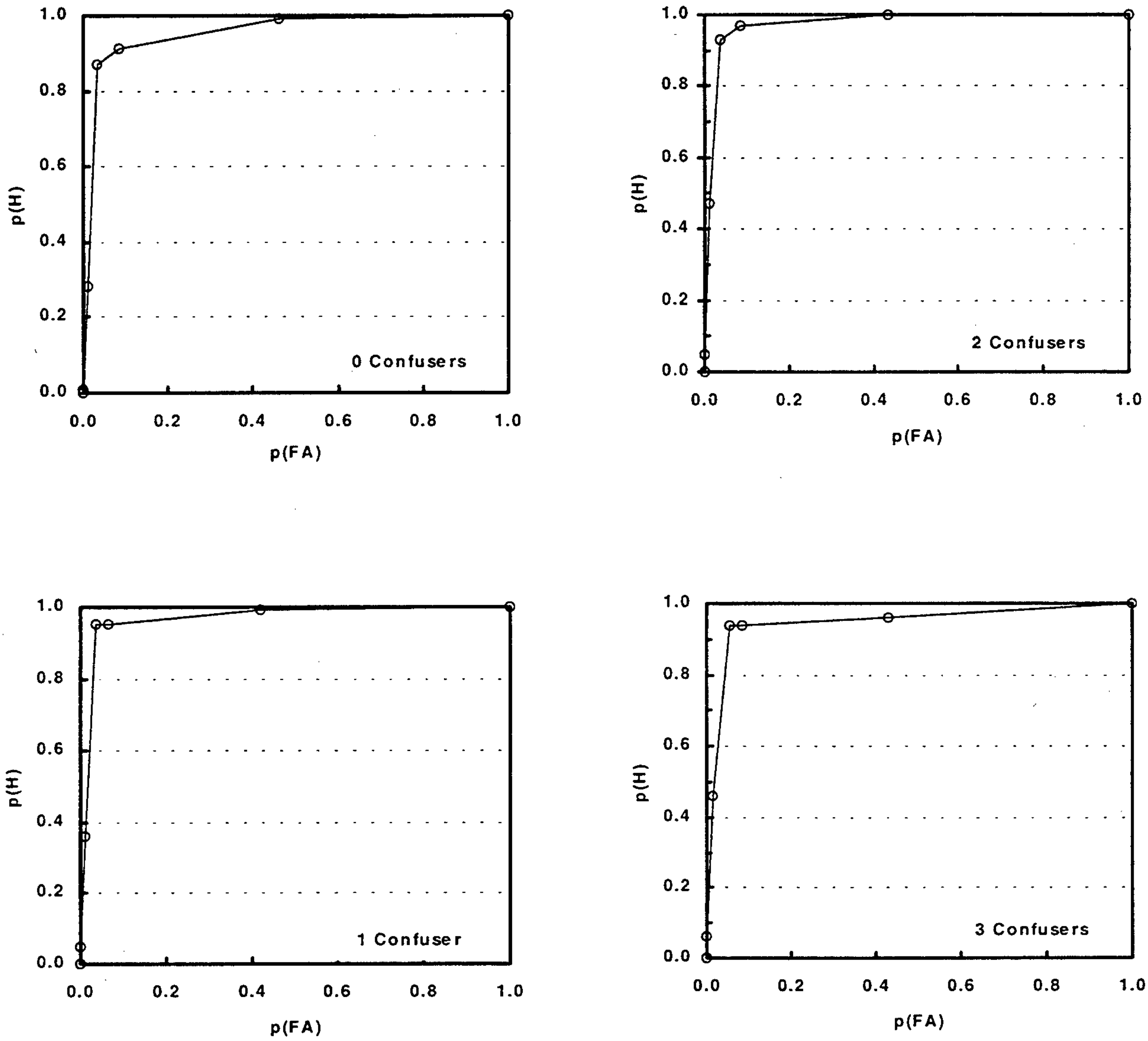


Figure C 21: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, medium clutter, 0°.

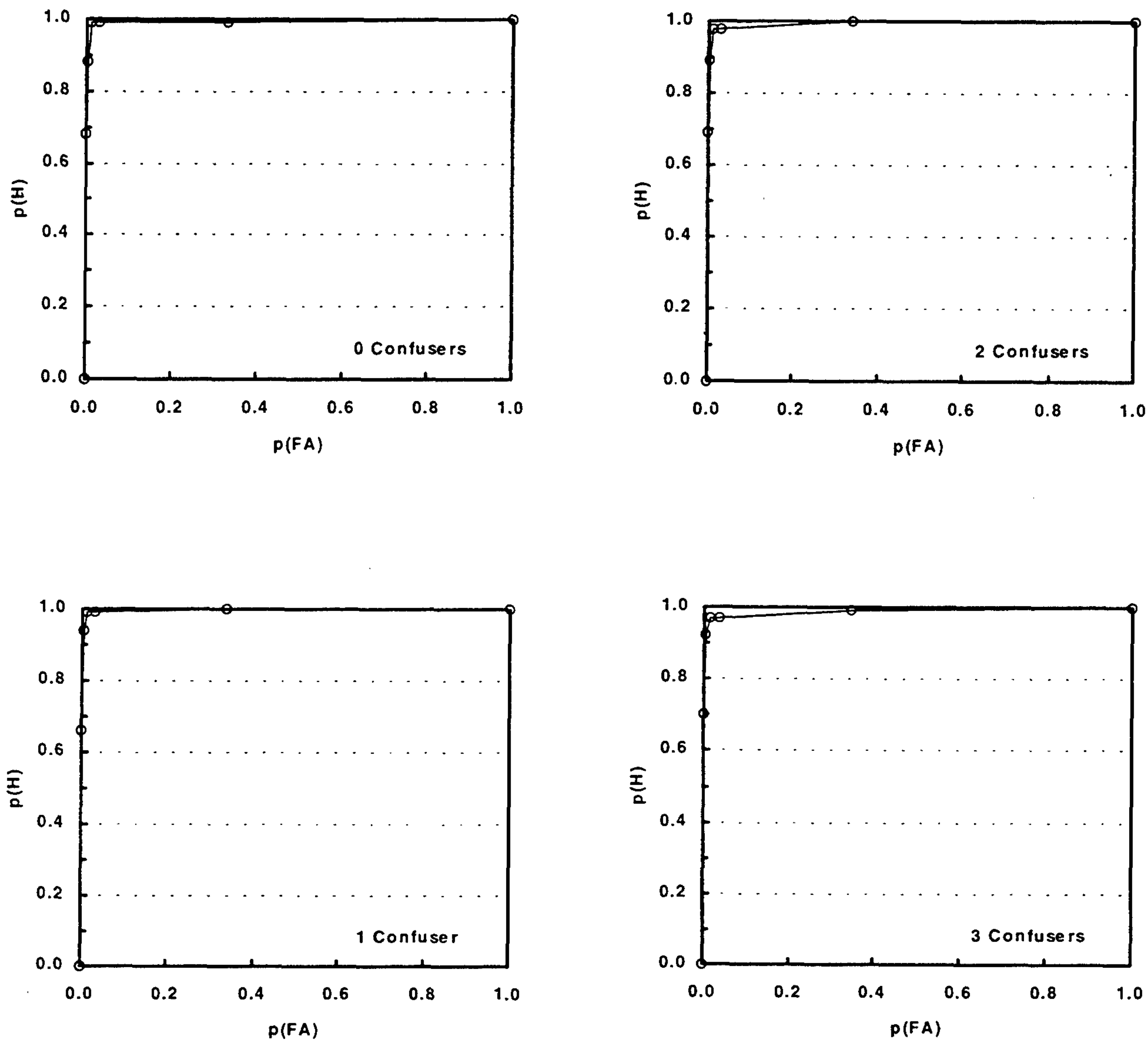


Figure C 22: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, medium clutter, 45°.

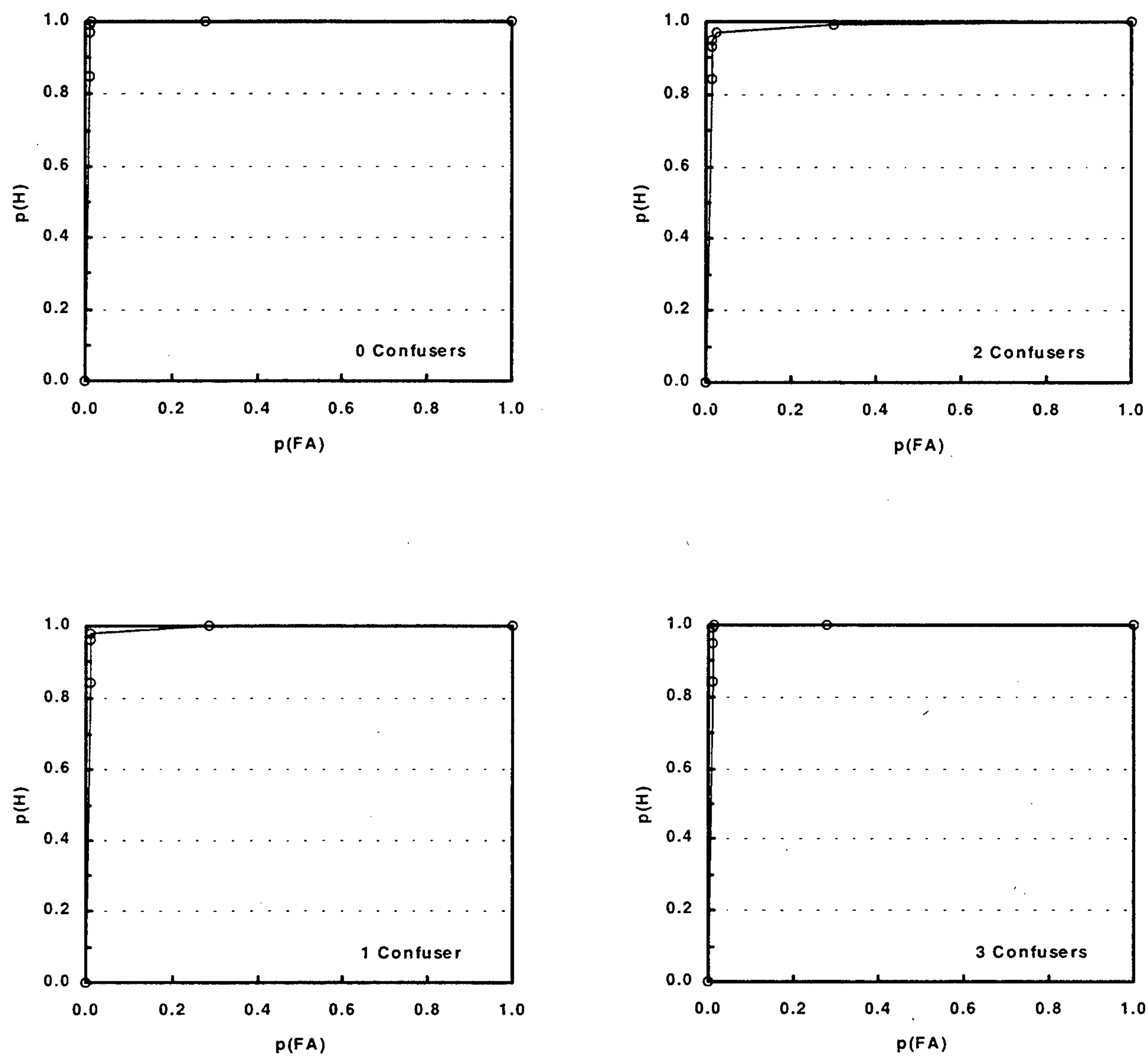


Figure C 23: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, medium clutter, 90°.

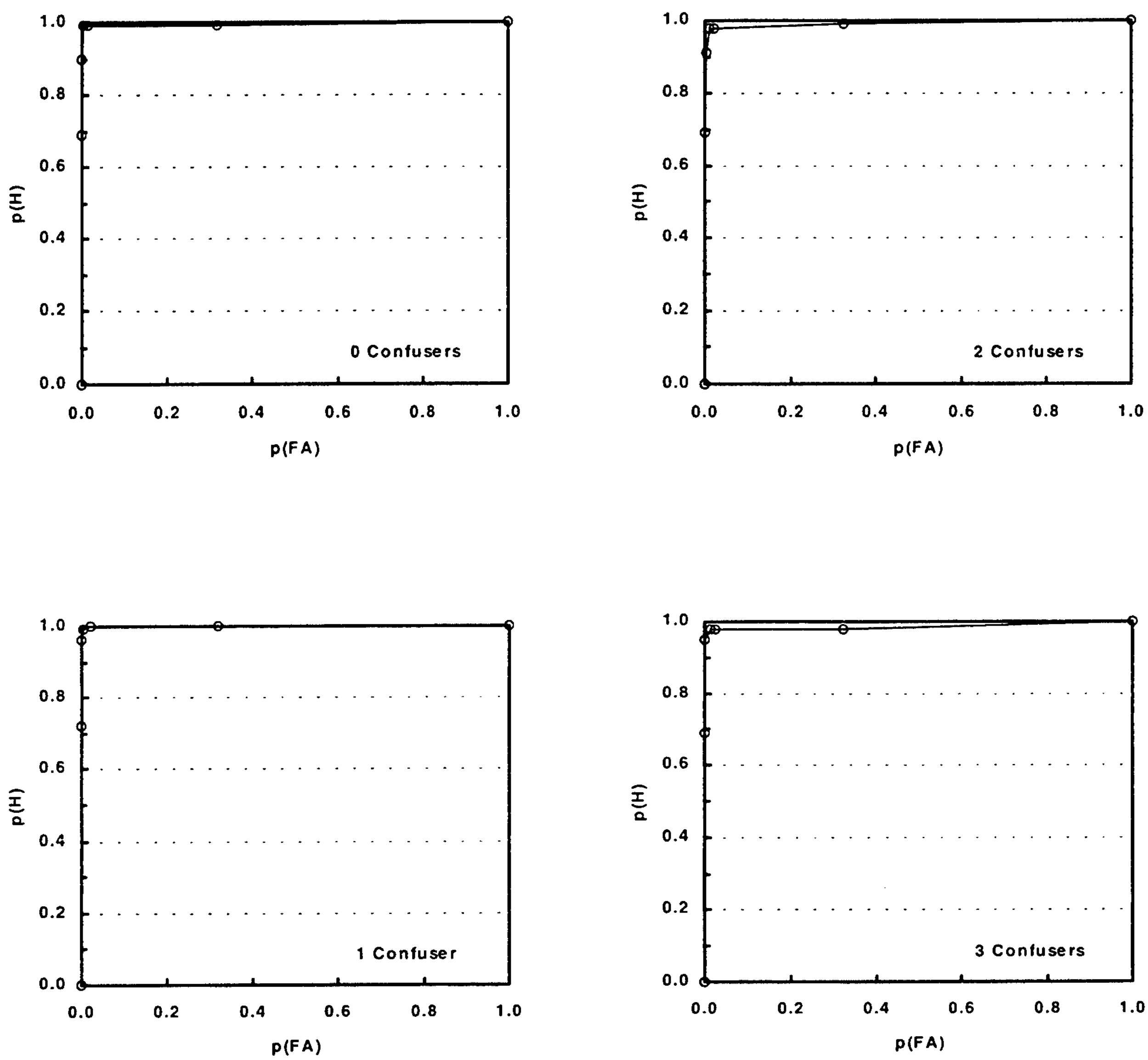


Figure C 24: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, medium clutter, 135°.

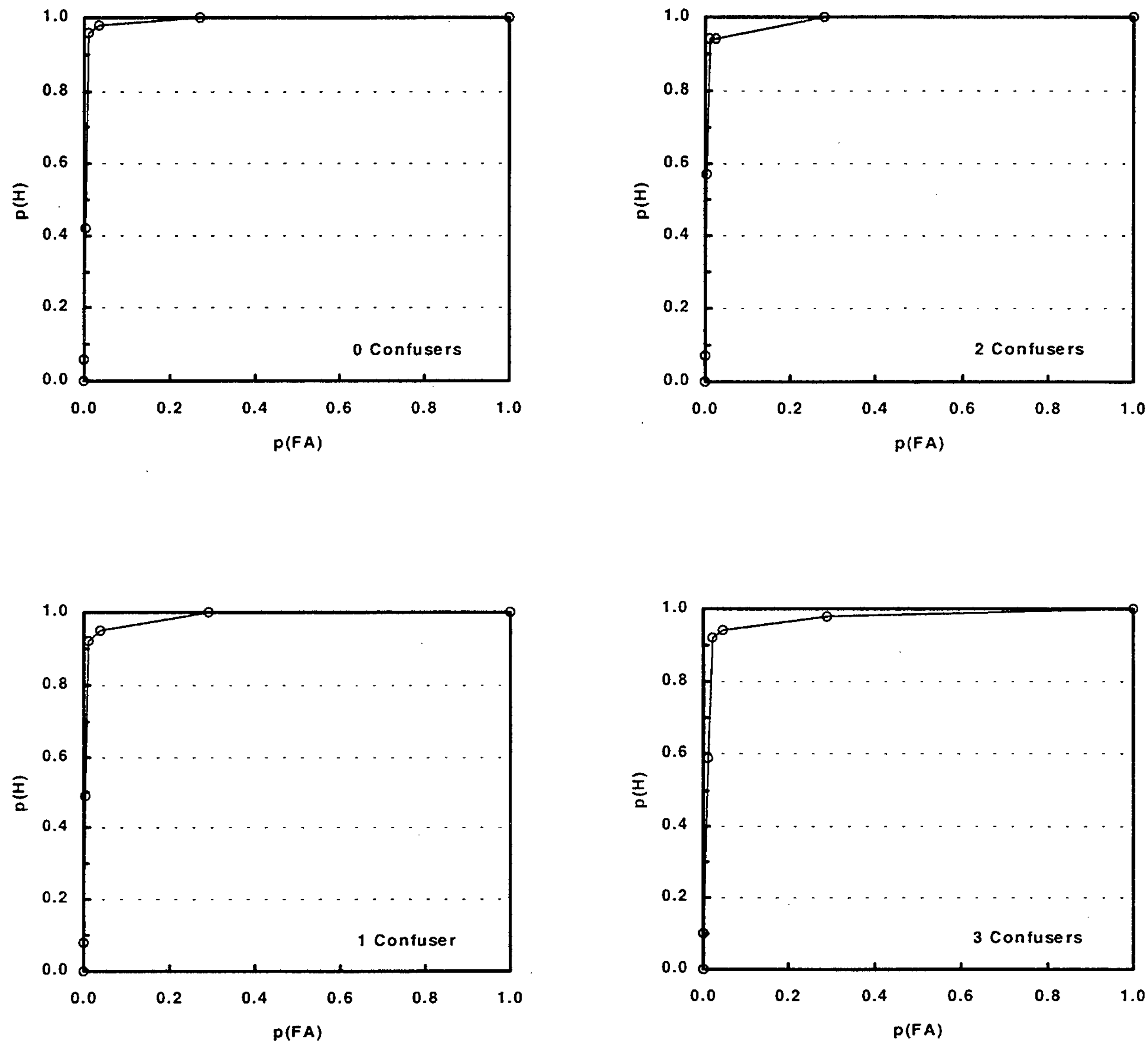


Figure C 25: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, medium clutter, 180°.

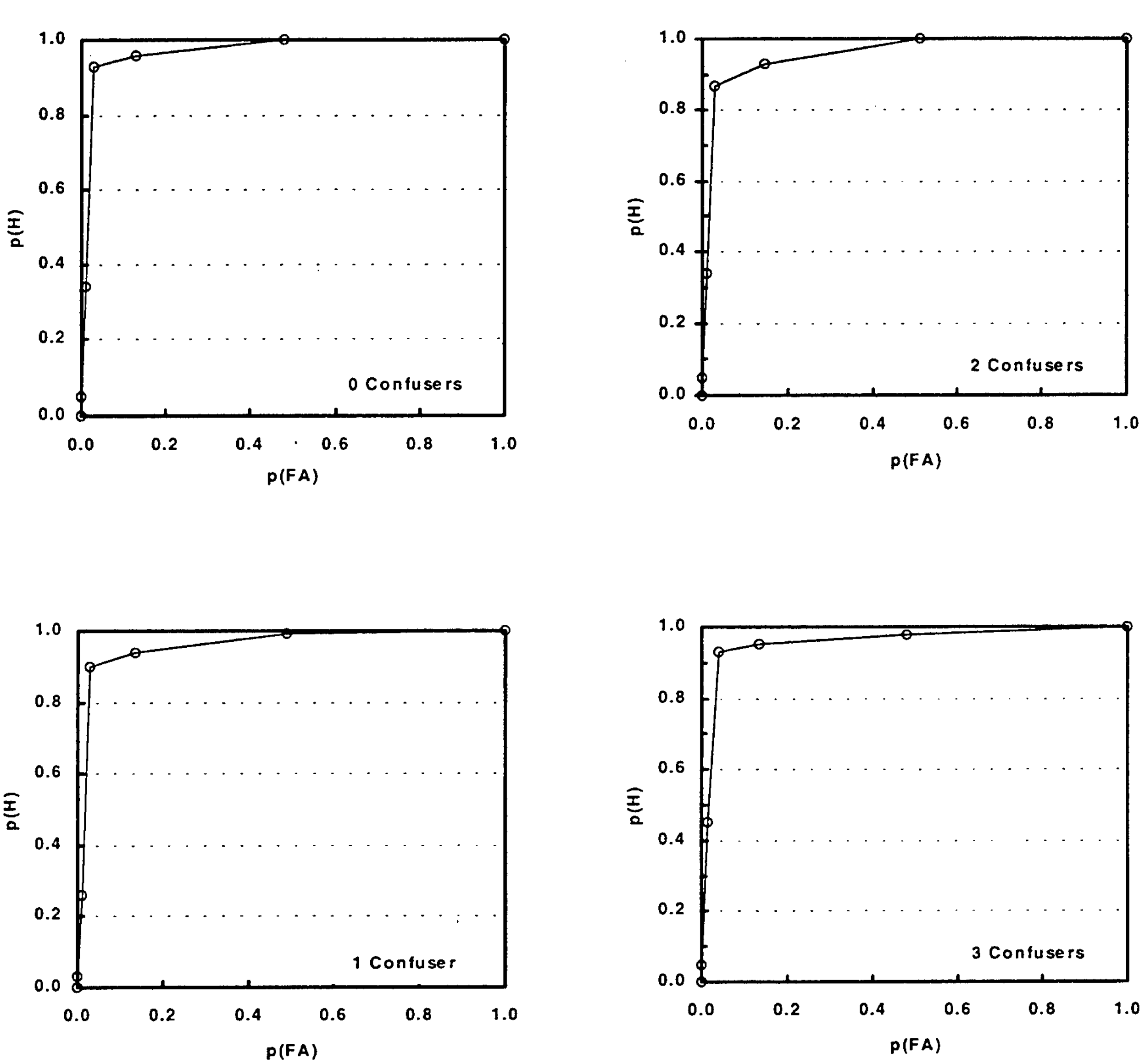


Figure C 26: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, high clutter, 0°.

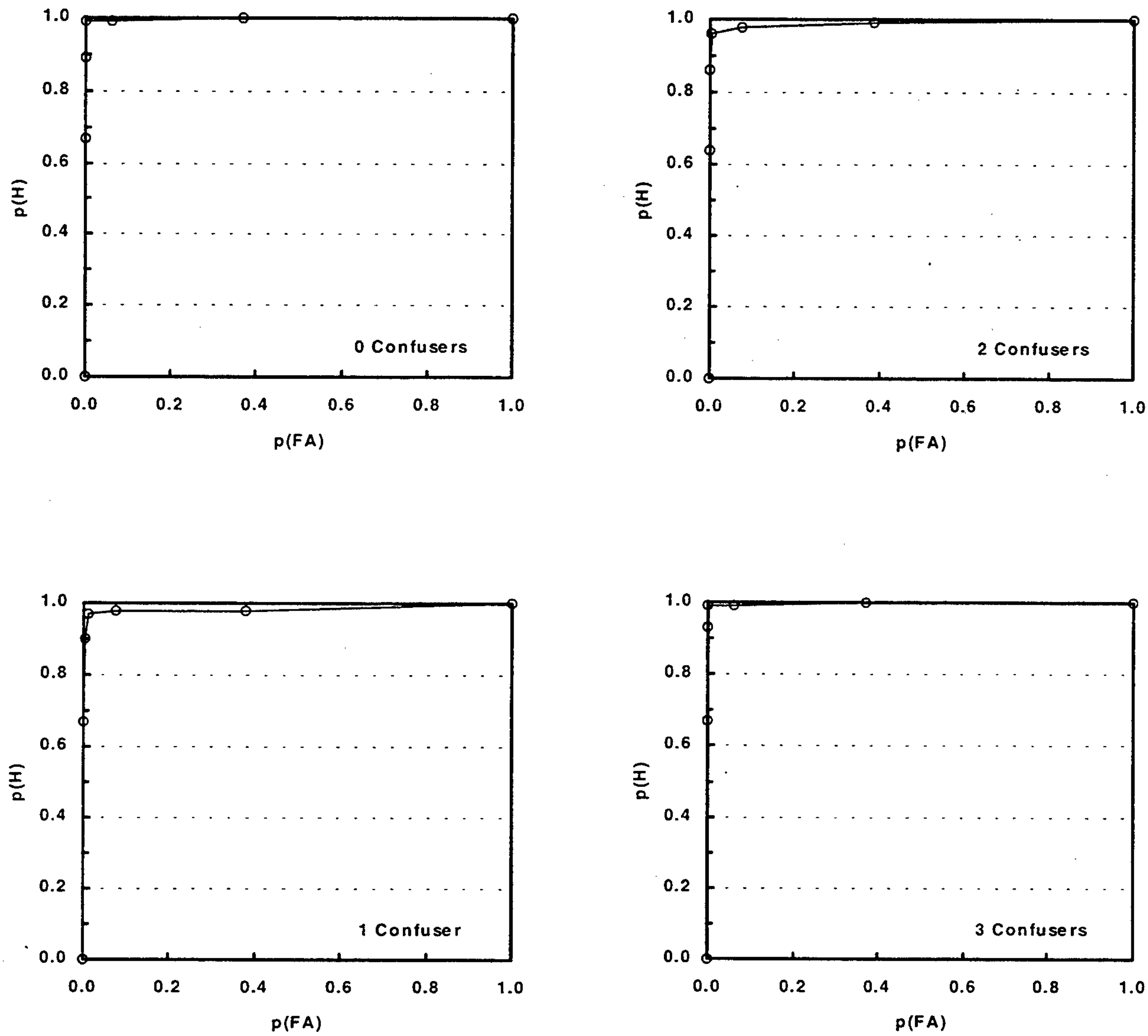


Figure C 27: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, high clutter, 45°.

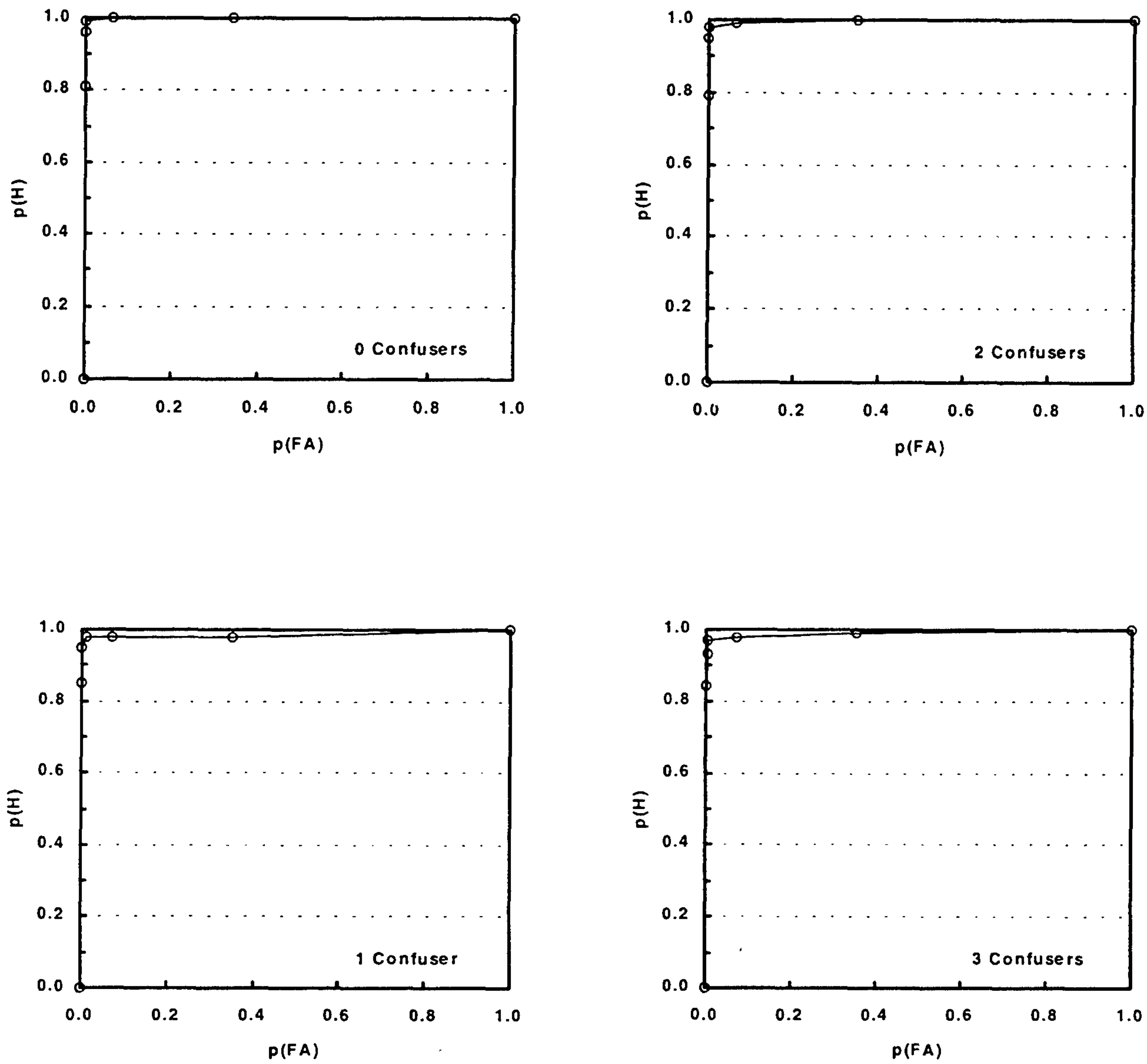


Figure C 28: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, high clutter, 90°.

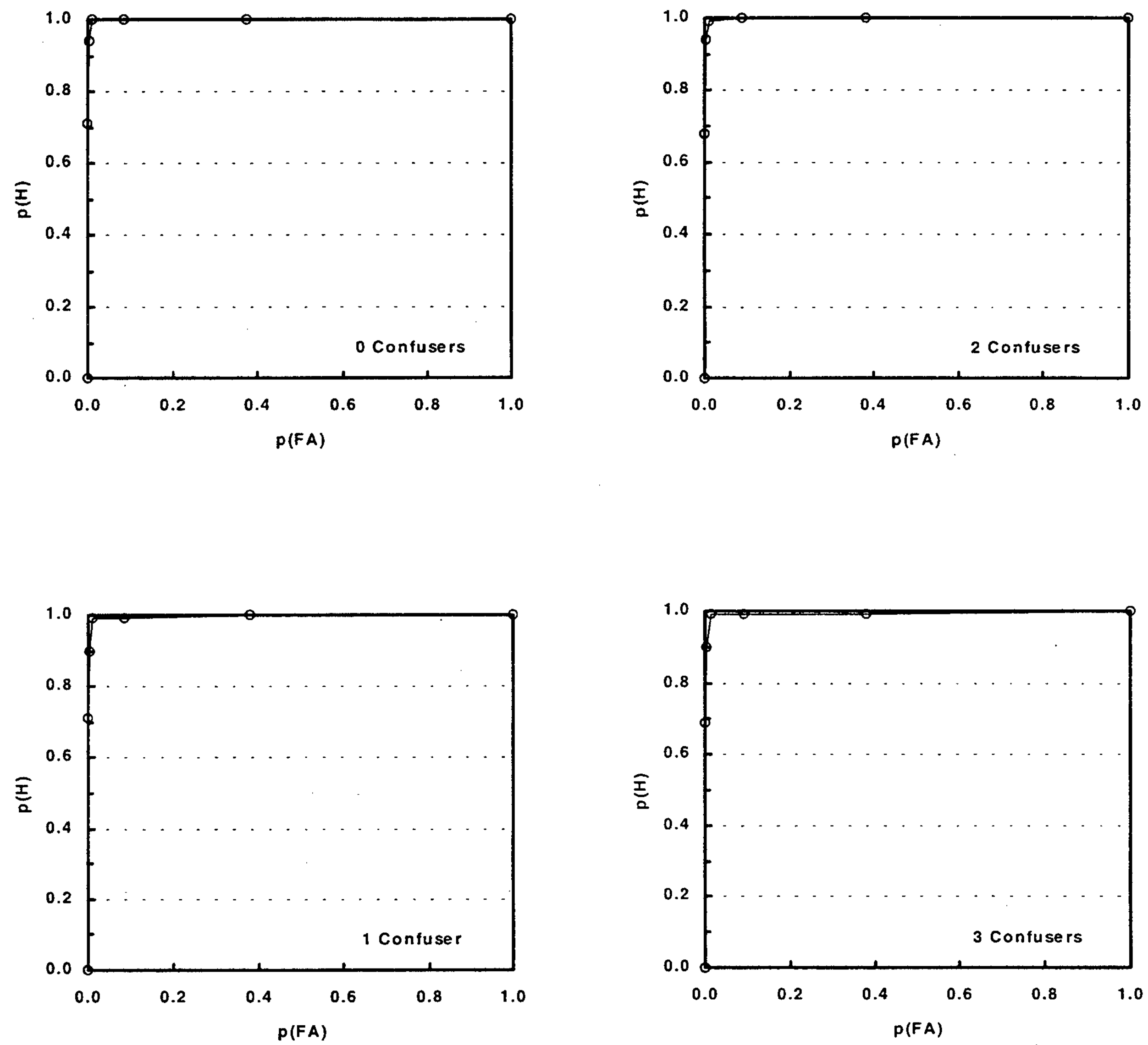


Figure C 29: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, high clutter, 135°.

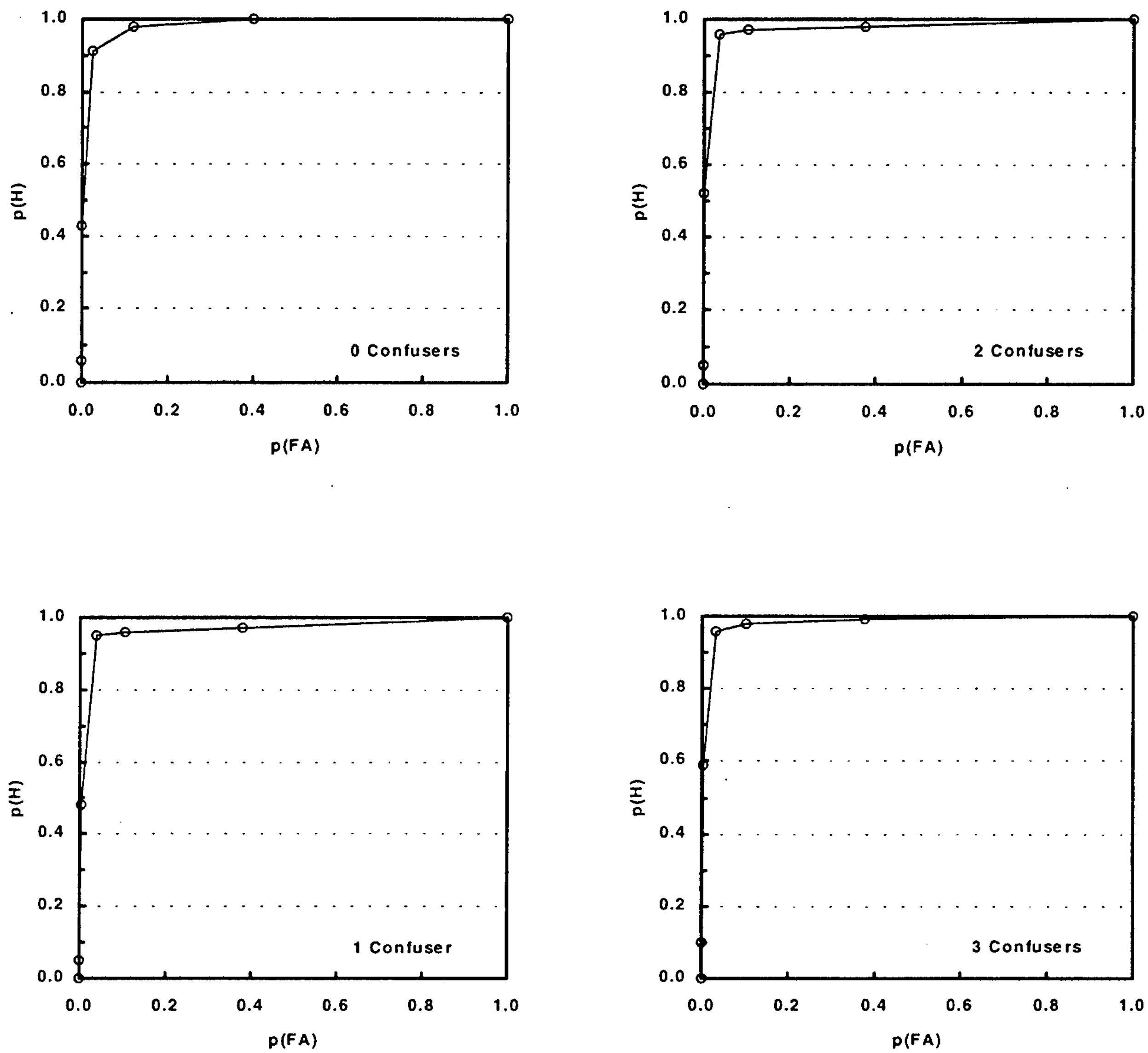


Figure C 30: ROC curves for 0, 1, 2, and 3 confusers at the 4 ft resolution, high clutter, 180°.

GLOSSARY

AFRL/SNAT	Target Recognition Branch, Sensor and ATR Technology Division, Sensor Directorate, of the Air Force Research Laboratory
ANOVA	Analysis of Variance
ATC/ATR	Automatic Target Cueing/Recognition
c	Signal Detection Theory Measure of Response Bias
CAD	Computer-aided Design
CIWAL	Crew Aiding and Information Warfare Analysis Laboratory
d′	Signal Detection Theory Measure of Perceptual Sensitivity
FA	False Alarm
H	Hit
IRN	Instructor Radar Navigator
IWSO	Instructor Weapons System Operator
J-STARS	Joint Surveillance Target Attack Radar System
LROC	Localization Receiver Operating Characteristic
M	Mean
MBVLAB	Model-based Vision Laboratory
MSTAR	Moving and Stationary Target Recognition
N	Noise
NT	Nontarget
ROC	Receiver Operating Characteristic
RT	Reaction Time
SAR	Synthetic Aperture Radar
SD	Standard Deviation
SN	Signal-plus-Noise
T	Target
TAD	Theater Air Defense
TEL	Transporter-Erector-Launcher
TM	Theater Missile
TSD	Theory of Signal Detection
UAV	Unmanned Aerial Vehicle
VSTM	Visual Short Term Memory
WSO	Weapons System Operator