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The Effects of Degraded Vision and Automatic Combat Identification Reliability on Infantry Friendly Fire Engagements

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The Effects of Degraded Vision and Automatic Combat Identification Reliability on Infantry Friendly Fire Engagements

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14. ABSTRACT

Fratricide is one of the most devastating consequences of any military conflict. Target identification failures have been identified as the last link in a chain of mistakes that can lead to fratricide. Other links include weapon and equipment malfunctions, command, control, and communication failures, navigation failures, fire discipline failures, and situation awareness failures. This research examined the effects of degraded vision and combat identification reliability on the time-stressed decision of a dismounted infantryman to engage friendly or threat targets.

Twelve soldiers with the military occupational specialty 95B (Military Police) participated in several live fire scenarios while wearing goggles with various levels of transmissivity and shooting an M16A2 containing a combat identification system operating at 100% and 60% reliability. As expected, there was a significant main effect of Transmissivity Level [$F(2, 22) = 8.168$, $p = 0.002$] and Combat Identification Reliability [$F(2, 22) = 38.467$, $p < 0.001$] and a significant interaction effect of Transmissivity Level x Combat Identification Reliability [$F(4, 44) = 3.111$, $p = 0.024$] on the number of friendly targets engaged. The main effects of Transmissivity Level and Combat Identification Reliability and their interaction effect on the number of missed threat targets were nonsignificant. An unexpected result was no practical increase in mean reaction time with a combat identification system on the M16A2.

As technology continues to improve the lethality of military weapon systems, a corresponding increase in target identification is required to avoid friendly fire causalities. Designers of future combat identification systems for the dismounted force will need to focus on operational reliability and ease of use to maximize the system benefits.

15. SUBJECT TERMS

automation	camouflage	fratricide	ICIDS	infantry	SPECS	vision
BCIS	decision aid	friendly fire	IFF	reliability	target identification	

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Introduction

“2 U.S. Servicemen Killed by Friendly Fire Near Kandahar”

This headline from an article written about fratricide describes one of the most devastating consequences in any military conflict (Shanker & Schmitt, 2001). The article documents the conditions when two U.S. Servicemen were killed and approximately 20 were wounded when a B52 bombing mission went astray. Besides the obvious pain and suffering associated with the loss of life, fratricide has negative “compounding effects” on combat effectiveness (Center for Army Lessons Learned, 1992). These may include a loss of initiative, loss of aggressiveness, hesitation in sub-optimal conditions, leader self-doubt, disrupted operations, or a devastating impact on morale.

The problem of fratricide has been long standing. General Stonewall Jackson was mortally wounded during a friendly fire incident when his own troops mistakenly fired upon him when returning to camp (Ayers, 1993). Reported friendly fire deaths during World War I and World War II represented approximately two percent of total casualties. This number increased to approximately three percent during the Korean and Vietnam conflicts (Office of Technology Assessment, 1993; Ayers, 1993). A new emphasis was placed on this problem during the Persian Gulf War where 35 Americans were killed and 72 wounded by “friendly fire” (BCIS, 2001). Some argue this increase in friendly fire deaths is due to the increased sophistication, complexity, and lethality of new weapon systems and the high-paced non-linear battlefield. Others argue this difference is due to reporting the causes of those killed in action more accurately. In either case, this problem has not been and most likely will not be eliminated completely.

The U.S. Army Training and Doctrine Command (TRADOC) defines fratricide as "the employment of friendly weapons and munitions with the intent to kill the enemy or destroy his equipment or facilities, which results in unforeseen and unintentional deaths or injury to friendly personnel" (PM CID, 1997). Often, target identification failures by gunners and commanders are acknowledged as the primary cause of fratricide. However, a systems approach reveals target misidentification as the "last link in a chain of mistakes" (Office of Technology Assessment, 1993). Other links in this chain include weapon and equipment malfunctions, command, control, and communication failures, navigation failures, fire discipline failures, and situation awareness failures.

Short-term solutions developed during Operation Desert Shield and implemented during Operation Desert Storm were the Defense Advanced Research Project Agency (DARPA) lights and thermal reflective tape (Sola, Dockery, Penn, Zirkle, Kohler, Kipp, and Colby, 1997). These target identification techniques were designed to increase the identification of friendly vehicles and personnel and reduce fratricide. However, they also became an excellent target identifier for the enemy. Recently, proposed solutions have been focused in both macro and micro areas. The macro approach includes education, training, modifications to tactics, techniques, and procedures (TTPs), and command and control. The micro approach includes technology and the advancement of new equipment for the identification of friend or foe. However, the Program Manager for Soldier Systems reports that "the means by which each element of the coalition, joint, and combined arms team are able to reveal themselves as being friendly whenever observed or interrogated have not yet been resolved" (PM Soldier Systems, 2001).

Numerous systematic approaches have been followed to identify the causes of fratricide, and emerging technologies have been identified and evaluated in an attempt to reduce its occurrence. This research addresses the effects of a perceptual variable and a cognitive variable on time-stressed decisions of dismounted infantrymen when engaging (friendly or enemy) targets. The perceptual variable is the degradation of vision caused by reduced ambient light levels. Degraded vision is a contributor to erroneous target identification, a major cause of fratricide. The cognitive variable is the use of an automated decision aid with three levels of reliability when making the “shoot or don’t shoot decision.” Automated combat identification is intended to mitigate deficient fire discipline, another major cause of fratricide.

Background

Visual Acuity and Contrast Sensitivity

Wickens and Hollands (2000) present a model of human information processing that can be used as a framework for analyzing an infantry soldier's identification of a target and decision to engage. The model contains a series of major information processing stages plus a feedback loop. Stimuli are received through the sensory system and interpreted in the perception stage. For example, a target is detected and recognized. Information is transformed in the cognitive stage which taps into working memory and long term memory. This corresponds to target identification. The results of the perception and cognitive transformation are used in the response selection and execution stages. In these stages, the infantry soldier decides whether or not to engage the target and actually pulls the trigger.

Visual acuity and contrast sensitivity play major roles in the early stages of human information processing and impact target detection, recognition, and identification. Visual acuity is the ability to discriminate fine detail (Sanders & McCormick, 1993). The Snellen letter chart is used commonly for visual acuity tests with acuity expressed as 20/30, 20/40, 20/50, etc. (Sanders & McCormick, 1993; Regan, 2000). A 20/30 acuity indicates the person being tested can see the same line of letters at 20 feet that a person with normal vision can see at 30 feet.

Some researchers are replacing standard visual acuity tests using high contrast and high spatial frequency stimuli with contrast sensitivity tests (McLeod, 2001; Sanders & McCormick, 1993; Regan, 2000; Evans & Ginsburg, 1985). Contrast is a comparison of the luminance of an object relative to the luminance of its background. Sanders and

McCormick (1993) and Regan (2000) define spatial contrast or Michaelson contrast as the minimum luminance subtracted from the maximum luminance divided by the sum of the minimum and maximum luminance (Lmax – Lmin)/(Lmax + Lmin). Contrast sensitivity is the reciprocal of the threshold contrast for detecting the difference between an object and its background. Spatial frequency is measured as the number of object and background cycles per degree of visual angle on a repeating grating (Sanders & McCormick, 1993). Contrast sensitivity is plotted against spatial frequency as a measure of visual capability (Regan, 2000).

In a combat shooting scenario, image quality and the ability to detect and identify targets can be affected by contrast, color, sharpness, target size, range, field of view, and ambient light levels (Beaton, 2001). One focus of this research is the impact of ambient light levels on target identification and ultimately the decision to engage friendly and threat targets. For a given target and background combination, contrast sensitivity is higher during bright day light hours as compared to dawn, dusk, or night. Target to background contrast can also be impacted if the shooter is wearing military eye protection (e.g. ballistic, laser, and/or ultraviolet) as the luminance transmission or amount of light energy reaching the eye is reduced. Freedman and Zador (1993) and LaMotte, Ridder, and Yeung (2000) researched the effects of reduced transmission of automobile window tinting on object visibility. They determined contrast sensitivity at higher spatial frequencies was reduced at the darkest level of tinting tested for younger participants. In addition, the contrast sensitivity for older drivers was degraded at the middle level of tinting and at mid-level spatial frequencies. These results, showing the effect of contrast luminance, are not unlike those reported by Van Nes and Bouman (1967), Van Meeteren (1973), and as estimated by Barten's (1987) band-pass model.

Based on the review of the visual acuity and contrast sensitivity literature, this research measured the impact of degraded vision on the number of friendly fire engagements by an infantry soldier. The transmissivity of lenses on shooting goggles was manipulated to degrade the shooter's vision. The baseline transmissivity level was 75% obtained through the clear lenses on the Army issue Special Protective Eyewear, Cylindrical System (SPECS) shooting goggles. The second transmissivity level was 10%. This approaches the visible light transmitted through the gray sunglass in the military Ballistic Laser Protection System (BLPS). The third transmissivity level was 2% which approaches the ambient light level at dusk.

Potential Technology Solutions to Fratricide

Two technology solutions, the Battlefield Combat Identification System (BCIS) and the Individual Combat Identification System (ICIDS), are being designed and developed as decision-making aids for target recognition and identification (Dzindolet, Pierce, Beck, Dawe, & Anderson, 2001). The BCIS is intended for ground and air mounted vehicle operations, and the ICIDS is intended for use by individual soldiers. Although both systems are described below, this research focused on the individual soldier. Throughout this document, the individual soldier is referred to as the "shooter."

Battle Combat Identification System. The dramatic increases in range, accuracy, and lethality of combat systems must be accompanied by a similar increase in target recognition and identification to avoid or reduce fratricide (BCIS, 2001). Following the Persian Gulf War, the U.S. Army was directed by the Joint Chiefs of Staff to address the problem of fratricide involving direct fire systems (BCIS, 2001; Gimble, Ugone, Meling, Snider, & Lippolis, 2001; Grabski, 1999). The Battle Combat Identification System (BCIS) is designed for ground combat vehicles to improve situation awareness and reduce fratricide through identification of friendly targets in all combat environments including light levels (day, dawn, dust, night), smoke, fog, smog, rain, and extended ranges (BCIS, 2001; Gimble et al, 2001). This is accomplished through a secure interrogation and response system between the "shooter" and potential "friendly target" (Gimble et al, 2001). The interrogation process is initiated when the ground combat vehicle's laser range finder is used to determine range to target and sends an encrypted query to the targeted platform. Any friendly target equipped with the appropriate transponder, sends a return signal to the shooter platform indicating it is a "friendly" target. If no response is received or if the response is invalid, an "unknown" indication is given to the gunner. The "unknown" indication is generated after interrogating any target (friend, non-combatant, or foe) not equipped with the appropriate transponder.

Individual Combat Identification System. As with crews operating ground combat vehicles, the dismounted ground forces face a similar dilemma in regard to target identification (PM CID, 1997; Kohlhase, 1998). The Combat Identification Device for the Dismounted Soldier (CIDDS) was designed to provide a friendly target identification capability similar to ground combat vehicles equipped with BCIS. The CIDDS program has been renamed the Individual Combat ID System (ICIDS). The ICIDS includes a weapon mounted laser interrogator and a helmet mounted radio transponder (PM CID, 2001; General Dynamics, 1999). Similar to BCIS, the weapon mounted interrogation system sends a coded signal toward the intended target. If the intended target is equipped with the appropriate transponder, the return signal will indicate "friend." If no signal is received or if the signal is invalid, the shooter will be given an indication of "unknown." Again, this could occur when interrogating friendly targets without transponders (or with non-operating transponders), non-combatants, or threat targets. The graphical representation of the ICIDS concept is shown in Figure 1 (Wood, Lyon, & Pfoutz, 2000).

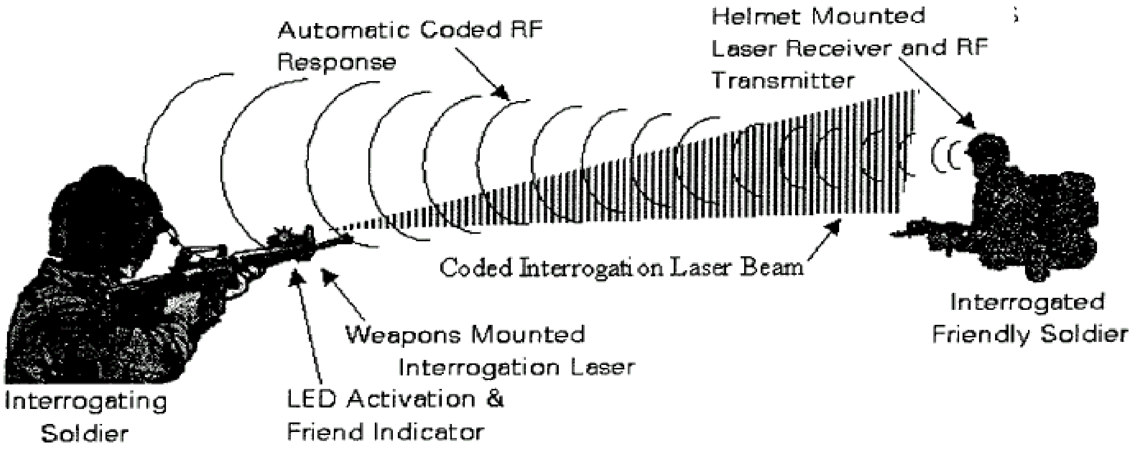

Figure 1. After target detection, the shooter uses the Individual Combat Identification System (ICIDS) to interrogate and identify the target to assist with the shoot or don't shoot decision.

Utilization of Automated Decision Aids

Parasuraman, Sheridan, and Wickens (2000) define automation as "a device or system that accomplishes (partially or fully) a function that was previously carried out by a human operator." They identified four broad areas for automation application as information acquisition, information analysis, decision and action selection, and action implementation. Moray, Inagaki, and Itoh (2000) define automation as “any sensing, detection, information processing, decision-making, or control action that could be performed by humans but is actually performed by machine.” Parasuraman and Riley (1997) define automation as “the execution by a machine agent of a function that was previously carried out by a human.” Wickens and Hollands (2000) provide the following rationale for introducing automation; task execution that only a machine can perform, executing tasks more efficiently, more accurately or with a higher level of safety, aiding areas of human limitations, and cost reduction (economics). Portions of these definitions, the augmentation rationale, and the first two application areas regarding information acquisition and analysis match the characteristics of both BCIS and ICIDS as previously defined. That is, the automation portion of these systems is augmenting the human limit in regard to information acquisition and analysis (i.e. target identification).

Parasuraman, et al (2000) couple a simplistic four-stage model of human information processing with the 10 levels of automation as defined by Sheridan and Verplank (1978). The four stages of this simplistic model are sensory processing, perception and working memory, decision making, and response selection. The 10 levels of automation start with the machine offering no assistance to the human operator, through levels where the machine suggests alternatives or executes suggestions with human approval to levels where the computer decides everything and executes tasks autonomously. For the BCIS and ICIDS, the automation supports the shooter’s perception and decision making by providing a limited set of alternatives after a target is interrogated (“friend” or “unknown”). It should be noted these systems are not designed to recommend shooting or not shooting at a specific target because the systems can not definitively identify a target as a threat (only as “unknown”). The shooter is still left with the final decision to fire the weapon based on this information.

Parasuraman and Riley (1997) specifically researched the use, misuse (over reliance), and disuse (under reliance) of automation. Along with others, they suggest trust in automation, as influenced by system reliability, is a major factor in user attitudes toward automation use (Wickens & Hollands, 2000; Parasuraman, et al, 2000; Parasuraman & Riley, 1997; Moray, et al, 2000; Muir, 1994; Muir & Moray, 1996; Skitka, Mosier, & Burdick, 1999; Lee & Moray, 1992; Lee & Moray, 1994). Intuitively, systems with high reliability increase operator trust, which increases automation use. Conversely, automation systems will low reliability decrease operator trust and consequently reduce automation use. Lee and Moray (1992, 1994) found that participants used automation only if their confidence in automation was greater then their confidence in manual controls.

It has been shown that people making decisions under conditions of uncertainty use heuristics principles to reduce the complexity in decision making to a more simplistic judgment (Tversky & Kahneman, 1982; 2000). However, the use of decision heuristics can lead to decision biases. The representativeness heuristic involves decision making using similarities or stereotypes. Tversky and Kahneman (1982, 2000) showed the representativeness heuristic can cause a decision bias because of insensitivity to prior probability of outcomes, sample size, the concept of chance, and predictability. Linked with automation decision aids, this decision bias can lead to over reliance on automation or automation bias (Mosier & Skitka, 1996; Parasuraman & Riley, 1997). Parasuraman and Riley (1997) labeled this condition as misuse of automation. They also developed the concept of automation disuse in which automation is under used. This condition typically occurs when a new technology is introduced and when a technology does not perform as anticipated. In both cases, operators tend to under rely on the automation capability or disuse the automation.

Dzindolet, et al (2001) conducted research to predict the misuse and disuse of automated combat identification decision aids operating at various levels of reliability (60%, 75%, and 100%). During this laboratory study, college students viewed images of military terrain from Fort Sill, OK with and without camouflaged soldiers present. The images were displayed on a computer screen, and the participants indicated when they detected the soldiers. These decisions were aided by an automated detection system with a reliability level manipulated to levels of 60%, 75%, and 100%. Dzindolet, et al (2001) found that misuse or over reliance on the automated decision aid exceeded disuse "even when the reliability of the automated system was very low." In fact, the results suggested the operators were not especially sensitive to the reliability of the system. Dzindolet, et al (2001) speculated this might be due to automation bias, overestimation of trust in the system, motivational factors, or some combination. They encouraged future research in this area using a more realistic combat-type setting and introducing a more chaotic, stressful environment. Consequences of decision failure were also encouraged within safety and human use limits of an experiment.

In addition to degraded vision, this research measured the impact of automatic combat identification system reliability on the number of friendly fire engagements by an infantry soldier. Although the realistic combat environment was nearly impossible to duplicate in a research setting, the following steps were taken to move in this direction. First, participants fired live ammunition at realistic pop-up targets and were provided rules of engagement that included “shoot on sight any threat target.” Second, consequences of engaging friendly targets and missing threat targets were fully explained. Third, targets were presented for a limited amount of time (i.e. three to four seconds or until hit). Although the only true test is actual combat, these steps helped move toward generalizing the results.

The reliability of the ICIDS hardware had been previously estimated at near 99% (Kohlhase, 1998). In general, actual system reliability is often much less because assumptions of the designer may not be met during actual operations (Parasuraman & Riley, 1997). In the case of ICIDS, this could include friendly troops (U.S. or coalition) not equipped with appropriate transponders, systems damaged in combat, missing components, or depleted individual soldier power supplies. In all of these situations, the system returns an indication of “unknown” when in fact the target was friendly. For this research, in addition to the base case (i.e. no automated combat ID system), the reliability levels of the combat identification simulator used during the firing scenarios was 60% and 100%. Degraded reliability could potentially be caused by system malfunction, loss of power, loss of antenna, operator error, or the fact that not every U.S. infantryman or ally in the theatre of action may be equipped with the proper receiver or transponder (Gimble et al, 2001).

Purpose of Research

The primary purpose of this research was to determine the effects of degraded vision and combat identification reliability on the time-stressed decision of a dismounted infantryman to engage friendly or threat targets. The secondary purpose was to determine if efforts to reduce or eliminate the occurrence of friendly fire adversely affect combat effectiveness as measured by shooter reaction time and the number of missed opportunities to engage a threat target.

Based on the reviewed literature, the following hypotheses were formed:

- The degraded vision caused by reduced transmissivity will increase the number of friendly targets engaged as potential targets will be more difficult to recognize and identify.
- The increase in target recognition afforded by a highly reliable combat identification system will decrease the number of friendly targets engaged.
- Regardless of the combat identification system reliability, reliance on the system will occur more often when combined with the lowest transmissivity level as opposed to the highest transmissivity level. Consequently, this will increase the number of friendly targets engaged when the combat identification system has a reduced reliability.
- Due to the extra step associated with interrogating a potential target, reaction time or time to first shot will increase when using a combat identification system.

Methods

Participants

The experiment was conducted using 12 soldiers with the Military Occupational Specialty (MOS) 95B – Military Police (Department of the Army, 1999). All participants had a shooting performance rating of "marksman" or above. The soldiers were randomly selected from the Directorate of Law Enforcement and Security (DLES) at Aberdeen Proving Ground, MD. Participation was voluntary, and the participants received no direct compensation. The intrinsic benefit indirectly gained by participating in this shooting experiment was the enhancement of their overall shooting performance. Participants self reported height, weight, age, handedness, Military Occupation Specialty, and the number of years of experience. Visual acuity was measured with a Snellen eye chart, and ocular dominance was measured using the Miles unconscious sighting method (Miles, 1929). Participant anthropometric, demographic, and vision data are provided in Table 1.

Table 1. Participant Anthropometric, Demographic, and Vision Data

	Participant Number											
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Height (in)	68	65	66	67	70	70	75	68	64	67	68	67
Weight (lbs)	170	144	160	138	169	160	172	190	135	155	205	155
Age	21	20	19	23	19	21	25	22	21	20	24	19
Gender	M	F	M	M	M	M	M	M	F	M	M	M
Handedness	R	R	R	R	R	R	R	R	R	R	R	R
Years Exp.	2	1	1	4	1	3	6	1	1	1	4	1
Dominant Eye	R	R	R	R	R	R	R	R	R	R	R	R
Vision	20/20	20/15	20/20	20/13	20/20	20/25	20/20	20/13	20/20	20/15	20/15	20/20

Experiment Design

A two-way, within-subjects design (3 x 3) was used to collect data to examine the effects of Transmissivity Level and automatic Combat Identification Reliability on shooting performance. Shooting performance was measured as the number of friendly target engagements, missed threat target opportunities, and shooter reaction time.

Independent Variables. Factor A included three Transmissivity Levels induced by participants wearing shooting goggles containing lenses with various intensities of shading. The transmissivity levels were 75%, 10%, and 2%. Factor B included three levels of automatic Combat Identification Reliability including firing an M16A2 without an automatic combat identification system (baseline) and firing an M16A2 with an automatic combat identification system with 100% and 60% reliability, respectively.

Dependent Variables. The three dependent variables for this research were the Number of Friendly Fire Engagements, the Number of Missed Threat Target opportunities, and Reaction Time (or time to first shot after threat target exposure).

Control Variables. The control variables for this research are listed in Table 2.

Table 2. Control Variables

VARIABLE	LEVEL	REMARKS
Ambient light level	2,000 – 6,000 fc	measured by illuminometer
Target types	2 camouflage patterns	BDU for friend; Tiger Strip for threat
Target range	75-200 meters	
Target scan angle	45 degrees	
Number of each target type	5 friend, 10 threat	per test condition
Target exposure time	3-4 sec	or until hit
Presentation delay	3-4 sec	randomly selected
Presentation order	Multiple	randomly selected for each test condition
Target location	Multiple	re-positioned after every 3rd test condition

Equipment

ARL Small Arms Shooting Performance Research Facility. The experiment was conducted at the U.S. Army Research Laboratory, Small Arms Shooting Performance Research Facility located at Aberdeen Proving Ground, MD. This facility is an outdoor live-fire range consisting of four firing lanes (A, B, C, and D) with computer controlled multiple pop-up targets at 50, 75, 100, 150, 200, 250, 300, 400, and 500 meters on each lane. An aerial photo of the shooting facility is provided in Figure 2.

Figure 2. The ARL Small Arms Shooting Performance Research Facility contains four firing lanes with pop-up targets behind berms located at various ranges between 50 and 500 meters on each lane.

Four parallel lanes afford the opportunity for multiple simultaneous shooters if desired. The standard targets are olive green E-type silhouette targets containing a foam core pressed between two thin sheets of aluminum and wired to an electronic sensor. Each target is attached to a holding mechanism, which is connected to a command and control center. The computer-driven target controller is capable of presenting a programmed array of targets on each lane in any sequence, exposure time, and interval.

When a shot is fired, a sensor in front of the firing position detects the shot and records a time of fire. When a projectile penetrates a target and connects the front and rear aluminum sheets, it completes a circuit, which electronically registers a hit and lowers the target. The controller electronically records shooter identification, target range and location, target exposure time, time to fire each round, number of rounds fired, which round hit the target, and total number of targets hit.

For the present experiment, target design and range operations were slightly modified. The standard E type silhouette targets were modified with characteristics representing threat and friendly targets. Two camouflage patterns (the standard Army Battle Dress Uniform - BDU and the Vietnam era pattern commonly defined as “Tiger Stripe”) were attached to the targets. An example of each camouflage pattern is provided in Figure 3.

Figure 3. Camouflage patterns representing friendly and threat targets. The Standard BDU pattern (left) represented friendly target, and the tiger stripe pattern (right) represented threat targets.

Shooters were positioned in the center firing position between lanes B and C to accommodate a total of 15 potential targets at approximately 75-200 meters. Five of these targets were designated as friendly and 10 were designated as threat as indicated by their camouflage patterns. Each target was presented one time during each treatment combination. The friendly and enemy target positions were randomly relocated after every 3rd scenario to mitigate the learning effect.

Shooting Goggles. Participants wore standard Army issue Special Protective Eyewear, Cylindrical System (SPECS) shooting goggles during all treatments. The Transmissivity Levels of the lenses were modified with commercially available window tinting material (Axius Window Film 2500). The lenses, with and without multiple layers of the tinting material, were analyzed with an HP8452A Diode Array Spectrophotometer. Results of the analysis are provided in Appendix A. Based on this analysis, the three transmissivity levels selected for the experiment were 75% (SPECS without tinting), 10% (SPECS with two layers of tinting material), and 2% (SPECS with four layers of tinting material).

M16A2 Weapon and Automatic Combat Identification Simulator. The M16A2 standard issue infantry weapon with its standard ammunition was used for all firing scenarios. The M16A2 was fired in the semi-automatic mode. The weapon was modified to accept an automatic combat identification simulator. The simulator consisted of a switch mounted on the forward stock of the M16A2 that the shooter activated to "interrogate" the target. It also included a headset that provided an audio feedback. After the shooter interrogated the target, the simulator provided one of two auditory responses through the headset; "friend-friend-friend" or "unknown". An audio feedback was selected to match the current BCIS feedback modality.

The reliability of the simulator was preset based on the selected level of Combat Identification Reliability. For level one, the system was not used. For level two, the reliability level was set to correctly identify 100% of the friendly targets. When the shooter interrogated a target, the simulator provided an audio feedback of "friend-friend-friend" for all five friendly targets and "unknown" for all 10 threat targets presented. For level three, the reliability level was set to correctly identify 60% of the friendly targets. When the shooter interrogated a target, the simulator provided an audio feedback of "friend-friend-friend" for three of five friendly targets presented. It provided a feedback of "unknown" for the remaining two friendly targets and all 10 threat targets.

Procedure

The experiment was conducted on four test days between 10 October and 04 November 2002. Twelve participants were divided into four groups of three shooters. Each group participated in a one day experiment. This combination produced the most efficient use of range time and minimized the impact on the military unit providing the participants.

The principal investigator distributed an informed consent form to each participant, reviewed the details of the form, and answered all questions. A copy of the informed consent is in Appendix B. All participants signed their individual informed consent forms and were provided copies.

Orientation. The orientation session was conducted at the ARL Small Arms Shooting Research Facility. The range manager and safety officer explained the standing operating and safety procedures for the shooting facility. The participants were instructed to follow all directions given by the safety officer during the conduct of the experiment. The principal investigator described the purpose and specific procedures related to this experiment.

Training. Each shooter participated in three training scenarios prior to the record test. During these scenarios, they became acclimated to the shooting goggles with the three transmissivity levels. They also became familiar with the shooting facility, the pop-up targets, and the automatic combat identification simulator mounted on the M16A2. Each participant completed two dry-fire and one live-fire pop-up target scenarios (friend and threat) while wearing the different shooting goggles and with the automatic combat identification simulator operating at a various levels of reliability. The range manager and principal investigator reviewed the results of the training scenario with each individual participant and determined when they were ready to initiate the experiment.

Test Condition Presentation Order. The order of treatment presentation was critical in mitigating the potential learning and practice effects. There was also a concern with light adaptation when a participant switched Transmissivity Levels. This concern was further magnified if changing from high light transmission (i.e. a bright condition) to a low light transmission level (i.e. a darker condition) since dark adaptation time is significantly longer then light adaptation time. Therefore, the presentation order was grouped according to the Transmissivity Levels. The order of presentation for the three levels of Combat Identification Reliability was partially counterbalanced within each Transmissivity Level (Keppel, 1991). During the experiment, a participant wore goggles representing one level of Transmissivity and completed all three levels of Combat Identification Reliability before changing goggles. The actual schedule of events is provided in Appendix C.

Participant Instructions and Shooting Sequence. To establish a consistent level of shooting aggressiveness, participants were provided two “rules of engagement” to follow during the experiment. The first was to “shoot-on-sight all threat targets,” and the second was to “minimize friendly and non-combatant engagements.” Also, the participants were informed of the reliability level of the combat identification system (i.e. no system, 100%

reliable, or 60% reliable) prior to initiating each scenario. These instructions were introduced as a result of participant comments from an earlier pilot test.

Participants wore the assigned shooting goggles for a minimum of 10 minutes prior to starting a scenario. A single participant entered the firing position and prepared to fire in the sequence as outlined in Appendix C. After the shooter took position and announced “ready”, the range controller initiated the computer-driven pop-up target scenario for the selected test condition. After all 15 targets were presented, the participant and range safety officer returned the weapon to a safe status, and the participant immediately departed the firing position. After departing the firing point, the participant completed a single question survey on whether they relied on vision or the combat identification system when making the “shoot or don’t shoot” decision. The next scheduled participant entered the firing position and repeated the process. This continued until the schedule of events was exhausted for the group. As indicated earlier, the target presentation was modified between test conditions. Also, target locations on the range were randomly changed after every 3rd test condition.

Results

All 12 participants completed all test conditions. This included a total of 108 firing scenarios containing 1620 friend and threat target presentations. The Number of Friendly Fire Engagements, the Number of Missed Threat Target opportunities, the Mean Reaction Time, and the subjective response data are provided in Appendix D. The following sections provide a statistical evaluation of these results.

Friendly Fire Engagements

The Mean Number of Friendly Fire Engagements was computed for the nine combinations of Transmissivity Level and Combat Identification Reliability. Figure 4 shows the mean and standard error data for the Friendly Fire Engagements.

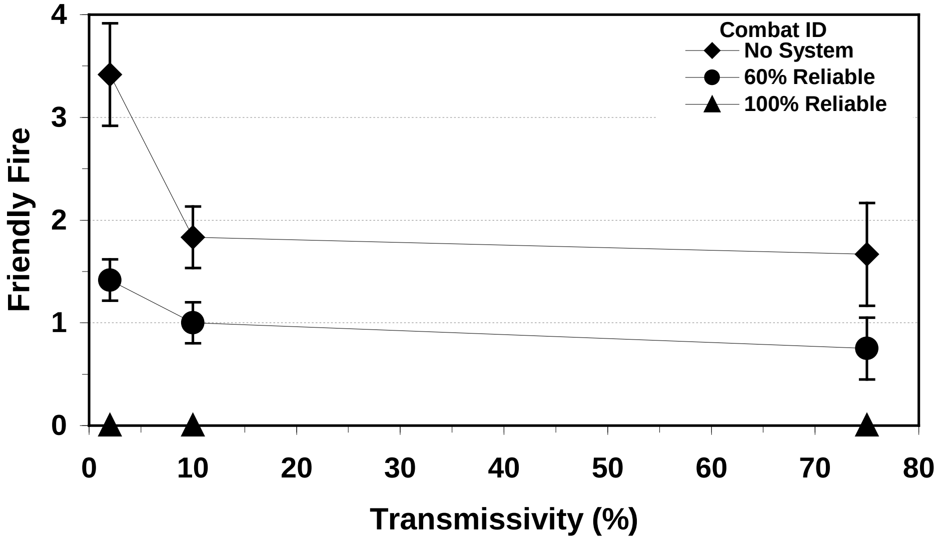

Figure 4. Mean and Standard Error for Friendly Fire Engagements during live-fire shooting scenarios containing 10 threat targets and five friendly targets.

Table 3 contains a summary of the Analysis of Variance (ANOVA) conducted on the Friendly Fire Engagement data. The ANOVA revealed significant main effects of Transmissivity Level and Combat Identification Reliability, and a significant interaction effect of Transmissivity Level x Combat Identification Reliability (α=0.05).

Table 3. ANOVA Summary Table for Friendly Fire

Source	Degrees of Freedom	Sum Square Error	Mean Square Error	*F*	*p*
Between					
Subject (S)	11	48.367	4.397		
Within					
Transmissivity (T)	2	13.352	6.676	8.168	0.002
T x S	22	17.974	0.817	-	
Reliability (R)	2	95.908	47.954	38.467	0.000
R x S	22	2.494	1.247	-	
R x T	4	11.760	2.940	3.111	0.024
R x T x S	44	41.580	0.945	-	
Total	107	231.435			

A post-hoc Newman-Keuls test was conducted on the Transmissivity Level x Combat Identification Reliability interaction. Figure 5 shows a line plot of the Mean Number of Friendly Fire Engagements with the nonsignificant comparisons underlined. The Newman-Keuls test revealed nonsignificant differences when using a combat identification system with 100% reliability at all three transmissivity levels and a 60% system at the 75% transmissivity level. There were nonsignificant differences in the means when using a 60% system at all three transmissivity and using no system at the 10% and 75% transmissivity levels. Using no system at the 2% transmissivity level produced significantly more friendly fire engagements than all other test conditions.

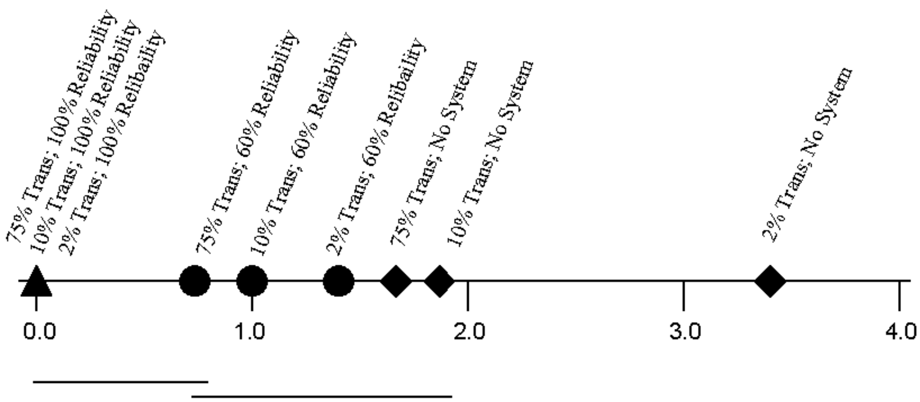

Figure 5. Results of the pot-hoc Newman-Keuls test on the Number of Friendly Fire Engagements. Nonsignificant comparisons are underlined.

Missed Threat Targets

The Mean Number of Missed Threat Targets was computed for the nine combinations of Transmissivity Level and Combat Identification Reliability. Figure 6 shows the mean and standard error data for Missed Threat Targets.

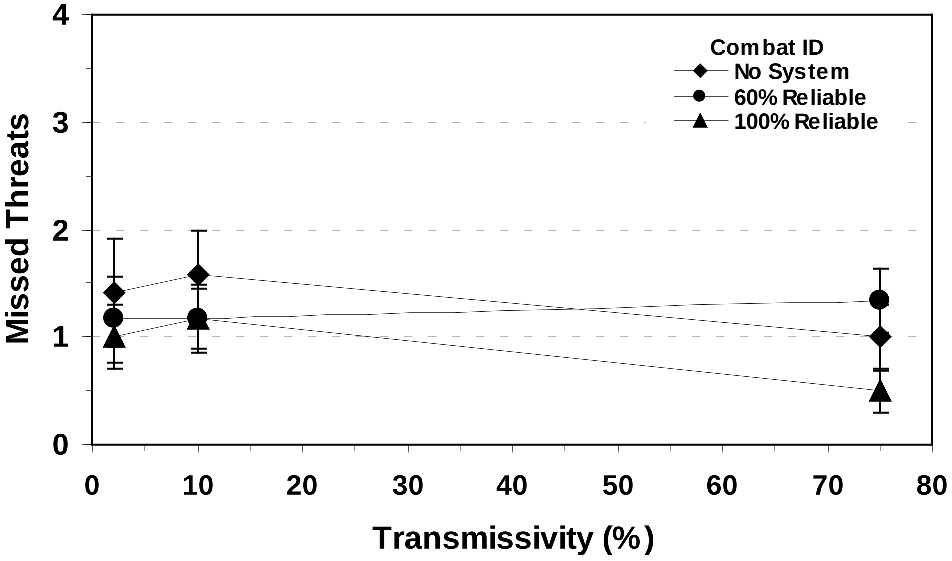

Figure 6. Mean and Standard Error for Missed Threat Targets during live-fire shooting scenarios containing 10 threat targets and five friendly targets.

Table 4 contains a summary for the ANOVA conducted on the Missed Threat Targets data. The ANOVA revealed the main effects of Transmissivity Level and Combat Identification Reliability and their interaction were nonsignificant (α=0.05).

Table 4. ANOVA Summary Table for Missed Threat Targets

Source	**Degrees of Freedom**	**Sum Square Error**	**Mean Square Error**	***F***	***p***
Between					
Subject (S)	11	35.185	3.199		
Within					
Transmissivity (T)	2	2.074	1.037	0.735	0.491
T x S	22	31.037	1.411	-	
Reliability (R)	2	4.019	2.009	1.309	0.290
R x S	22	33.759	1.535	-	
R x T	4	2.593	0.648	0.664	0.620
R x T x S	44	42.963	0.976	-	
Total	107	152.630			

Mean Reaction Time

Figure 7 shows the Mean Reaction Time for the nine combinations of Transmissivity Level and Combat Identification Reliability.

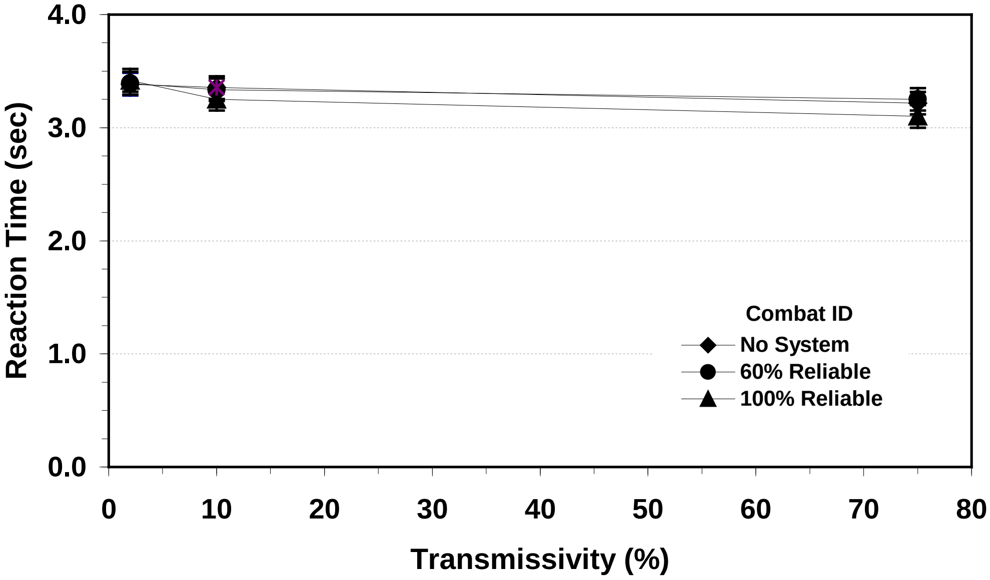

Figure 7. Mean and Standard Error for Mean Reaction Time for first shot fired at threat targets during live-fire shooting scenarios containing 10 threat targets and five friendly targets.

Table 5 contains a summary of the ANOVA conducted on the Mean Reaction Time data. The ANOVA revealed a significant main effect of Transmissivity Level (α=0.05). The main effect of Combat Identification Reliability and the interaction effect of Transmissivity Level x Combat Identification Reliability were nonsignificant.

Table 5. ANOVA Summary Table for Reaction Time

Source	Degrees of Freedom	Sum Square Error	Mean Square Error	*F*	*p*
Between					
Subject (S)	11	3.181	0.289		
Within					
Transmissivity (T)	2	0.767	0.384	6.495	0.006
T x S	22	1.299	0.059	-	
Reliability (R)	2	0.095	0.048	1.390	0.270
R x S	22	0.752	0.034	-	
R x T	4	0.154	0.039	0.853	0.500
R x T x S	44	1.992	0.045	-	
Total	107	8.240			

A post-hoc Newman-Keuls test was conducted on Transmissivity Level. Figure 8 shows a line plot of the Mean Reaction Time with the nonsignificant comparisons underlined. Mean Reaction Time at the 75% Transmissivity Level was significantly lower than that observed for the 10% and 2% levels. While these differences may be of interest in a laboratory setting, they have no practical meaning relative to the firing scenarios or when engaging targets in combat.

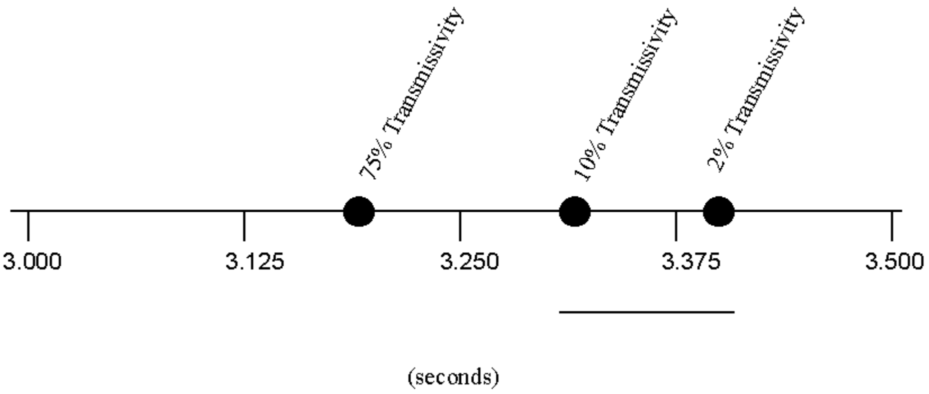

Figure 8. Results of the post-hoc Newman-Keuls test on Mean Reaction Time. Nonsignificant comparisons are underlined.

Subjective Response Data

Immediately following each shooting scenario, participants were asked to indicate what was used to make their “shoot” or “don’t shoot” decision during the scenario just completed. They were provided the following six choices:

1	2	3	4	5	6
100% Vision 0% Combat ID	80% Vision 20% Combat ID	60% Vision 40% Combat ID	40% Vision 60% Combat ID	20% Vision 80% Combat ID	0% Vision 100% Combat ID

Figure 9 shows the mean and standard error of the subjective response data for the six test conditions using the combat identification system. The long columns indicate the shooter relied more on vision than the combat ID system. Short columns indicate the combat ID system was relied on more than their vision. The results for the test conditions involving no combat ID system were not included as all answers were “100% Vision”.

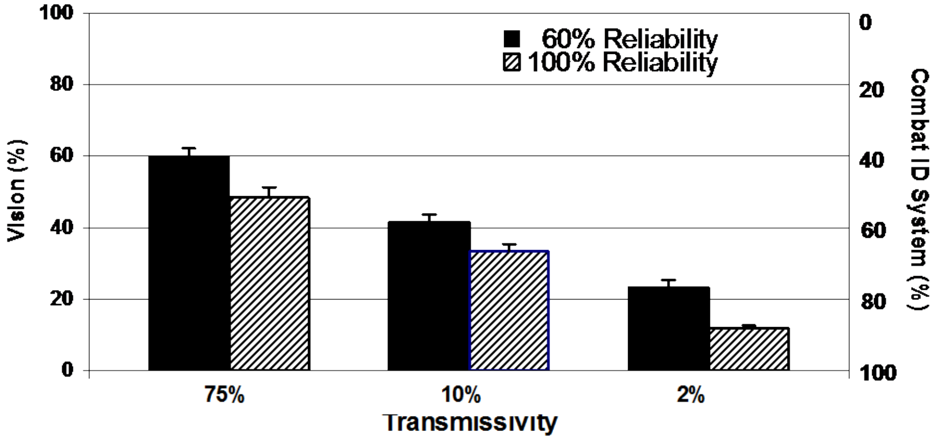

Figure 9. Mean and Standard Error of Survey Results for Vision vs. Combat ID utilization. The longer columns indicate the shooter relied more on vision than the combat ID system. The shorter columns indicate the shooter relied more on the combat ID system than their vision.

Table 6 contains a summary of the ANOVA conducted on the Mean Subjective Response data. The ANOVA revealed a significant main effect of Transmissivity Level (α=0.05). The main effect of Combat Identification Reliability and the interaction effect of Transmissivity Level x Combat Identification Reliability were nonsignificant.

Table 6. ANOVA Summary Table for Subjective Response Data

Source	Degrees of Freedom	Sum Square Error	Mean Square Error	*F*	*P*
Between					
Subject (S)	11	21194.4	1926.8		
Within					
Transmissivity (T)	2	15477.8	7738.9	14.2	0.000
T x S	22	11988.9	544.9	-	
Reliability (R)	1	1800.0	1800.0	3.3	0.098
R x S	11	6066.7	551.5	-	
R x T	2	33.3	16.7	0.1	0.942
R x T x S	22	6100.0	277.3	-	
Total	71	62661.1			

A post-hoc Newman-Keuls test was conducted on Transmissivity Level. The Mean Subjective Response for all three Transmissivity Levels were significantly different. This indicates shooters relied more on their vision than the combat identification system at the 75% transmissivity level and more on the combat identification system than vision at the 2% transmissivity level.

Discussion

Friendly Fire Engagements

The statistical findings for Friendly Fire Engagements revealed several significant differences among the test conditions. The first set of statistical findings involved the simple main effect of Transmissivity Level specifically at the no combat identification system level. At this level, shooters wearing goggles with 2% transmissivity engaged about 68% (3.4 of 5) of the friendly targets. This level of fratricide was significantly higher than that observed when using goggles with 10% and 70% transmissivity. This is consistent with the notion that the light level induced by the goggles with 2% transmissivity produced a contrast modulation on camouflage targets that was below the threshold level. This eliminated the ability to identify the target type. These findings are in agreement with Freedman and Zador (1993) and LaMotte, Ridder, and Yeung (2000). They also support the hypothesis that degraded vision caused by reduced transmissivity increases fratricide.

The second set of statistical findings involved the simple main effect of Combat Identification Reliability specifically at the 100% level. At this level, shooters engaged significantly fewer friendly targets than that observed when using a system with 60% reliability or using no system. In fact, when using the combat identification system with 100% reliability not a single friendly target was engaged during 36 firing scenarios containing 180 friendly target presentations. These findings support the hypothesis that a highly reliable combat identification system decreases fratricide.

The third set of statistical findings involved the interaction effect of Combat Identification Reliability x Transmissivity. With shooters wearing goggles with 75%

transmissivity, there was no significant difference in fratricide between the combat identification systems with 60% reliability and 100% reliability. However, there was a significant difference in fratricide between the 60% and 100% combat identification systems when shooters were wearing goggles with 10% transmissivity and again when shooters were wearing goggles 2% transmissivity. This significant interaction effect partially supports the hypothesis that regardless of reliability level, reliance on the system will occur more often at the lowest transmissivity level as opposed to the highest transmissivity level which increases fratricide when using a combat identification system with 60% reliability.

This hypothesis is further supported by the results of the user opinion survey and a more in-depth analysis of fratricide when the combat identification system with 60% reliability was used. The survey reveals shooters wearing goggles with 75% transmissivity relied more on their vision than the combat identification system, and shooters wearing goggles with 2% transmissivity relied more on the combat identification system than their vision. This is in agreement with Lee and Moray (1992) that automation is used only when confidence in automation (i.e., the combat ID system) is greater then confidence in manual controls (i.e., vision). Combining this reliance trend with the 2% transmissivity level and a combat identification system with 60% reliability increases fratricide. Specifically, when the shooters relied more on the combat identification system due to their degraded vision and the system erroneously returned the “unknown” auditory signal for two of the five friendly targets presented, the decision was to shoot friendly targets. This is in agreement with research on the misuse of automation (Parasuraman and Riley, 1997).

Missed Threat Targets

The ANOVA for Missed Threat Targets revealed nonsignificant main effects of Transmissivity Level and Combat Identification Reliability and their interaction effect. Across all nine combinations of Transmissivity Level and Combat Identification Reliability, approximately one of 10 threat targets presented during a firing scenario was not engaged. It is not known whether the decision was not to shoot a threat target due to inconclusive identification or the shooter reaction time was longer then the target exposure time. In either case, the results indicate efforts to reduce friendly fire engagements with the combat identification system did not have an adverse effect on engaging threat targets.

Reaction Time

The ANOVA for the Mean Reaction Time data revealed a significant main effect of Transmissivity Level. The pair comparison analysis revealed no significant difference in reaction time between the 10% and 2% transmissivity levels. However, the reaction time for the 75% transmissivity level was significantly lower then that observed for the 2% and 10% levels. The difference in mean reaction time was 0.1 sec and 0.2 sec. Although the means are statistically different, there is no practical difference in regard to the shooting scenarios used in this test or in combat.

An unexpected result in this research was the nonsignificant main effect of Combat Identification Reliability on Mean Reaction Time. This does not support the hypothesis that reaction time would increase due to the extra step associated with interrogating a potential target with the combat identification system. The extra time needed to interrogate a target with the combat identification system was offset by the efficiency afforded by the system with making a faster decision. This notion is illustrated in Figure 10.

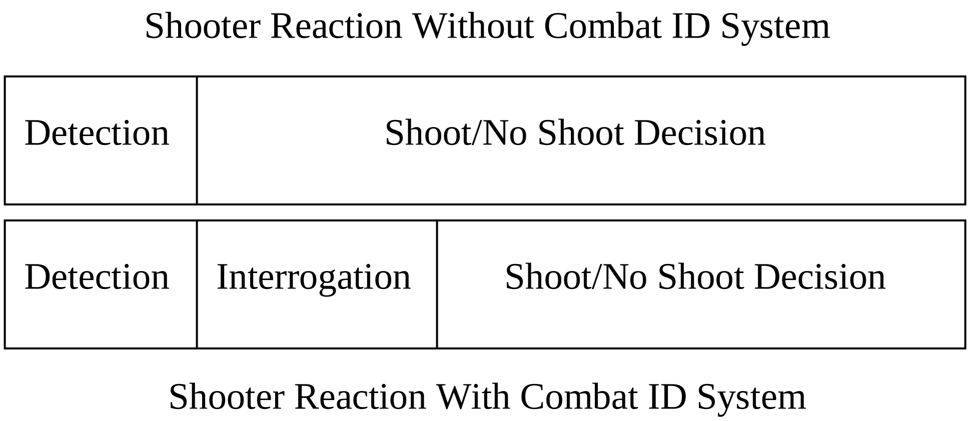

Figure 10. Shooter reaction sequence including target detection, target interrogation, and the target engagement decision showing the efficiency of decision making with the combat ID system.

When using the combat identification system, the mean interrogation time for all friend and threat targets was 1.9 seconds (n=1025, sd=0.7). The Mean Reaction Time to engage all threat targets was 3.3 seconds (n=720, sd=0.26). This included the interrogation time. Without the combat identification system, the Mean Reaction Time was 3.4 seconds (n=360, sd=0.34). Therefore, the “shoot” or “don’t shoot” decision was determined in less time with the aid of the combat identification system. In summary, the reduction in fratricide as afforded by the combat identification system was not accompanied by an increase in reaction time.

Conclusions & Recommendations

Degraded vision is a major contributor to target identification failures and fratricide. The findings of this research provide empirical evidence that degraded vision is a significant contributor to fratricide in a live-fire, infantry shooting scenarios containing threat and friendly target opportunities.

Technology is currently being implemented into military weapon systems to improve combat identification of friendly forces and to reduce fratricide. The results of this research confirm that a highly reliability combat identification system significantly reduces fratricide. In fact, a system performing at 100% reliability completely eliminated fratricide in the context of this study. However, the results also indicate that systems performing at a lower level of reliability will not produce the same fratricide reduction and may increase it if the system is misused.

The use of an automatic combat identification system had no adverse effect on combat effectiveness. There was no significant increase in the number of missed opportunities to engage threat targets when the combat ID system was used. Also, there was no significant increase in shooter reaction time against threat targets when the combat ID system was used.

Designers of future combat identification systems must consider reliability in both the benign laboratory environment and all operational environments. The operational environment must include degraded system states including power supply loss, antenna loss, system damage, and non-combatant targets not equipped with automated friendly target identifiers. Without this consideration, the actual operational reliability may drop to levels that adversely impact the goal of reduced fratricide.

Designers must include features in the combat identification system that accommodate ease of use. The findings of this research indicate a relatively easy to use combat identification simulator had no adverse effect on shooter reaction time. However, if fielded systems are difficult or timely to operate, the reduction of fratricide could be sub-optimal and lead to an increase in missed threat targets.

In the short span of time in which this research was conducted, several friendly fire engagements occurred in Afghanistan. This is in addition to the one mentioned in the opening paragraph of this document. If technology continues to improve the lethality of military weapon systems without a corresponding increase in target identification, fratricide and its devastating impact will continue.

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APPENDIX A

SPECTROPHOTOMETER ANALYSIS OF WINDOW TINTING MATERIAL

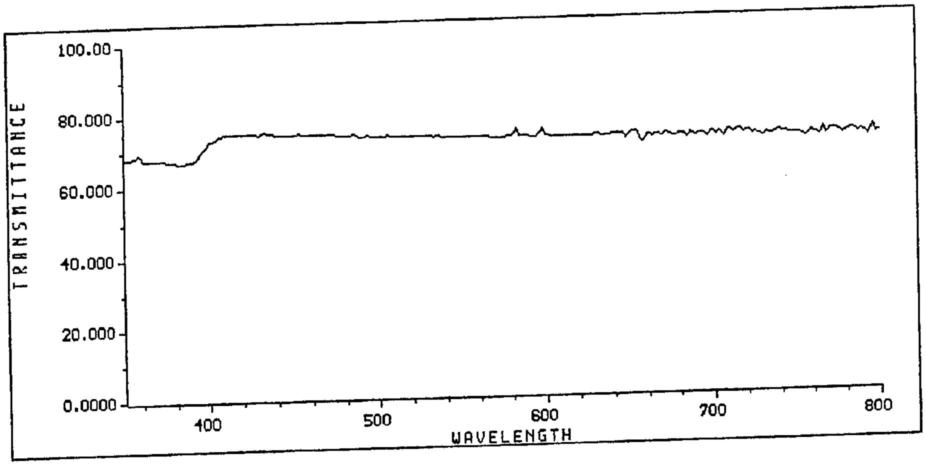

Figure 11. Transmissivity of lenses on SPECS goggles without tinting.

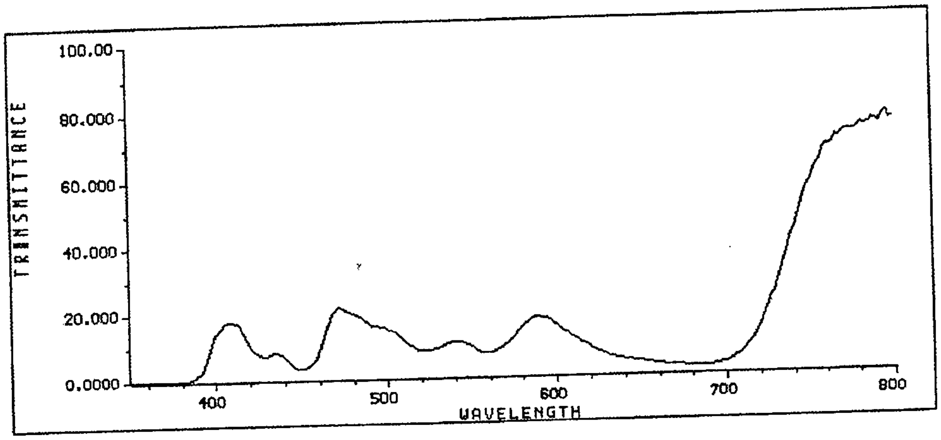

Figure 12. Transmissivity of lenses on SPECS goggles with two layers of tinting.

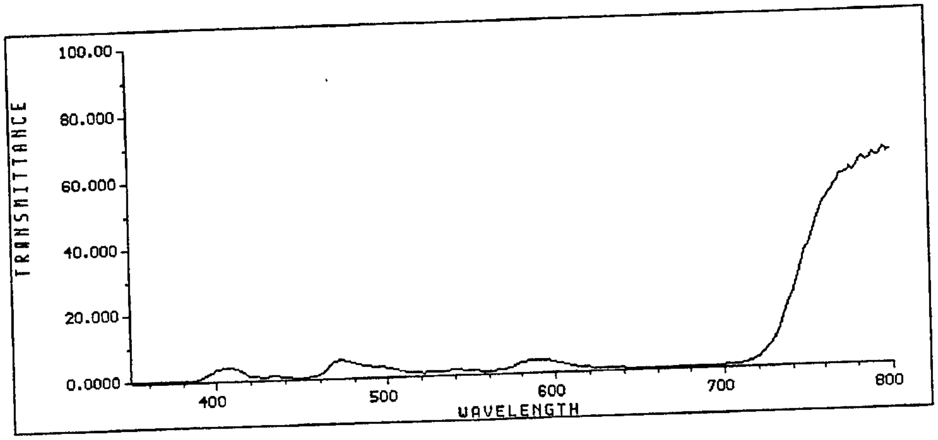

Figure 13. Transmissivity of lenses on SPECS goggles with four layers of tinting.

APPENDIX B

VOLUNTEER AGREEMENT AFFIDAVIT

VOLUNTEER AGREEMENT AFFIDAVIT:

ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is:	**U.S. Army Research Laboratory** **Human Research and Engineering Directorate** **Aberdeen Proving Ground, MD 21005**

Authority:	Privacy Act of 1974, 10 U.S.C. 3013, [Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (4) Equipping (including research and development), 44 USC 3101 [The head of each Federal agency shall make and preserve records containing adequate and proper documentation of the organization, functions, policies, decisions, procedures, and essential transactions of the agency and designed to furnish the information necessary to protect the legal and financial rights of the Government and of persons directly affected by the agency's activities]
Principal purpose:	To document voluntary participation in the Research program.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects

Note: Volunteers are authorized medical care for any injury or disease that is the direct result of participating in this project (under the provisions of AR 40-38 and AR 70-25).

Title of Research Project:	The Effects of Degraded Vision and Automatic Combat Identification reliability on Infantry Friendly Fire Engagements	
Human Use Protocol Log Number:	ARL-20098-xxxxx	
Principal Investigator(s):	Mr. Timothy M. Kogler, AEC	Phone: 410-306-1406 E-Mail: kogler@usaec.army.mil
Associate Investigator(s)	none	Phone: E-Mail:
Location of Research:	ARL-HRED Small Arms Shooting Research Facility (M-range), Aberdeen Proving Ground, MD	
Dates of Participation:	4 test days between 17 June & 30 September 2002	

I do hereby volunteer to participate in the research project described in the table above. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the **ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at 410-278-0612 or DSN 298-0612.** I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human volunteers and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well being.

Part B • To be completed by the Principal Investigator
Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with
Appendix C, AR 40-38 or AR 70-25.

Purpose of the Research

The primary purpose of this research is to determine the relative effects of a perceptual variable (degraded vision) and a cognitive variable (utilization of an automated decision aid) on the time-stressed decision of a dismounted infantryman to engage a friendly or threat targets. The secondary purpose is to determine if efforts to reduce or eliminate the occurrence of friendly fire adversely affect combat effectiveness as measured by shooter reaction time and the number of missed opportunities to engage a threat target.

Procedures

You are being asked to participate in a live fire exercise using the standard issue M16A2. Your tasks will include observing the impact area of the ARL Small Arms Shooting Performance Facility and deciding to engage or shoot at threat and friendly targets as they pop-up from behind protective berms. After the orientation and training sessions, you will participate in 12 shooting scenarios with 16 targets presented during each scenario. During selected scenarios, your vision will be temporarily degraded by wearing shooting goggles containing lenses with three levels of shading. Also, the M16A2 used in this study has been modified with an automated combat identification simulator including a small push button to activate when pointing the weapon at a potential target and an audio feedback indicating if the target is friendly. The reliability of the combat identification simulator will be modified on selected scenarios.

The information collected during this experiment will be used for research purposes only and full confidentiality will be maintained. In compliance with federal law, individual performance will not be directly connected with a participant's identity and will never be released by the research establishments. This study will last approximately 1 day; however, changes in ambient light levels may impact the start and stop time for the experiment, which may increase the total number of days. Your work schedule will be on selected days between Monday through Friday from approximately 0800 to 1600 hours.

Benefits

Your participation in this study will help researchers quantify factors contributing to friendly fire engagements and determine if potential mitigating factors have an adverse impact on combat effectiveness.

Risks

The risks in this pilot study are considered minimal. You may experience minor shoulder irritation after firing the scheduled trials. During the shooting phase, you will be required to wear hearing protection as provided by the range safety officer.

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. Photographic or video images of you taken during this data collection will not be identified with any of your personal information (name, rank, or status). All examinations will be recorded using a volunteer identifier code and a separate file with your consent form and the Principal Investigator will keep your assigned volunteer identifier code in a locked cabinet. Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Medical Research and Materiel Command (MRMC-RCQ) officials may inspect the records.

Compensation

None

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The test administrator will provide a copy to the volunteer.

Your signature below indicates that you: (1) are at least 18 years of age, (2) have read the information on this form, (3) have been given the opportunity to ask questions and they have been answered to your satisfaction, and (4) have decided to participate based on the information provided on this form.

Printed Name Of Volunteer (First, MI., Last)

Social Security Number (SSN)	*Permanent Address Of Volunteer*
Date Of Birth *(Month, Day, Year)*	
Today's Date *(Month, Day, Year)*	*Signature Of Volunteer*

Signature Of Administrator

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee
U.S. Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005
(410) 278-0612 or (DSN) 298-0612

OR

Office of the Chief Counsel
U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197
(301) 394-1070 or (DSN) 290-1070

APPENDIX C

SCHEDULE OF EVENTS

Table 7. Schedule of Events

Time	Event	Participant	Description
0800-1100		1, 2, 3	Informed consent, Orientation, Training
1100-1200			Lunch Break
1200-1205	1	1	75% transmissivity; no combat ID
1205-1210	2	2	10% transmissivity; no combat ID
1210-1215	3	3	2% transmissivity; no combat ID
1215-1220	4	1	75% transmissivity; combat ID 100% reliability
1220-1225	5	2	10% transmissivity; combat ID 100% reliability
1225-1230	6	3	2% transmissivity; combat ID 100% reliability
1230-1235	7	1	75% transmissivity; combat ID 60% reliability
1235-1240	8	2	10% transmissivity; combat ID 60% reliability
1240-1245	9	3	2% transmissivity; combat ID 60% reliability
1245-1300			Adjust target locations
1300-1305	10	1	10% transmissivity; combat ID 100% reliability
1305-1310	11	2	2% transmissivity; combat ID 100% reliability
1310-1315	12	3	75% transmissivity; combat ID 100% reliability
1315-1320	13	1	10% transmissivity; combat ID 60% reliability
1320-1325	14	2	2% transmissivity; combat ID 60% reliability
1325-1330	15	3	75% transmissivity; combat ID 60% reliability
1330-1335	16	1	10% transmissivity; no combat ID
1335-1340	17	2	2% transmissivity; no combat ID
1340-1345	18	3	75% transmissivity; no combat ID
1345-1400			Adjust target locations
1400-1405	19	1	2% transmissivity; combat ID 60% reliability
1405-1410	20	2	75% transmissivity; combat ID 60% reliability
1410-1415	21	3	10% transmissivity; combat ID 60% reliability
1415-1420	22	1	2% transmissivity; no combat ID
1420-1425	23	2	75% transmissivity; no combat ID
1425-1430	24	3	10% transmissivity; no combat ID
1430-1435	25	1	2% transmissivity; combat ID 100% reliability
1435-1440	26	2	75% transmissivity; combat ID 100% reliability
1440-1445	27	3	10% transmissivity; combat ID 100% reliability
1445-1530			Slack

Note: This sequence was repeated for participants 4-6, 7-9, and 10-12 on subsequent test days.

APPENDIX D

TEST RESULTS

Table 8. Number of Friendly Targets Engaged

Participant	Reliability (%)	Transmissivity (%)		
		75	10	2
1	No System	5	4	5
2	No System	0	1	3
3	No System	3	2	5
4	No System	1	2	1
5	No System	0	0	5
6	No System	0	2	4
7	No System	5	1	1
8	No System	1	4	3
9	No System	1	2	5
10	No System	0	1	0
11	No System	3	2	4
12	No System	1	1	5
1	100	0	0	0
2	100	0	0	0
3	100	0	0	0
4	100	0	0	0
5	100	0	0	0
6	100	0	0	0
7	100	0	0	0
8	100	0	0	0
9	100	0	0	0
10	100	0	0	0
11	100	0	0	0
12	100	0	0	0
1	60	2	2	1
2	60	0	1	0
3	60	0	0	1
4	60	0	2	1
5	60	0	1	1
6	60	1	1	1
7	60	0	0	2
8	60	2	2	2
9	60	2	1	2
10	60	0	0	2
11	60	1	1	2
12	60	1	1	2

Table 9. Number of Missed Threat Targets

Participant	Reliability (%)	Transmissivity (%)		
		75	10	2
1	No System	2	1	1
2	No System	2	2	5
3	No System	0	3	4
4	No System	0	1	0
5	No System	1	5	0
6	No System	2	0	1
7	No System	0	1	2
8	No System	0	1	1
9	No System	0	1	0
10	No System	2	3	2
11	No System	2	1	1
12	No System	1	0	0
1	100	1	1	0
2	100	0	2	1
3	100	2	1	3
4	100	0	0	0
5	100	0	3	0
6	100	0	0	0
7	100	1	1	2
8	100	0	3	1
9	100	1	2	2
10	100	0	0	0
11	100	0	1	2
12	100	1	0	1
1	60	3	2	0
2	60	3	2	4
3	60	2	1	2
4	60	1	1	0
5	60	1	0	0
6	60	0	2	1
7	60	2	0	0
8	60	1	0	2
9	60	0	3	3
10	60	0	0	0
11	60	2	0	0
12	60	1	3	2

Table 10. Mean Reaction Time To Engage Threat Targets

Participant	Reliability (%)	Transmissivity (%)		
		75	10	2
1	No System	3.40	3.19	3.73
2	No System	3.56	4.06	3.78
3	No System	3.18	3.29	3.10
4	No System	3.52	3.05	2.94
5	No System	3.00	4.25	3.24
6	No System	3.25	3.26	3.44
7	No System	3.25	3.29	3.54
8	No System	3.13	3.26	3.36
9	No System	3.21	3.37	3.57
10	No System	2.82	2.89	2.78
11	No System	3.28	3.21	3.49
12	No System	3.00	3.13	3.64
1	100	3.42	3.30	3.31
2	100	2.92	3.70	3.91
3	100	3.10	3.01	3.42
4	100	2.77	3.17	3.15
5	100	3.24	3.26	3.44
6	100	3.05	3.11	3.35
7	100	3.36	3.51	3.66
8	100	3.10	3.71	3.61
9	100	2.94	3.08	3.34
10	100	2.75	2.68	3.14
11	100	3.32	3.38	3.38
12	100	3.23	3.11	3.31
1	60	3.28	3.03	3.23
2	60	3.52	3.55	3.88
3	60	3.57	2.85	3.67
4	60	3.13	3.02	3.19
5	60	3.25	3.50	3.36
6	60	3.30	3.34	3.18
7	60	3.14	3.63	3.49
8	60	3.22	3.43	3.53
9	60	3.14	3.24	3.60
10	60	2.92	3.09	3.19
11	60	3.37	3.76	3.25
12	60	3.17	3.59	3.15

Table 11. Subjective Response Data

Participant	Reliability (%)	Transmissivity (%)		
		75	10	2
1	100	20	0	0
2	100	80	60	0
3	100	20	20	0
4	100	100	80	40
5	100	80	80	20
6	100	20	0	0
7	100	80	20	0
8	100	20	20	0
9	100	20	0	20
10	100	40	40	20
11	100	20	20	40
12	100	80	60	0
1	60	40	80	0
2	60	80	0	20
3	60	20	20	20
4	60	100	60	40
5	60	80	60	20
6	60	40	40	20
7	60	80	20	0
8	60	0	20	0
9	60	60	60	60
10	60	80	40	60
11	60	60	40	20
12	60	80	60	20

Note: Data are the vision component of subjective response

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