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MANAGEMENT IMPLICATIONS OF THE USE OF
MULTIPLE RETINAL PATTERNS
AS A MEANS OF PERSONAL IDENTIFICATION

by

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Management Implications of the Use of Multiple Retinal Patterns As a Means of Personal Identification

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

A group of 51 adults was studied to determine if multiple patterns improved the overall recognition rates of a selected retinal scan device. The experimental mode was a laboratory simulation of a locking door mechanism controlled via The EyeDentification System 7.5. The study examined single, double, or triple patterns of individual participants over the course of eight weeks to see if any improvement in successful recognition rates could be obtained. After four weeks, the system achieved 100% successful recognition rates over all three groups regardless of the number of templates in memory. No false acceptances were recorded for the experiment. The conclusion drawn from this study was that the use of multiple patterns versus the use of a single eye template reference pattern, with The EyeDentification System 7.5, did not significantly increase the overall success rate of recognition for a given population.

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I. INTRODUCTION

The current surge in technologies in the field of biometrics has increased public awareness of the realm of possibilities and has manufacturers producing a range of new products. Biometrics is defined as the use of unique personal characteristic(s) to identify an individual. Via biometric devices, a person is identified "by virtue of what he is rather than what he has (a key, a number, or an ID card)." [Ref. 1: p. 78]

The theory behind the new biometric technologies is that it is much harder to falsify retinal patterns, fingerprints, palm prints, or voice patterns than to duplicate card keys, personal identification numbers (PIN), or photo access badges that are separate and easily misplaced. Any additional, non-biometric security measure often requires just another item to keep up with in a daily operational mode. Often cipher locks are successfully navigated after taking the combination out of a wallet or pocket. Use of a biometric device requires that the individual is physically present and is familiar with operational procedures.

Greater effectiveness of any security measure is a necessity in today's world of sensitive materials and protected communications. A variety of biometric technologies are being offered on the commercial security market today and more investigation into the protocols and processes of fully implementing a system of any type becomes a necessity. [Ref. 2: p. 6]

Beta testing, confirmation that the designed software and hardware produce the desired (and future advertised) effect, is usually completed before the product is offered on the market. Testing for protocols and procedures encompasses the actual use within the specific operational setting and all interim refinements. The resulting guidelines/procedures conform to all managerial expectations and thresholds. Depending on site specific requirements and rising/lowering expectations, the "final" procedures can be a drawn out and many looped iterative process.

This experiment examines the managerial implications of using a single personal identification device in a simulated controlled work environment. The biometric parameter chosen for the study was the retinal blood vessel pattern, [Ref. 3: p. 238] due to the retina's unique and relatively unalterable pattern.

TABLE I

COMPARISON OF BIOMETRIC SECURITY METHODS

biometric measure	METHOD	ERROR RATES	UNIT COST
FINGER-PRINT	optical digitization	low	3.5-7K
HAND PRINT	photo sensitive	medium	7-8K
RETINAL SCAN	infra-red heat detection	very low	10K
PALM PRINT	optical digitization	low	12K
VOICE PRINT	contour voiceprint	low	5-20K
SIGNATURE DYNAMICS	pressure/ acceleration	low	2-5K

* table adapted from Government Computer News, July 19,1985

One manufacturer, EyeDentify Inc. of Beaverton, Oregon, currently markets a retinal scan device for use in physical security applications. The EyeDentification System 7.5 model was chosen for use on a sample of young adults at the Naval Postgraduate School.

Other physical features, as seen in Table I, are unique and can be used as a means of control. None of the other measures are as stable and unchanging as the retinal vascular pattern. The eye shares the same stable environment as the brain. Only a few diseases or injuries are serious enough to alter the blood vessel pattern of the retina. These rare occurances would probably place the individual in a non-working status and not change the overall effectiveness of the biometric device. An indirect benefit of use of the retinal scan could be as a rudimentary diagnostic tool. If problems with identification of an individual by the retinal scan surfaced after a

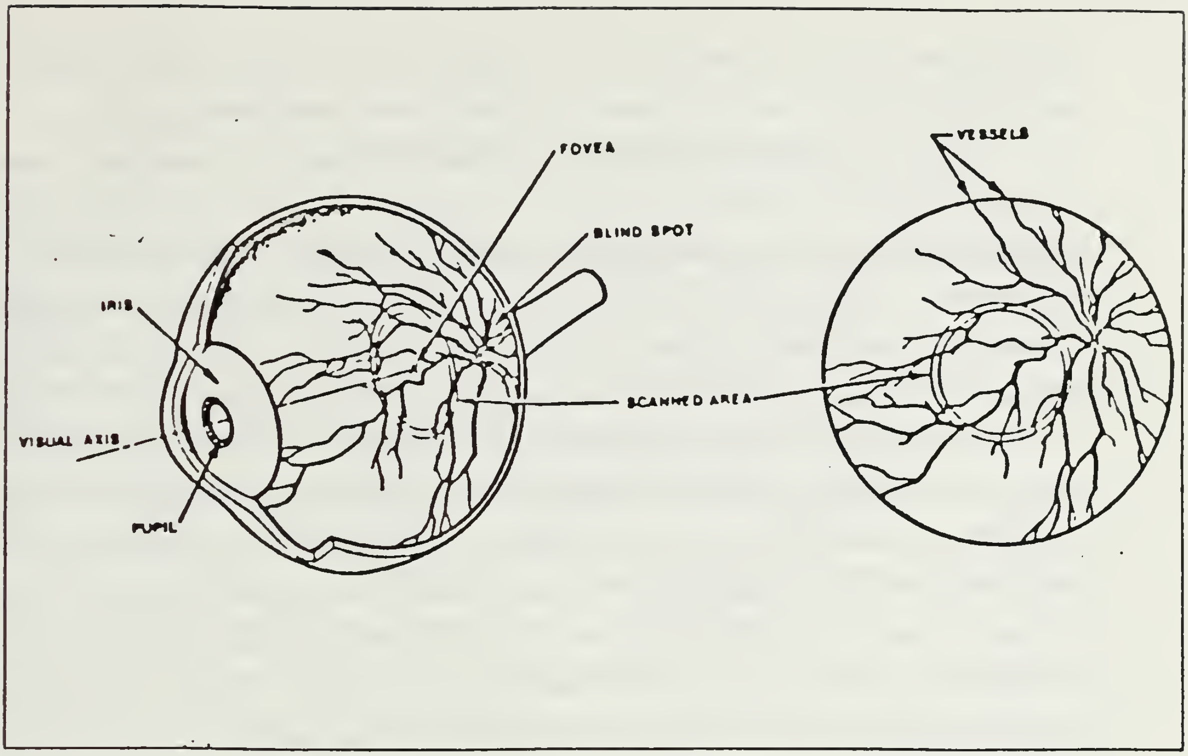


Figure 1.1 Retinal Scan Diagram.

period of successful use, one possible conclusion could be the onset of disease serious enough to alter blood vessel patterns.

Biometric devices and their usefulness to security applications depends on the capability of comparing an image of a physical characteristic with a stored record of that image.

> EyeDentify's retinal scanning method starts with a 450-degree circular scan of the portion of the retina centered on the fovea, or the area of sharpest vision. A low-intensity infrared light is used by a camera (called the ICAM) to make the retinal scan. As it scans the area, the camera takes 320 readings, measuring the variations in reflections that indicate the pattern of blood vessels. A software-implemented phase corrector compensates for rotations of the head or eye by the user. The scan by the ICAM produces a waveform that is converted into digital impulses and sent to a microprocessor. [Ref. 4: p. 1-5]

Figure 1.1 illustrates the specific area of the retina that the EyeDentification System 7.5 ICAM measures to produce the eventual stored eye template. The stable environment of the eye should provide nearly identical patterns, if the ICAM is focused on the same area for each trial. Multiple eye templates, when taken under the same enrolling protocols or procedures by the same system operator, merely reflect minor head alignment variations that should not affect overall recognition capability.

This experiment was based on the premise that one set of managerial guidelines is used to find the best device (biometric or not) to start or add to current security. A completely different set of managerial guidelines, procedures or protocols is required to know how to use any device as efficiently and effectively as possible on the specific site. The decision points and pathways to developing in-house protocols by a management system operator are based on observed performance of individuals using the system.

The author's use of protocol or protocol materials refers to the preliminary draft procedures of mandated in-house usage at the specific site of installation. Using this definition protocols will vary from installation to installation depending on use as specified by individual managers. Procedures and protocols, until finally in place, are the result of an iterative process between the users (of the system) and the overseeing manager. As the organization or security requirements change, any established protocol(s) will have to be evaluated and reworked as necessary.

This experiment observed 51 adults and compared results with other commercial installations currently using The EyeDentification System 7.5. Comparison of the experimental results with the site responses are discussed in detail in the conclusions.

II. DESCRIPTION OF PROBLEM

Several previous studies had used retinal scans to study small groups under highly controlled conditions. [Ref. 5,6: pp. 42, 57] These studies established the feasibility of using the retinal scan for physical security. This study investigated the effective use of various managerial protocols in conjunction with the retinal scan and sought ways to increase the probability of obtaining a successfully recognized scan.

Effective "on-the job" retinal scan usage should entail a manageable system that allows self service of identification. When used in conjunction with a locking door mechanism, ideal usage would produce no false rejects of authorized personnel (Type I error) and not admit any unauthorized person (Type II error). Type I error refers to the mathematical probability that a person enrolled in the system and an authorized user, will be rejected or not identified as an authorized user. Type II error refers to authorized users, unauthorized users or imposters that are incorrectly identified as another authorized user.

A manager's nightmare is a marketed complete physical security mechanism that would allow access to unauthorized personnel (Type II error). Additional managerial concerns are the authorized workers who are held in an isolation booth or are unable to get through a locked door and become frustrated (Type I error). Effective managers would choose to have a system that produces the least possible combination of Type I and II error. Unauthorized entry problems (Type II error) is a far more critical security problem for managers and is treated with different procedures than employee frustrating Type I error.

This experiment sought to explore individual usage patterns and the effect of multiple eye signature patterns in memory when used daily to simulate the controlled entry to work spaces. Although both recognition and verification modes were available on the System 7.5 , only the recognition mode was used in the study.

Recognition mode on the System 7.5 checks the 'new' retinal scan against all other patterns contained in memory for a positive match. In other words, the just scanned retina must match another pattern in memory for the individual TO BE recognized. The verification mode operates by the machine comparing the Personal Identification Number (PIN) entered with the stored retinal pattern in memory for that

PIN. Operating with the verification mode does not remove the hazard of an individual writing down the PIN on a slip of paper to carry in a wallet because the biometric parameter is not the sole source of identification.

Recognition mode was determined to most closely simulate working conditions with positivé identification of the individual scanned as compared to verification of a personal identification number (PIN) in the verification mode. Both modes on The EyeDentification System 7.5 utilize the 40-byte eye signature template. Baseline system parameter is prescribed by the manufacturer for recognition, as a correlation score of 75% between reference templates, or individual eye signature(s) in memory, and the newly acquired fresh scan. The lowest correlation scores recommended by the manufacturer are those that are pre-set at the factory (75% for recognition, 70% for verification). [Ref. 4: p. 2-12] Individual sites have the option of going in through the change menu and raising or lowering the threshold based on degree of sensitivity required by that particular facility.

The recognition mode compares the freshly acquired scan, taken at the press of the scan button, with the stored reference templates of all individuals currently contained in memory. A successful match against the databank produces the PERSONAL IDENTIFIER from that eye signature in the window of The EyeDentification System 7.5. (See Figure 2.1) The PERSONAL IDENTIFIER is normally the full name of the individual or the last name and first initial of the person enrolled. Any department name or other identifying label up to eight (8) characters could be entered into memory as deemed necessary by the system operator or overseeing manager.

Coupled with a locking door mechanism, the successful match would also unlock the interior access door of the isolation booth. An unsuccessful match produces the message REPEAT which indicates that no match was found and tells the individual to repeat the scanning process. With an unsuccessful match the door remains locked. Three consecutive unsuccessful attempts are allowed before the message SEE SECURITY is displayed in the window. At this point a "panic" button, or other device to alert security/management, is necessary for the individual to get through the controlled access door. By law, all access devices have to allow the individual to easily retrace attempted entry path if access is blocked due to failed identification or recognized unauthorized user.

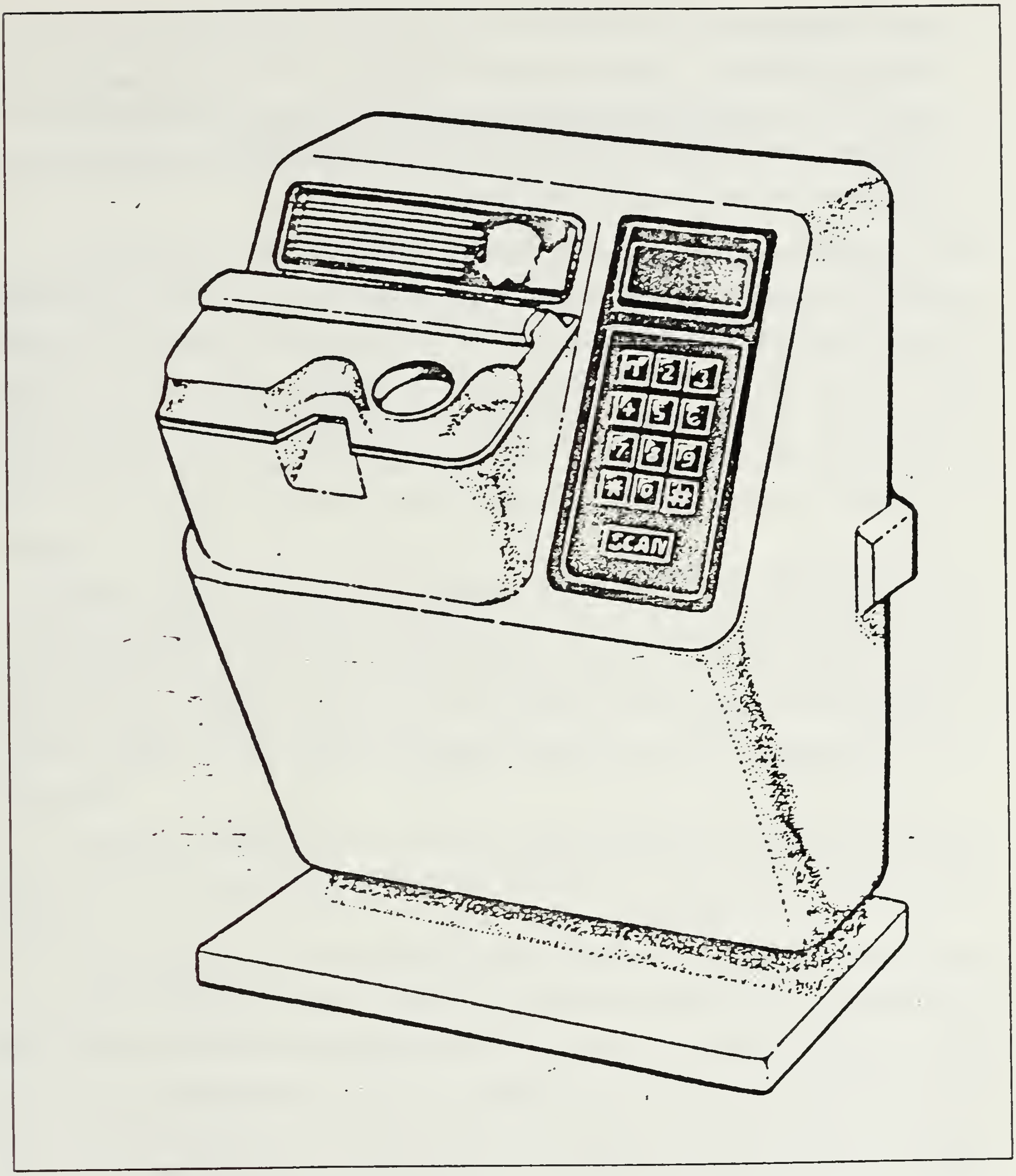


Figure 2.1 The EyeDentification System 7.5.

An ideal management goal would be to flawlessly operate the scan with zero percent type I and II error for maximum security and minimum employee frustration. Operating with an advertized Type I error rate of 1% [Ref. 1: p. 78], The System 7.5

has an established success rate of 99% for recognizing enrolled retinas correctly. With additional protocols, a realistic managerial expectation would be to operate the retinal scan with a successful recognize rate of above 99%. The area of this investigation was to examine whether Type I and Type II errors were affected by the use of one or more eye signature reference templates in memory.

III. DESIGN AND METHODOLOGY

A request for volunteers for a thesis experiment was circulated in two subpopulations of the Naval Postgraduate School, Monterey, California. Operations Research (OR) class 3404 and section PL-53 of the Computer Curriculum provided a majority of the human subjects for the experiment. Due to the nature of the population at the Naval Postgraduate School (NPS) and the method of invitation to participate, this study cannot be considered free of bias of the school population as a whole, but with the uniformity of the students, it is likely this is a representative sample.

Excellent general health and eyesight that is correctable to 20-20 are basic underlying attributes of the Naval population at large that provided the majority of the baseline personnel pool for the overall testing pool of subjects. Three (3) foreign officers, two (2) civilians (one staff and one NPS student), and 46 Department of Defense (DOD) NPS students comprised the group that volunteered for the experiment.

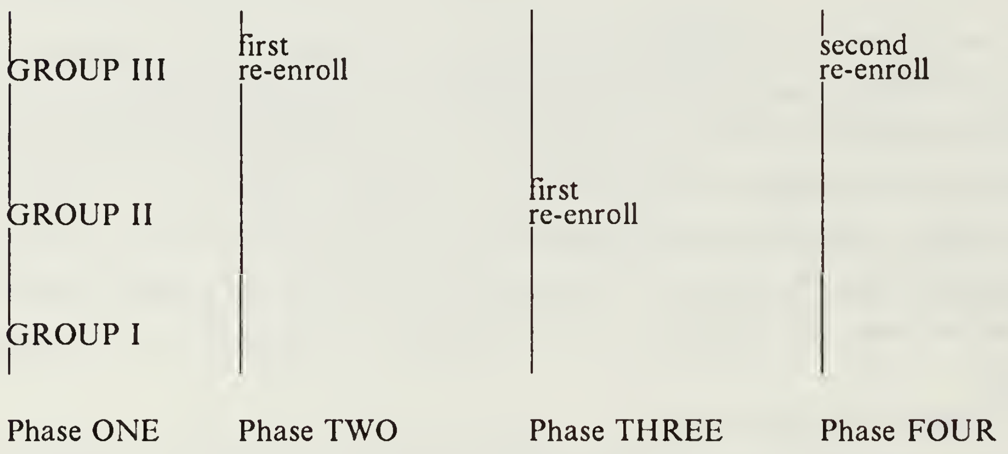
Age range studied was 25 to 40 years in this experiment. Thirty-nine (39) male and twelve (12) female participants were studied over a nine (9) week period. (See Table II)

This original group of 51 subjects was broken down into three (3) subgroups for the purposes of experimentation. Group III (Appendix A) was randomly selected from the original starting group and was re-enrolled on two (2) separate occasions during the run of the experiment. The first re-enrollment for Group III took place at week four (4) or about the one third mark of the time period. A second re-enrollment was taken during week six (6) or approximately a two thirds mark. Seventeen individuals were selected for Group III participation.

Group II (Appendix B) was also randomly selected from the original group but was only re-enrolled once during the experiment, at about the halfway point or during week five (5). An additional seventeen individuals were selected and tagged for Group II from the remaining thirty four people left of the original starting group.

TABLE II

DIFFERENT PHASES OF THE EXPERIMENT



Group I (Appendix C), those seventeen individuals not randomly placed in one of the other groups acted as a control group and provided baseline data for comparison purposes. Individuals in Group I had a single enrollment at the start of the experiment and were never re-enrolled.

Experimenter desired baseline success level for the retinal scan experiment, as outlined in the experimental description section, is a 99% recognition rate. Each participant would daily attempt to scan and log all occurances for the eight week period. Upon completion of the experiment, each group would be statistically analyzed for usage trends and behavioral patterns.

All subjects were given an introductory brief description of what the retinal scan was, how operation was performed and why it was most important to get the best patterns at the enrollment process because the resulting template would affect the success rate of future use. Enrollment was conducted in the Man-Machine Interface (MMI) Laboratory on The EyeDentification System 7.5 (model # 100519) with head alignment bar and luminous dot target. Over a two (2) day period all 51 individuals were enrolled in a sequential order determined by their respective personal schedules. Although sequentially arranged in the bubble memory the participants were not aware they were assigned a Personal Identification Number (PIN) or that they were arranged sequentially.

Participants were instructed to take a seat and look into the eye lens while arranging their hands on either side of the machine with their right thumb lightly over the scan button. After finding the light source(s) with their right eye, they were instructed to align all observed sources so that the intense pin point of light was in the exact center of any blob or circle(s) of light. Five individual retinal patterns with a correlation of 90% or higher were used to produce a single averaged reference eye signature pattern for each individual, which was stored in memory, and served as the master pattern against which all fresh scans were compared. Any subsequent re-enrollment followed the same procedure of five patterns with a correlation of 90% or higher.

> Enrollment is simply the process of creating and storing an individual's eye signature template. Each eye scan is built from a minimum of three to five retinal scans. Each scan is stored by the system, based on how it compares with the previous scans. The better the comparison, the higher the score. The eye signature template created during individual enrollment is the key to consistent, positive identification of each authorized individual. This template allows the system to recognize an enrollee, while rejecting any imposter who may have a similar, but not identical, eye signature. Usually, an organization appoints one person to act as the system operator. High quality eye signatures are the key to successful operation of the EyeDentification System 7.5. [Ref. 4: p. 2-7]

The software component of the 7.5 drives the process of enrollment. An eye signature template is built from several ICAM (eye camera) scans for each individual as they are enrolled in the system. Reflected light from the infrared ICAM is collected and converted into an analog signal. The analog waveform is digitized and stored in memory. The System uses forty (40) bytes (320 bits) of the enrolled template in memory to successfully reference the desired template per individual or eye in PIN verification mode, or 72 bytes (576 bits) per individual or eye in recognition mode. These differing bit templates are system requirements and are a function of the software processing to either recognize or verify against the original stored eye signature templates. Once this eye signature is built, it is linked with other individual identification information such as name, department, or other data, and stored in the IBANK (enrollee databank) memory along with other eye signatures. On the initial enrollment, usually more than five patterns were attempted but only those patterns meeting the criteria of a correlation of 90% or better for each retinal eye signature template attempted were used in the enrolling portion of the experiment.

Few difficulties occured at initial enrollment. Most questions and concerns were attributed to the learning curve of a new piece of machinery or with the potential eye health problems with shining a light in the eye. Use of the EyeDentification System 7.5 poses no danger or risk to the individual of physical injury. The source of illumination is a gallium aluminum arsenide infrared light-emitting diode. [Ref. 4: p. 1-6] The levels of light emitted during scanning are several orders of magnitude below the safety standards established by the American Conference of Governmental Industrial Hygienists. Products using this same technology include refrigerator door lights, smoke detectors, television remote controls, and wireless headsets.

Noted by the system operator was the ease of use by artillery and bombardier-navigator (BN) officers who had never used a retinal scan but had familiarity with sighting equipment. This concentration of individuals with such experiences would not be possible in an unbiased population but will not unduely skew any overall results of the experiment.

As subjects were re-enrolled, their new pattern and PIN were stored in bubble memory *without deleting any previous pattern(s)*. Eighty (80) templates were already contained in bubble memory at the beginning of the experiment from previous, unrelated work. Consequent enrollment of the entire original group caused the enrollee databank to grow to 131. Re-enrolling Group III during phase TWO of the experiment brought the Ibank total to 144 by adding 13 second templates. Only thirteen templates were added on the first re-enroll of Group III. Four of the selected group did not re-enroll despite numerous scheduled re-enrollment sessions. After a two week period of unsuccessful total group re-enrollment, Group III was redefined to be the thirteen (13) individuals who had re-enrolled and were willing to re-enroll during week six.

Phase THREE added 17 re-enrollments from Group II to bring the total to 161 eye signatures in memory. No problems were encountered with obtaining re-enrollments on the randomly selected seventeen individuals from the original 51. Group II remained as chosen during the entire experiment without any modifications or personnel shifts.

The last re-enrollment of Group III, with their 13 templates, in Phase FOUR brought the total to 174 templates in Ibank memory. As the study progressed through the four phases, the number of templates against which any fresh scan was compared did not remain constant during the eight weeks. An additional two (2) templates were added to the Ibank memory by re-enrolling two individuals that were having a difficult time getting recognized by the 7.5 during the first weeks of the experiment. At the completion of the Phase FOUR, the 176 total templates were the result of the scheduled 174 templates from the re-enrollments of Groups II and III plus the two unscheduled re-enrolls to assist individuals with their potential access problems.

Individuals were logged on a daily log sheet (see Table III) so progress could be watched and determination could be made how patterns were being matched in the Ibank. Listed participants only had to record their attempts for daily trials beside their name.

TABLE III

FIRST WEEK LOG-IN SHEET

WEEK: 1

name	first trial SCAN ATTEMPT "the message or personal identifier displayed as a result of the scan attempt"	second trial SCAN ATTEMPT
ADCOCKJ	adcockj	*R, adcockj
AGAPIOUNE	**R, R, see security	R, agapioune
ALDERMANB	aldermanb	aldermanb
BABBR	babbr	R, R, babbr
	. . . .	. . . .

* R represents the single REPEAT message followed by a success

** multiple R's and SEE SECURITY represents an unsuccessful attempt

The experiment consisted of an individual entering the lab, looking through the eye lens, finding the light source(s) and aligning the head correctly before pressing the scan button. The EyeDentification System 7.5 was set in the recognition mode for the duration of the study, so that on attempted entry an individual's fresh scan was compared against all templates in memory.

> When the EyeDentification System is in recognition mode, it checks all templates in memory in search of a match. Identification time depends on the number of eye signature templates stored in memory. You can tell if your unit is in recognition mode by looking into the eye lens. If the dot alignment target is present, the unit is in recognition mode. To gain access when the unit is in recognition mode, look into the eye lens and concentrate on the dot alignment target visible inside the ICAM. When the smallest brightest dot is centered within the larger dots, press the SCAN button. The system then compares the resulting wave form with all stored eye signatures. The person is recognized or not, depending upon whether or not a matching signature is found. Upon recognition, the system automatically activates release of the security mechanism involved. [Ref. 4: p. 2-30]

Phase ONE of the experiment was to complete the initial enrollment process and start everyone on a five day per week schedule of two (2) attempted recognitions a day. Daily use was defined to be at least two (2) attempts sometime during the day. A total of ten (10) attempts were logged for a complete week for each subject. All three groups had a single template in memory and were following the exact same scan and log-in sheet procedures.

This initial phase was designed to get all participants used to the system and its successful use and providing baseline data. Three weeks of the Phase ONE operation would do away with any learning curve effects that might affect later phases. During Phase ONE subjects either experienced successful recognition that they logged as a 'Y' on the daily log sheets or 'R' (repeat) or 'SEE SECURITY' for unmatched attempts at retinal scans.

Phase TWO was the first re-enrollment of Group III. This provided a second set of patterns in bubble memory for this group. At the onset of Phase TWO everyone in the entire original group began logging the PERSONAL IDENTIFIER that appeared in the window of the 7.5 Eye-dent on the daily log sheets. So Brooks (PIN 89 and PIN 143) might be recognized as either BROOKSJ (PIN 89) or BRO2 (PIN 143) depending if the daily scan was matched to the first or second enrollment pattern.

Phase THREE was the first re-enroll of Group II individuals. At this point (see Table IV) in time, two thirds of the original group had a second pattern in the database contained in bubble memory. Group II personnel were instructed to carefully log which pattern was used in recognition by writing down the exact PERSONAL IDENTIFIER used in each recognition attempt.

TABLE IV

FIFTH WEEK LOG-IN SHEET

WEEK: 5

name	first trial SCAN ATTEMPT "the message or personal identifier displayed as a result of the scan attempt"	second trial SCAN ATTEMPT
ADCOCKJ	adcockj	*ad2
AGAPIOUNE	agap2	**ag3
ALDERMANB	aldermanb	aldermanb
BABBR	b3	babbr
	.	.
	.	.
	.	.
	.	.

* ad2 represents the occurance of the second template (1st re-enroll)

** ag3 represents the third template (2nd re-enroll)

Phase FOUR was the second re-enrollment of Group III subjects with their third set of templates within the database of The Eyedentification System 7.5 . Quensels (PIN 104, PIN 141 and PIN 171) could be recognized against the patterns QUENSELS (PIN 104), QUEN2 (PIN 141), or Q3 (PIN 171). Login procedures were to record which of the three templates was used in recognition.

IV. EXPERIMENTAL RESULTS

Successful recognition during the study was the identification of the individual pressing the scan button from the eye signature templates in memory. Identification, via any of the personal identifiers, was considered successful as long as the SEE SECURITY message was not produced before the personal identifier. Any of a number of combinations could be considered within the allowable three (3) consecutive unsuccessful attempts which produced the SEE SECURITY message.

All 51 individual records were examined against the subjective benchmark success rate goal set for the experiment at 99%. The average mean for the entire original group of 51 was 98.29%, which included all initial learning trials. By the end of three weeks of the experiment, all groups were achieving 100% recognition rates. No false acceptances (Type II error) were encountered during the eight weeks of the experiment. All following discussions will examine Type I error.

Seventeen (17) participants were found to have average successful recognition scores below the 99% threshold. Of those 17, two (70% for PIN 99 and 80% for PIN 82) were determined to be outliers and were deleted from the any computations involving the original group. These two individuals were omitted for their consistent poor performance and obvious skew from the entire group.

PIN 82 and PIN 99 were deleted from statistical analysis because of the questionable nature of their trials. Consistent poor use practices of the retinal scan apparatus led to continuous failures on the part of PIN 99. Repeated instructions and cautions on operating procedures did not produce any noticable change in user methods or recognition success. A perceived enrollment problem led to several weeks of total failure on the part of the System 7.5 to successfully recognize PIN 82. With a different eye signature template of this same individual in memory (PIN 134), no other single failure was produced or recorded. Both records were removed from the raw data prior to analysis.

The remaining 49 individuals, as shown in Figure 4.1, used for experimental analysis, ranged from 92.86% to 100% for total successful recognition rates. Total successful recognition rate was determined by dividing the number of successful trials by the total number of trials. Thirty four individuals from the experiment had perfect or 100% recognition records. Group I produced thirteen people who exhibited 100% successful recognition rates. Group II broke out with twelve of the 17 individuals exhibiting a perfect recognition rate. Seven of the thirteen members of Group III had a 100% recognition rate. Fifty three to 72 percent of each group had a perfect successful recognition rate.

midpoint of total success rate interval by percentages	count	
70%	1	*
72%	0	
74%	0	
76%	0	
78%	0	
80%	1	*
82%	0	
84%	0	
86%	0	
88%	0	
90%	0	
92%	1	*
94%	0	
96%	5	*****
98%	9	*********
100%	34	**********************************

51 total participants@

the 51 success rates in the above histogram represents pooled success rate for all conditions over all attempts.

@ for illustration purposes only.

2 questionable data points (PIN 82 and PIN 99) were removed from the database so only 49 participants results were used as the the raw data for statistical analysis

Figure 4.1 Histogram of Pooled Success Rate.

A corrected mean for the 49 data points, with the deleted two scores of 70% (PIN 99) and 80% (PIN 82), was found to be 99.15%. Both the corrected mean (99.15%) and the trimmed mean [Ref. 7: p. 39] for the original group (99.23%) fell above the experimentally determined threshold for success. The trimmed mean is a mathematical device whereby the top 5% and the bottom 5% of the sorted raw data is deleted from the sample and the remaining raw data (90% of the original data) is averaged and used in place of a conventional mean. A trimmed mean better represents the data points as a normal distribution.

Group III (the subgroup with two separate re-enrolls) had a mean success rate of 98.26%. Group II (the subgroup with a single re-enroll) had a mean success rate of 99.04%. Group I, the subgroup with no additional enrolls beyond the initial enroll at the start of the experiment, had an average success rate of 99.23%. These averages alone support the contention that additional enrollments may not improve the overall effectiveness and success of the Eyedentification System 7.5. Whether the decrease in success rate for Groups II and III is due to the additional number of patterns or due to the additional retraining and awareness of the factors that affect successful recognition cannot be distinguished from this experiment. Overall average success rates for all three groups were approaching the 95 to 100 percent rate. Managerial concern may not distinguish between the three approaches so much as the overall success rate is well above 90%. The effort expanded to get a fractionally better success rate on site enters into the managerial equation for efficiency and effectiveness.

A. GROUP ANALYSIS

1. *Group I*

Group I over the full eight weeks of data collection followed a pattern that was relatively predictable. A learning curve influence can be seen in Fig. 4.2 in that the first week had the lowest over all success rate of 97.78%. Second week average success rate showed improvement over the first week with 98.89%. The third week showed perfect total recognition rates for the entire group. Unsuccessful attempts at recognition did not occur after the third week of the experiment for any member of Group I, II or III with the exception of PIN 99, who was deleted from the statistical database. Weeks four four through eight averaged 100% over the nineteen (19) participants studied.

2. *Group II*

Group II results as seen in Fig. 4.3 showed an interesting and distinctive pattern when viewed over the full eight weeks. The first two weeks had the same

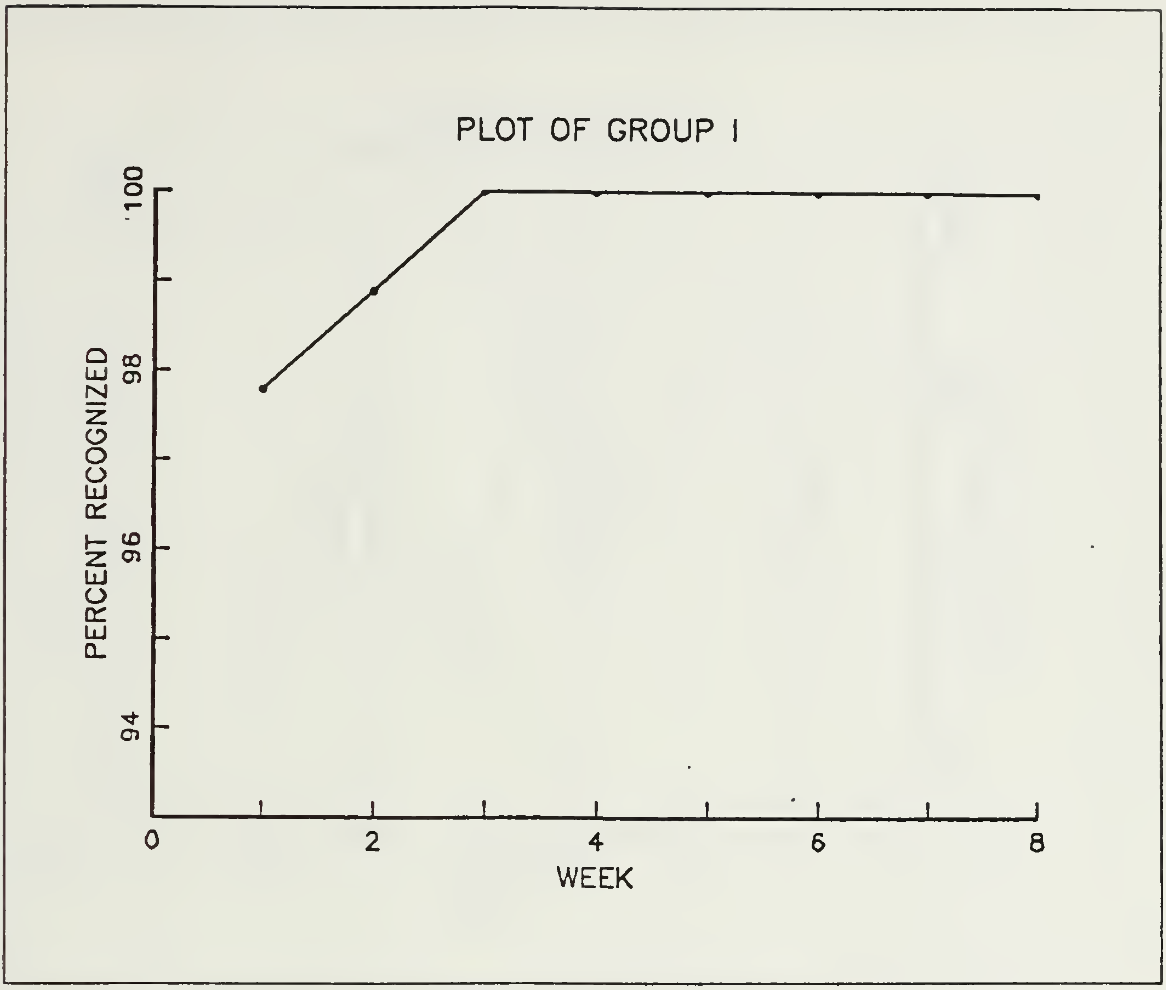


Figure 4.2 Plot of Group I.

overall average for the 17 participants. A drop in successful recognition rates occured during the third week for an average of 95.88%. Weeks four through eight showed a consistent success rate of 100%. Interesting to note is that the re-enrollment for Group II took place during the fifth week. No recognition problems were seen after the re-enrollment BUT 100% successful recognitions were occuring the week before the re-enrolling. By examining the averages for each week all the failures occured in the first three weeks with the least successful week being week three.

3. *Group III*

Group III was the group with two separate re-enrolls; the first took place during week four, and the second re-enroll took place during week six. As seen in Fig.

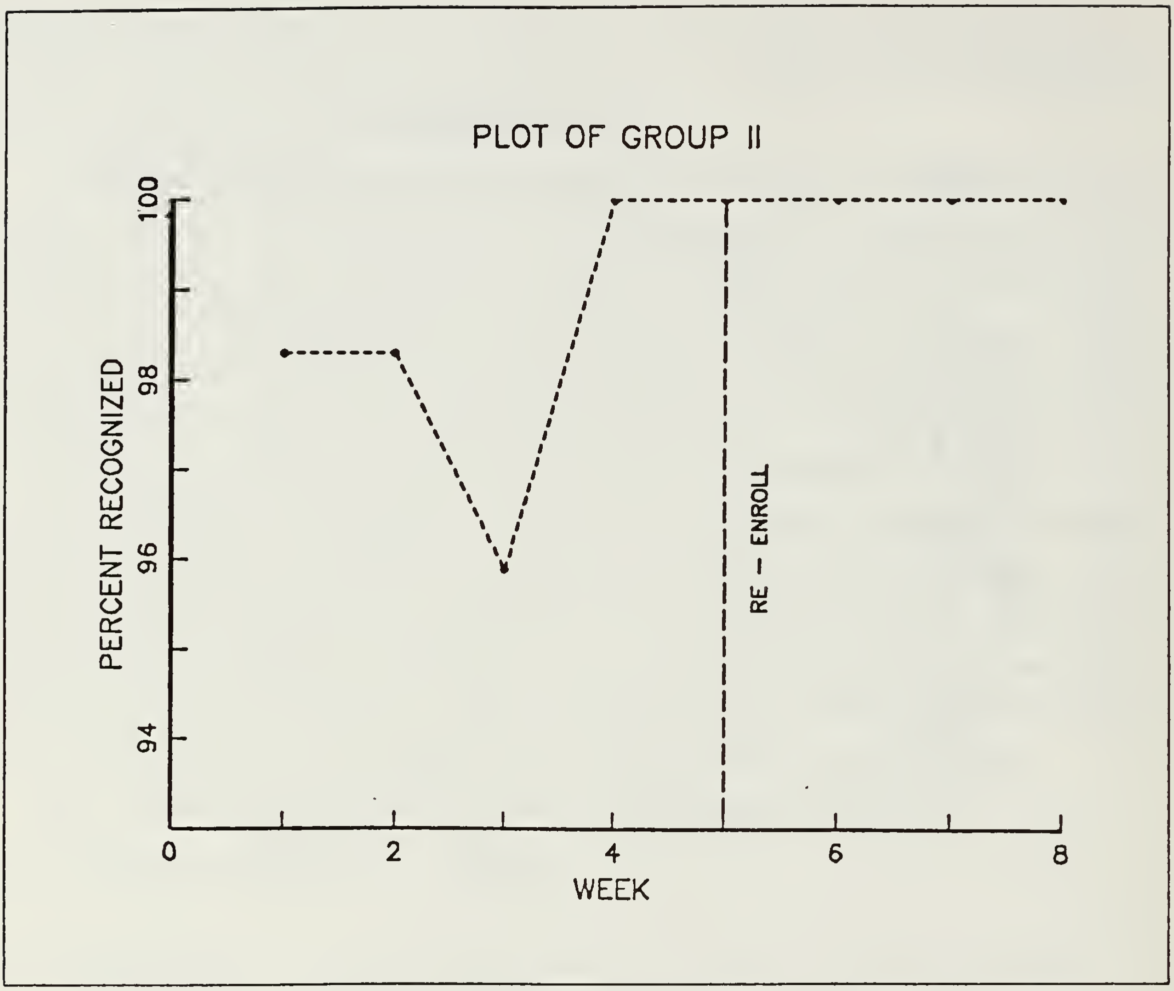


Figure 4.3 Plot of Group II.

4.4, week three showed the least successful recognition rate for the group as a whole with 94.62%. Week one had an overall rate of 93.85%, the lowest single week for any of the groups. Week two showed a strong improvement and some indication of learning curve effects with a 97.69% recognition rate. A noticable drop to 94.62% occured during the third week in Group III. The week (four) of the first re-enrollment produced 100% successful recognitions and this 100% was sustained for the remaining weeks of the experiment. The third eye template in memory had little effect on the overall success rate for the group.

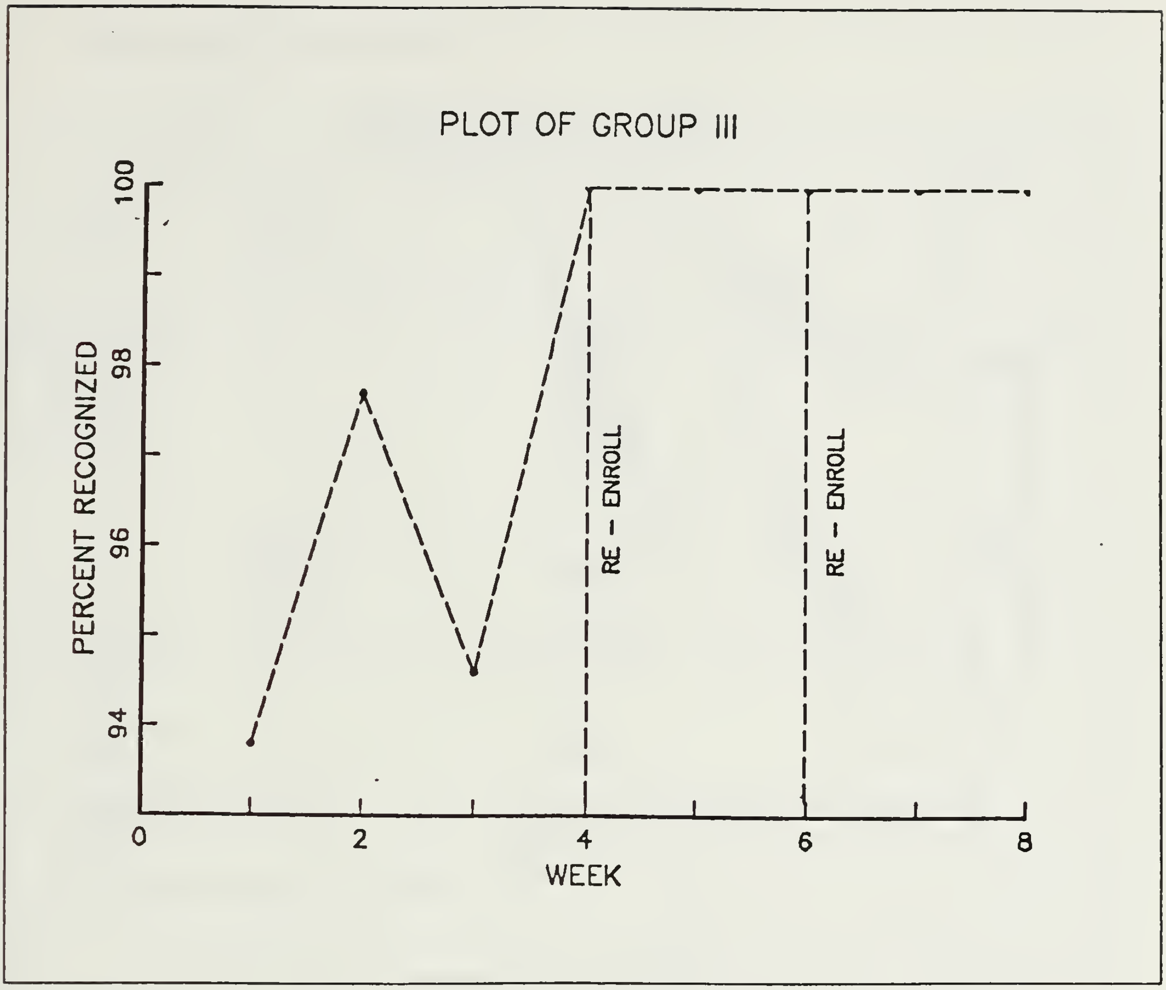


Figure 4.4 Plot of Group III.

4. *Combined Groups*

By transposing the three groups, as seen in Fig. 4.5, over the eight weeks of the experiment a pattern begins to emerge. Overall the first week of the study had the lowest recognition rates for the whole experiment, as would be expected. Introduction of a new technology or a new security measure will produce some trial and error on the part of the involved participants. Any drop in current levels of access are directly attributable to the learning curve an individual (and a new site) has to go through in mastering new concepts and protocols. A critical week for the experiment occured on week three. Groups III and II exhibited a reversed trend and showed drops in overall success rates during week three. No experimental parameters were changed from week

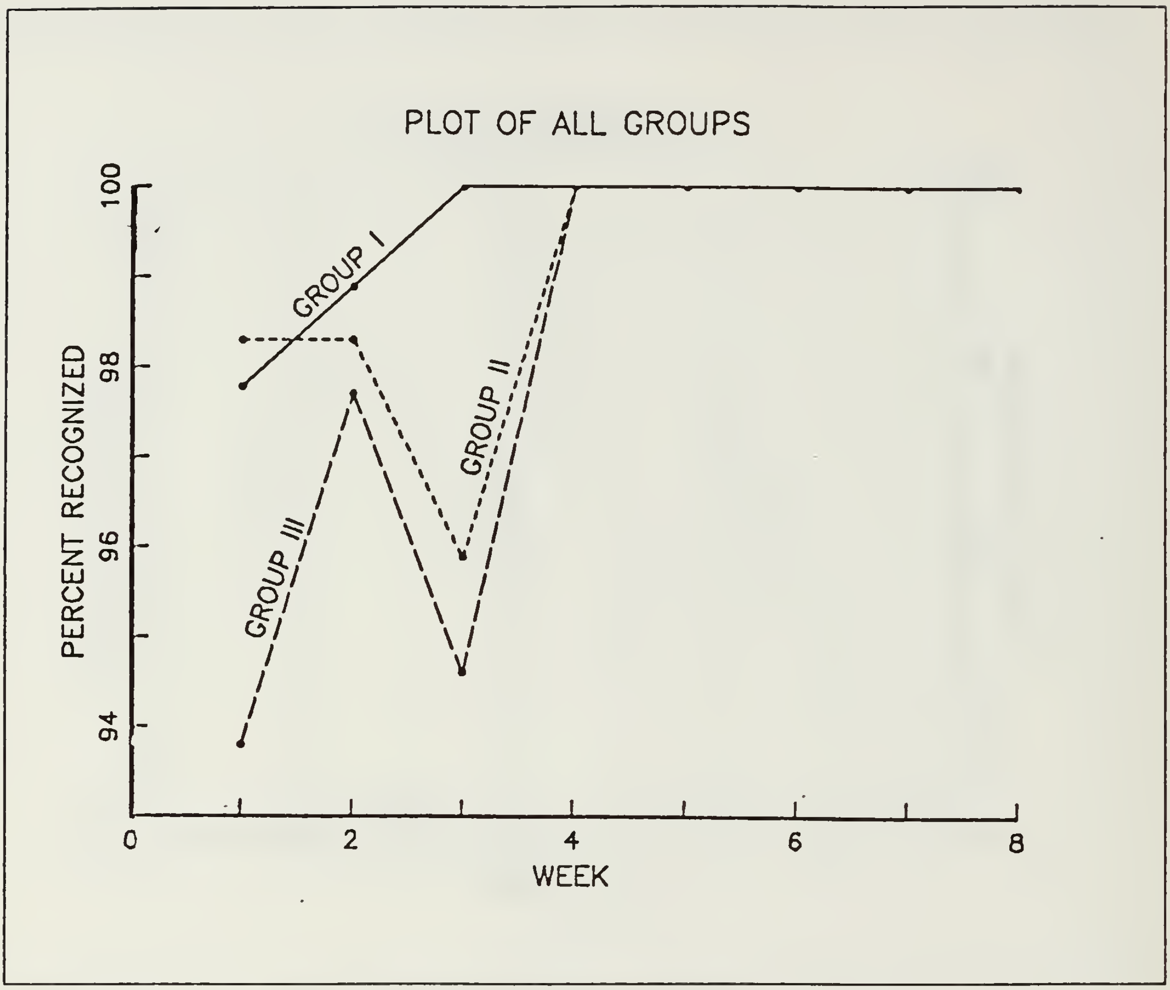


Figure 4.5 Group I, II and III Plot.

two to week three. The first re-enrollment for Group III occured during week FOUR. A lessening diligence or attention to procedures could be one explanation for the drop in success rates for week three but Group I was already experiencing 100% recognition by week three, which tends to refute any conclusion based on a lack of procedures on the part of the individual. Learning curve trends do not support a DROP in recognition during week three on the part of any group. The theory behind the learning curve is the tendency to keep improving performance as learning takes place and is acted on by the individual. The third week phenomena cannot be accounted for based on the experimental design.

B. ANALYSIS OF VARIANCE

source	degrees of freedom	ss	ms	F
FACTOR	2	0.0478	0.0239	0.77
ERROR	46	1.4343	0.0312	
TOTAL	48	1.4821		

group	number of data points	mean	st dev
GROUP III	13	2.9727	0.2121
GROUP II	17	3.0396	0.1733
GROUP I	19	3.0464	0.1516

POOLED ST DEV = 0.1766

```
          -------|------------------|------------------|-------------
GROUP III
GROUP II
GROUP I
          -------|------------------|------------------|-------------
              2.900              3.000              3.100
```

Figure 4.6 One-way Analysis of Variance.

Raw data for Phase ONE for the three groups was converted via arcsine transformation to a form that could be statistically manipulated by analysis of variance. Phase ONE transformations were used because Phases TWO through FOUR showed no statistical differences between the three groups with overall success rates of 100%.

TABLE V

COMPARISON OF WEEKLY RATES

	Phases of the Experiment			
	Phase ONE weeks 1-3	Phase TWO week 4	Phase THREE week 5	Phase FOUR weeks 6-8
GROUP I	95.39% (one template)	100% (two templates)	100% (two templates)	100% (three templates)
GROUP II	97.45% (one template)	100% (one templates)	100% (two templates)	100% (two templates)
GROUP III	98.89% (one template)	100% (one template)	100% (one template)	100% (one template)

The three groups (I, II and III) were treated as three separate samples and compared via analysis of variance to determine if the individual means were different from group to group or the difference was due to random differences. The null hypothesis was that the transformed means between the groups were the same. The F test showed no difference in F(2,46) between the group means and statistically the means were comparable as shown in Figure 4.6. A .05 level of significance yielded an F value of 3.23 [Ref. 8: p. 614] and the derived F for the experiment was 0.77. In order to reject the null hypothesis with a .05 level of significance, the experimental F value would have to be larger than the 3.23 value taken from F tables. Therefore, the hypothesis was not rejected. [Ref. 9: p. 19] Not enough statistical data exists from the experiment to point conclusively to the causes of the third week slump in Groups II and III. All that can be concluded from the study is that additional patterns did not significantly contribute to an overall increase in recognition success rates, [Ref. 7: p. 197] as seen in Table V.

C. TYPE I ERROR

The learning curve had an obvious effect on the individual attempting successful use and recognition via the EyeDentification System 7.5. All recorded cases of non-recognition (which resulted in the 'see security' message) occured in the first three weeks of the experiment, with the exception of MAUCKL (PIN 99). Sixty seven (67) cases of failure to be recognized, accounting for 1.67% of Type I error were logged during the 3972 experimental trials of this study. This 1.69% corresponds to the advertized one percent Type I error rate [Ref. 4: p. 1-6] published by the EyeDentify Company.

The 1.69% Type I error from the study compares favorably with the 1.04% Type I error found by Masiero in 1986. [Ref. 6: p. 34] Although a moving platform study might not be directly comparable to the multiple template hypothesis, the hardware for the EyeDentification System 7.5 performed with strikingly similar results. Based on the literature put out by the manufacturer and the Masiero study, the experimental Type I error results fell well within an acceptable range.

Two individuals were found to have 53% (36 of the 67) of the failures or unsuccessful trials. Both of these individuals were re-enrolled after the second week to try and eliminate any potentially 'bad' pattern in memory. One participant LOCH (PIN 82 and PIN 134) never had another unsuccessful attempt during the course of the experiment. This specific case was assumed to be enrollment error, system error or system operator error. The other case PIN 99 had failures throughout the experiment. Casual observation of this individual on several occasions noted poor technique and general non-adherence to system procedures as outlined at the start of the experiment. A total of seventeen (17) individuals experienced some sort of non-recognition or failure out of the 51 participants. With the deletion of PIN 82/134 and PIN 99 from the statistical database, as previously mentioned, the residual 31 unsuccessful trials were spread over 15 different participants.

No unsuccessful recognition was due to the fact that any individual was entered incorrectly into memory at the start of the experiment and at no time during the course of the experiment were any of the patterns inoperable or deleted from the Ibank (enrollee databank). Type I errors represent a failure of legitimate, authorized users to gain access via the retinal scan.

Unsuccessful attempts or Type I errors are more an issue of control for the manager, as compared with preventing Type II error. A prime managerial concern is the elimination of Type II error while limiting Type I error. False acceptance (Type II error) is the recognition of an unauthorized user as an authorized user, even if the individual is authorized under his or her own identity yet mistakenly identified as another PIN or authorized user. Imposters, one source of Type II error, are individuals not in the databank who gain entry by being falsely matched against anothers pattern already in memory. As stated before , this Type II error is the quintessential security managers nightmare; access to the unauthorized.

Of the individuals in either Group II or III, all unsuccessful attempts were logged before any second or subsequent re-enrollment took place. From existing data, the existance of additional patterns in memory never in any case contributed to an unsuccessful trial.

For most individuals in the experiment, the existence of a third pattern in memory did not significantly affect the overall chance of successful recognition. As stated above all, failures occured before the existence of the second pattern. Whether or not the first pattern effectively reduces failures, or the existance of that single pattern eliminates additional error factors that may be introduced through the multiple patterns remains to be discussed below.

D. MULTIPLE PATTERN USE RATES

By examining the use of the different templates in memory as logged for Groups II and III, an indicator of the contribution of the individual template toward each recognition attempt can be determined. Group II had a second template placed into memory at week five. For weeks five through eight, or over 40 trials per individual, an equal chance existed for either of the two patterns to be used in the recognition process. For the seventeen participants of Group II, the first enroll template was used on an overall average of 63.65% of the successful trials during Phase THREE and FOUR. One individual (PIN 102) used the first pattern to the exclusion of the second template (PIN 130). This was not common to the whole group, but all individuals in Group II did exhibit a tendency to recognize on one pattern over another consistently. The second pattern was used in 36.3% of the recognitions logged during the last two phases of the experiment for Group II.

Group III also had an equal chance of using either of the first two templates during Phase TWO and THREE of the experiment. The original enrollment template was used in 43.46% of the trials during weeks four and five. There was no strong preference between the two separate templates. Template two (or the first re-enrollment) was used in 56.69% of the recognition trials.

During Phase FOUR with an equal chance of using any of the three templates in memory, a stronger tendency to use a single pattern emerged. With an expected use of 33.3% (for an equal chance) on any of the three templates, the third template (second re-enroll) was the most often used template for recognition during Phase FOUR. The three weeks of Phase FOUR presented the possibility of thirty trials per individual. Only one individual (PIN 85, PIN 146, and PIN 162) did not use one of the three patterns during Phase FOUR. PIN 146 was not used once in the thirty trials of Phase FOUR as the template for recognizing that individual. This was a viable template because it was used 55% of the time in Phases TWO and THREE to recognize this same individual.

The first template for the thirteen Group III participants was used in 27.32% of the thirty trials. The second eye template (first re-enroll) was used in 25.93% of the recognition trials for this same time period. The second re-enroll (third separate template on the individual) was used in 42.06% of all recognition attempts made by Group III during Phase FOUR. Individual logged attempts show a preference for a single template over the other two patterns in all trials by Group III, with the noted exception of PIN 146.

By comparing the use of multiple templates within Groups II and III no strong statistical trend stands out. A preference was shown by both groups when using multiple patterns but not a preference based on sequence of enroll or use of template in the previous recognition. Template preference probably is an indication of closer head alignment corresponding to the template used in recognition. Toward the end of the experiment several participants noted the ability to predict the template used based on the cant of the head on the fresh scan. A single template used for recognition purposes, may be more indicative of the enrolling expertise of the system operator, slight angle variation of the head or searching mechanism of the system 7.5 than a definitive trend toward successful recognition.

The mechanism by which the 7.5 operates in the recognition mode lends itself to the maintenance of multiple patterns. All patterns in the databank contained in bubble memory are used for matching purposes. The five (5) closest patterns are compared directly with the freshly scanned retina for a match. With several patterns in memory for one individual, the opportunity to compare against several patterns should effectively eliminate all Type I and Type II error.

Patterns in the memory of The EyeDentification System 7.5 retinal scanner are not subjected to 'aging' in the sense of degradation with use. Multiple patterns can be easily collected on a periodic basis as long as memory capacity is not broached. Current allocations in memory allow for 1200 patterns at one time. With the prospect of continued personnel turnover, protocols for eye signature removal from retinal scan databanks or as part of a check out procedure would comply with any security or managerial requirements. Vacancies could be utilized or reused as necessary.

E. TIME ZONE OBSERVATIONS

One interesting outcome of the experiment was the occasional time zone error encountered by participants over the period of the study. All time zone parameters had been set to 1 (one) to allow for 24 hour access and to preclude any possible errors over the whole testing period. At random intervals, five (5) individuals encountered "TZ DENY" messages that indicated attempted entry during an unauthorized time of the day or shift.

After each occurance of the "TZ DENY" the system operator rechecked the databank to ensure no corruption or system operator error had affected the databank. On each occasion, the databank was found to be whole and complete (as entered originally by the system operator without any changes to the parameters). With ten (10) separately logged occurances of the "TZ DENY" message, occuring during weeks two, four, five, and six of the experiment, the time zone error was considered of value to examine along with other experimental results. One conclusion is that the machine being used for the experiment may have had a slight 'bug' either in the software driving the hardware or the system operator introduced some transparent error to the databank itself. Whether this same problem has occured in other units of the same model, only the EyeDentify company would have access to that information and can investigate. In either case, the "TZ DENY" occurances accounted for 0.25% (10 instances out of 3972) of the experimental trials.

F. IMPOSTER TESTING

Imposter testing, the success of an individual, not in the authorized databank, to be falsely recognized as a pattern in the databank, was not formally studied in the experiment. Informal imposter testing went on during the nine weeks due to the attempts by friends of participants that would "try their luck" on the retinal scan. No successful attempt occured in these casual attempts. An excellent area of follow-on research would be to further study imposter attempts at access via the 7.5 EyeDentify. Sandia National Laboratories conducted a study using forty one (41) imposters who made 6520 attempts [Ref. 10: p. 5] at verification using both right and left single eye scans. No false verifications occured in over six thousand attempts. A similiar study needs to investigate imposter attempts in recognition mode and deliberate attempts to 'spoof' the 7.5 System with retinal pattern sketches, special glasses and other attempts at unauthorized entry.

V. CONCLUSIONS

In general, participants were highly motivated and willing to use the 7.5 EyeDentify during the experiment. No real user resistance was encountered during any phase of the experiment. Several individuals questioned the levels of light or daily frequency required by the retinal scan. Without question, most individuals had not been exposed to the retinal scan or had limited knowledge of biometric devices. All questions and comments during Phase ONE were aimed at gaining a greater understanding of the technology and protocols of use. The high level of acceptance and use of the retinal scan during the experiment can be partially attributed to the military population. Military, in general, may be more used to using relatively unknown technology or devices than the population at large.

A. QUESTIONNAIRE

Questionnaires sent to current users of the EyeDentify report no real managerial or user resistance to the technology. Russ Maxwell of Sandia Labs reported "There was some reluctance at first by several users who were concerned about getting some kind of eye disease from contact with the rubber cups on the early model 7.5 EyeDentifier used in our tests" at Sandia Labs. He also noted that "About two or three percent of users, especially those with severe eye correction, had abnormally high false reject rates" or Type I error.

Participants in the experiment were left to their own devices to decide to use the scan by removing their glasses that they wore for normal daily wear or to use contacts instead. It was noted that through the first weeks, users with the more heavily corrected vision tended to scan with contacts rather than attempting a scan by removing their glasses. Too much difficulty in aligning the targets without their corrected sight interfered with the convenience of the system of being able to come into the lab and scan on the way to a class or between classes. This fact probably precluded more potential problems with unsuccessful attempts. The convenience of access is probably one of the stronger selling points of the unit and would be one of the stronger concerns on the part of management for using the 7.5 on site.

All users contacted (Sandia National Laboratories,Pacific Telecom, One Safe Place, Pacific Power and Light, Rockwell International) reported very good to excellent acceptance of the retinal scan technology by both users and management. Units were installed for controlling access to data center, warehouse or laboratory spaces. After installation, reported use has been expanded to include time zone access, substantiating shift attendance or back-up security with other card access devices. All respondents were very satisfied with the technology, initial operating/management procedures and vender support.

All units installed and in use were found to be effective without any additional protocols for intended site use. No managerial protocols external to EyeDentify Inc. had been developed to improve effectiveness or increase efficiency for the EyeDentification System 7.5. All information from current users was solicited on a voluntary basis.

No other site had yet developed additional protocols. One site (One Safe Place) observed that "the only problem is that it needs to have another way of shut-down or over riding access if we do not wish someone to enter." On site use of the retinal scan for the privately owned bank vault company has determined an additional safeguard that the company feels would be a good addition for their application. This over ride mechanism, if ever developed, could help prevent the entry of a false recognition, or a Type II error, to the controlled spaces of One Safe Space by manual intervention. However, the additional expense or requirement of an attendant or security personnel to oversee all attempts would be a limiting factor for operation of the retinal scan at other less unique sites.

The 7.5 EyeDentify was tested as a stand alone device for effective access control via multiple eye templates. The technology of the retinal scan provides the managerial attractiveness for a single system to accomplish security for specific spaces. Any cost-benefit analysis would have to take into account a comparison cost of traditional security guards' salaries and benefits if paid by the company. The initial costs for the unit (in the range of $ 10K) can then be compared toward the prescribed use in the organization.

B. SUCCESS RATE

The 7.5 EyeDentify used in the experiment recognized the 51 participants, regardless of subgroup, with a corrected success rate of 98.298%. Success of recognition was defined as correct identification of the individual on either the first, second, or third attempt to gain access. (After three attempts the SEE SECURITY message was illuminated) Two individuals encountered a disproportionate amount (53%) of the unsuccessful attempts in the study. Removing these two individuals and statistically re-analyzing the data brings the success rate up to 99.23% which is consistent with the desired predetermined managerial goal of 99% accuracy. In a manager's world, 99% accuracy with only a nominal possibility of Type I error, is a powerful selling point.

Group III with two additional eye signature templates in memory was found to have an overall success rate of 98.26%. Compared with the 99.04% success rate for Group II with only one other eye template in memory, two templates provide a better success rate than three templates. But the highest success levels were the result of using the single eye signature template, Group I, with an overall success rate for the experiment of 99.23%. Multiple patterns in memory were found to not enhance the overall success rate.

Overall average success rates were skewed by the initial weeks of the experiment. Each group had varying levels of success, but all groups were experiencing 100% recognition by week four of the experiment. The 100% success rate was not dependent on the group or the number of eye templates in memory used for recognition purposes.

For environments involving small numbers of users, effective physical security can be managed using the 7.5 as proved in earlier studies. [Ref. 5: p. 42] Although using a dot eye alignment apparatus as found on the current model of the EyeDentification System, as compared to the daisy alignment system used in the Helle study, several research recommendations from that study were paralleled by the current study. An age range of 15 years was found to not affect the overall success of recognition. Additional re-enrollment was shown not to reduce or lessen the effect of Type I error.

Time zone testing was ignored due to the fact that the lab area where the testing took place was only accessible between the hours of 0700 and 1630 Monday through Friday. The time zone feature has a large potential for use in a manufacturing or operational setting where shift access as well as recognition needs to be controlled and managed. However, due to the physical access constraints of the lab used, the time zone feature could not be effectively tested.

VI. RECOMMENDATIONS

Although the existence of additional eye signatures in memory does not boost the overall success rate of recognition for a single eye, the possibility exists that improvement may be gained for both eyes or two individuals being combined into a single double template for recognition. The EyeDentification System 7.5 retinal scan was found to be a highly consistent and reliable device. All queried current users of this specific system reported complete satisfaction of application. With the exception of several minor recognition incidents, the 7.5 operates at least as well as advertized. Perhaps no better praise exists than to say that something does what it is supposed to do and does it well. For the eight weeks of testing at the Naval Postgraduate School, the retinal scan 7.5 was found to be so well designed and engineered that the addition of external procedures or protocols could not significantly improve the mean success rates for individuals. In the managerial world the difference between 97% and 99% is often attributed to luck, which is just another label for random error.

The EyeDentify System 7.5 functioned so well during the rigors of the experiment that any Navy consideration for site application would be endorsed by the experiment system operator. With infrequent use of incorrect procedures, individuals "gaming" the unit and evidence of unnecessary force on the scan button, the System 7.5 continued to operate in a consistently superior manner from experimental design through eight weeks of daily operation.

It appears that, based on the experiment, if an individual exhibits severe problems using the retinal scaner during the enrolling procedure, and initial weeks, these sorts of problems do not improve over time. One of the two individuals that exhibited the most problems never showed any real improvement over the eight weeks and was deleted from the analysis for that reason. Re-enrolling the individual only showed improvement in one of the two chronic cases. These two cases represented only 3.9% of the study population. In the statistical study population with two individuals deleted, all remaining individuals were of equal importance. A work environment probably contains a more critical core(s) of individuals that may or may not encounter these same problems. If critical workers can not easily gain access, then a whole new set of managerial problems have been introduced into the workplace.

Simplifying the manager's concerns and creating a workable access system were the original goals of the study. As with any project under consideration, a manager has to take a good hard look at all the real and probable parameters involved in site implementation.

After reviewing the results for this study, the following recommendations are proposed in Figure 6.1:

1. Imposter testing in recognition mode should be studied based on the on the observations of this study and earlier tests. Additional experimentation in the area of 'spoofing' the system with retinal pattern sketches and the like needs to be conducted.

2. Investigate the possibility of other time zone errors to deduce if the cause was from a faulty system operator or if other reports to the manufacturer have isolated a possible software 'bug'.

3. In-depth investigation of units already in the field for possible parallel uses or additional applications for the EyeDentification System 7.5.

4. Greater awareness of the potential for 'playing the system' and protocols for the managerial safeguard of the intended use.

5. Study any possible long term use effects of the EyeDentify System 7.5. (hardware or software failure)

6. Develop mechanisms for incorporating modifications to existing 7.5 software (as demanded by individual sites) or adapting updated software as developed by the manufacturer.

Figure 6.1 Observations and Recommendations.

APPENDIX A
GROUP III

Group three-- re-enroll TWICE during the experiment (THREE templates)

Q (PIN 104, 141, 171)

B (PIN 89, 143, 169)

G (PIN 96, 147, 165)

M (PIN 85, 146, 162)

I (PIN 107, 135, 170)

B (PIN 92, 142, 163)

P (PIN 123, 148, 173)

G (PIN 115, 138, 175)

M (PIN 110, 137, 172)

A (PIN 131, 144, 167)

O (PIN 111, 136, 176)

S (PIN 124, 139, 177

B (PIN 126, 153, 168)

APPENDIX B

GROUP II

Group two--- re-enroll ONCE during the experiment (TWO templates)

M (PIN 118, 155)

N (PIN 116, 149)

P (PIN 114, 157)

W (PIN 109, 150)

A (PIN 101, 161)

F (PIN 102, 130)

R (PIN 105, 160)

U (PIN 120, 152)

H (PIN 88, 164)

C (PIN 93, 166)

A (PIN 84, 159)

C (PIN 127, 154)

S (PIN 122, 151)

R (PIN 98, 158)

K (PIN 128, 156)

C (PIN 94, 145)

H (PIN 95, 140)

APPENDIX C
GROUP I

Group one--- NO additional re-enroll (ONE template)

E (PIN 87)

C (PIN 86)

L (PIN 113)

M (PIN 103)

W (PIN 108)

C (PIN 129)

R (PIN 121)

L (PIN 112)

P (PIN 90)

A (PIN 117)

M (PIN 119)

K (PIN 97)

H (PIN 100)

H (PIN 83)

B (PIN 83)

D (PIN 106)

F (PIN 133)

D (PIN 81)

P (PIN 132)

LIST OF REFERENCES

1. Bakke, T.O., "Foolproof ID With New Body-Language Security System," *Popular Science*, vol. 228, June 1986.

2. United States Printing Office, *Government Computer News*, Washington DC, July 19,1985.

3. Tower, P., *The Fundamental Oculi in Monozygotic Twins*, American Medical Association Archives of Opthamology, vol. 54, 1955.

4. EyeDentify Inc., *The EyeDentification System 7.5 HB Users Manual*, Beaverton, Oregon, 1986.

5. Helle, D.K., *Examination of Retinal Pattern Threshold Levels and Their Possible Effect on Computer Access Control Mechanisms*, Naval Postgraduate School, California, September 1985.

6. Masiero, D.A., *Examining the Effect of Transverse Motion on Retinal Biometric Identifiers Relating to Shipboard Security Mechanisms*, Naval Postgraduate School, California, March 1986.

7. Ryan B., Joiner, B., and Ryan T., *Minitab Handbook* second edition, Duxbury Press, 1985.

8. Chou, Y., *Probability and Statistics for Decision Making*, Holt, Rinehart and Winston, New York, 1972.

9. Iverson, G. and Norpoth H., *Analysis of Variance*, Sage University Papers, California, 1976.

10. Maxwell, R., *The Status of Personal Identity Verifiers* Sandia National Laboratories, New Mexico, undated.

BIBLIOGRAPHY

EyeDentify Inc., *7.5 Camera Function Definition*, unpublished, 1984.

EyeDentify Inc., *White Paper : Health, Safety and Statistical Performance of the 7.5*, 13 December 1984.

Goldstein, I. and Simon, C., *New York State Journal of Medicine*, vol. 35, September 15, 1935, no. 18.

Oregon Museum of Science and Industry Test, *Results of MassEnrollment of Live Eye Signals*,. 10 October 1984.

Stein, W.M., *Standardized Testing of Personal Identification Equipment*, Mitre Corp., March 1985.

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