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ESSENTIAL ELEMENT OF COMBAT READINESS

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THE UNITED STATES ARMY MEDICAL DEPARTMENT

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Perspectives

COMMANDER'S INTRODUCTION

MG David A. Rubenstein

Every combat commander's vision of perfection is an effective, sustainable fighting force comprised of healthy, physically fit Warfighters. Obviously there is much work from many, many people working very hard to give that commander what he needs. Among them, the Army Medical Department has one of the most complex of tasks—ensuring the health, physical capabilities and effectiveness, and, ultimately, the survival of the Warfighters themselves. For most people, the concept of Army medicine is the combat medic, medical evacuation helicopters, the combat hospital, and surgeons and nurses working together to save the lives of wounded Warriors. While the remarkable skills and combined efforts of that team represent the pinnacle of immediate, direct, life-saving medical capabilities, that is just one component of the total responsibility that the AMEDD has for each Soldier's health and well-being.

Force health protection is the umbrella term for all we do to keep the Soldier healthy, which essentially involves the consideration of all medical threats to our forces, whether natural or a creation of the enemy. Force health protection is also applicable to nondeployed units and personnel, as medical casualties from diseases, accidents, and, sadly, lifestyle choices represent significant threats to readiness. The Army continues to refine its capabilities in research, planning, application, and resources to address this multifaceted responsibility. A significant example of those efforts is the recent establishment of the Army Public Health Command. This new organization combines Army medicine's public health and preventive medicine resources into a coordinated, focused entity to provide support directly to both garrison and deployed commands, as well as direct high-level research, planning, doctrine development, and data collection and management.

The scope of AMEDD's commitment to force health protection is impossible to convey in a few short paragraphs, or even an entire issue of the *AMEDD Journal*. Fortunately, over the last four years, COL Mustapha Debboun has regularly assembled articles from preventive medicine and public health professionals for dedicated issues of the *Journal*, providing true insight to the diversity and complexity of their responsibilities and their work. Those issues have been invaluable sources of information, and this one is no different. The articles in this issue cover the gamut of force health protection concerns, from extensive research studies and surveillance, to solutions for potential threats. As you read this *AMEDD Journal*, you will be impressed and educated by the breadth and depth of this vital work and vigilance that are never-ending, mostly behind the scenes. Their success is reflected in an absence of disease and injury, and the improved health of us all. For this these medical professionals have truly earned our respect and gratitude, both for what they have done, and what they will do to protect our most valuable asset, the Warriors who defend our nation and our way of life.

EDITORS' PERSPECTIVE

The US Army initiated war against mosquito vectors of serious diseases in 1900, when MAJ Walter Reed experimentally proved that yellow fever was indeed transmitted by an identified species of mosquito. That war continues to this day as a mainstay in the efforts of Army public health professionals to identify and control arthropods and other pests that enable the transmission of severely debilitating, often fatal, diseases to humans throughout the world. This issue of the AMEDD Journal contains four articles presenting various aspects of this component of military public health responsibilities. Brian Zeichner and COL Mustapha Debboun contributed an excellent article discussing an innovative, relatively simple idea to control mosquito vectors for two serious diseases that have resurged and expanded over the last several decades. They describe the development of a lure for female mosquitoes seeking an egg-laying site, wherein the mosquito is exposed to an insecticide. Obviously, elimination of the females and their eggs will significantly reduce the number of mosquitoes in the area. The lures are small and inexpensive, requiring only water to activate, and are much safer than sprays or broadcast poisons. This is an interesting, important approach to an age-old problem—another weapon in

the public health arsenal to combat mosquito-borne diseases.

COL Leon Robert and CDR Steven Rankin discuss the expanding real-world roles and responsibilities that are placed on military entomologists in today's counter-insurgency and stability operations. Their experience is that the entomologist is involved more than ever before with an assortment of disparate military and government agencies and individuals, as well as nongovernmental international organizations. Beyond that, the entomologist must also be able to work among the de facto power structure in local areas to be effective. Their article discusses these experiences and successes, and offers recommendations as to how to better prepare military entomologists for this reality.

Dr Leopoldo Rueda and his coauthors describe another important role in the battle against vector-borne pathogens. Identification of the different vector species found in areas inhabited by our military is the first step in countering the threat. This article details the work on Guam and neighboring islands to ensure that the data on potentially harmful mosquitoes is as complete as possible. This is especially important in anticipation of the planned significant increase in military and civilian personnel on Guam in the next 5 years.

As with any war, the battle against vector-borne disease requires intelligence, in this case, surveillance records documenting mosquito species, dates, and locations where found. This data is important in planning effective mosquito control programs. The Army began collecting surveillance data for US military installations during World War II. Organized data from 1947 until the present exist and are available online. In their article, Dr Desmond Foley and his coauthors describe the ambitious project they undertook to map the entirety of that data in a state-of-the-art georeferencing system designed specifically for mosquito surveillance. Now the mosquito data can be analyzed within different parameters, including geography, climate, seasons, vegetation types and coverages, among others. Furthermore, this analysis tool may be used by all researchers and planners to develop preventive intervention strategies for mosquito-borne disease threats.

Predictions of the risk of injury are important to force health protection planners. As part of an effort to determine if the risk of lower extremity injuries of Soldiers could be estimated using measurements of endurance, flexibility, strength, and power, LTC Deydre Teyhen and her team had to first assess the reliability and precision of those measurements performed by novice raters. Their article is a thoroughly referenced, detailed report of their measurement procedures, the data collected, and the statistical analysis of the results. This article is an excellent example of the high caliber of medical research and analysis that is the standard for AMEDD professionals.

There are few true absolutes in life, but one of them is that the human body must have water to survive. Unfortunately, water can also transport disease or toxic substances, transforming it into an instrument of sickness and death, often across large populations. Two articles demonstrate how science and engineering collaborate to produce safe, clean water for our Warfighters, both in US garrisons and in deployed environments. In his article, Steven Clarke describes how a waterborne pathogen, *Cryptosporidium*, was identified in the raw water source for a continental US military facility's water treatment plant. The plant was evaluated and it was determined that improvements in the existing treatment processes were necessary to mitigate the threat. The resulting changes not only substantially reduced the potential risk, but also improved the efficiency and lowered the operating costs of the plant. The other perspective, providing clean water to troops on the battlefield, is presented by Arthur Lundquist and his coauthors. Their article discusses how the evolving nature of modern asymmetric combat operations has seriously complicated the task of getting potable water to dispersed forces, for both engineers and logisticians. This article provides excellent insight into how our multidisciplinary professionals anticipate, identify, and respond to the challenges of today's dynamic combat environment.

CPT Edgie-Mark Co and his coauthors have contributed an article which demonstrates the high level of research and analysis capability we have within AMEDD. Their team sought to identify a better test for specific types of infection-causing organisms which would produce definitive results much more quickly than current laboratory methods in deployed environments. The time saved can be vital, in that the provider can begin targeted antibiotic treatment as soon as the type of infection is identified, rather than guess with broad spectrum antibiotics while additional tests were performed. CPT Co et al's laboratory research found that another, readily available test panel produced

expanded test results with higher levels of sensitivity and specificity than the panel currently used. Again, such initiative, skill, and expertise will potentially increase the odds of survival of our wounded Warriors.

MAJ Kent Broussard looks at the challenges that the Army combat organization of today pose for those charged with public health support of deploying units. The integration and coordination of 5 levels of support across the 3 phases of a deployment cycle can be daunting tasks, requiring significant organizational skills, attention to detail, and, ideally, some level of experience in deployments. This article itemizes the doctrinal responsibilities of the public health resources that are involved, and illustrates the complexity of such an enterprise. It is a good synopsis of the commitment of the Army healthcare system to force health protection of our deploying forces.

The *AMEDD Journal* welcomes Dr Coleen Baird back to these pages with another excellent article addressing concerns about the respiratory health of deployed personnel, both during and following deployments to combat theaters. There is a growing concern in the medical community about the relationship between deployments and respiratory problems, and in this issue, Dr Baird examines the available data on that possible linkage, and discusses the ongoing efforts to improve the quality of the data gathered, and refine the assessments. Her article provides an important insight for healthcare providers involved with evaluating and treating respiratory problems among our deploying military and civilian personnel.

Evaluation of long term health effects (other than traumatic injury) of the combat environment are difficult to perform, in that the parameters are difficult to establish and quantify, and the target population is often dispersed and affected by unrelated factors. Dr Hikmet Jamil and his coauthors designed and performed a study in 2002 to examine the native population, civilian and military, who lived and/or served in the war zone of the 1991 Gulf War. Their article describes their extensive study, presents the analyzed data, and evaluates the results. Their accumulated data had to be examined from numerous perspectives and statistical categories, and carefully analyzed to account for nonrelevant influences or corrupting factors. This is an excellent presentation of a study which had to be carefully designed and conducted to examine a large, complex set of possible elements and circumstances.

One of the tenets of our military of is that "we train as we fight." Combat training has developed the most realistic environments possible, and our combat Warriors are placed in those environments time and again to experience every conceivable scenario and situation. Of course safety is paramount, but combat operations are risky, and the training can be as well. However, the combat effectiveness of a fighting force can be compromised by injuries to Warfighters during training, especially if such injuries are not obvious. Hearing and vestibular damage are often subtle, but can be cumulative, and can be a dangerous disadvantage in combat. Dr Paul St. Onge and his team of researchers examined a training evolution in which the trainees and instructors are repeatedly exposed to explosions in close proximity, often in closed spaces. All participants are trained and equipped with hearing protection, but the particular circumstances of this training environment are unique, and the effects had not been scientifically evaluated. This important article describes the detailed design and careful execution of the study, as well as the evaluation and interpretation of the resulting data. It is another excellent example of the level of expertise and skills that our medical professionals bring to work every day.

Starting and maintaining any type of exercise program is usually more of a psychological effort than actual physical work. Many ideas about ways to turn normal functions into useful exercise have come and gone, probably because they are easily forgotten. CPT Mary Staudter and her team conducted a study with staff members at Brooke Army Medical Center to examine if use of a pedometer and tracking step counts could encourage more exercise with simple increased walking in their normal daily activities. Other studies had indicated that this can be the case, and this study looked at such use of pedometers among the select population of military healthcare providers and their families. Their article describes this carefully designed, meticulously conducted study, presents the details of the statistical data analysis, and discusses the results, and the complications to any conclusions that may be derived. All readers should find this article informative and instructive, and perhaps an inspiration to consider such a program for themselves.

The Lethal Ovitrap: A Response to the Resurgence of Dengue and Chikungunya

Brian C. Zeichner
COL Mustapha Debboun, MS, USA

ABSTRACT

There has been a global resurgence in dengue fever since the 1960s and now more than one third of the world's population lives in dengue endemic areas. Chikungunya, another mosquito-borne disease, had been limited to sub-Saharan Africa and Southeast Asia, but recently spread to Italy and France, raising concerns that it could spread to many more countries in Europe and the Americas. There are currently no vaccines available to prevent infection with either virus and medical care is limited to symptomatic and supportive treatments. Suppression of the mosquito vector populations reduces disease transmission, however, the tools currently available to control the main vectors of dengue and chikungunya are inadequate. Larval control is very labor intensive and pesticide sprays do not adequately penetrate the microhabitats where adult mosquitoes are sequestered. The lethal ovitrap addresses these shortcomings by luring the potentially viremic female mosquitoes to an egg laying site where they are exposed to a toxic insecticide dose. It is a safe, environmentally sound, economical, and simple means of dengue and chikungunya vector control whose efficacy has been documented in 9 research papers. Management programs using the lethal ovitrap have been shown to halt dengue and chikungunya transmission. Efforts are underway to mass produce the lethal ovitrap under the registered trade name Trap-N-Kill which will ensure its availability to our armed forces deployed in dengue and chikungunya endemic areas.

INTRODUCTION

Dengue is a virus spread through the bites of infected mosquitoes. In human patients, infection is characterized by fever and may include rash, severe headache, pain behind the eyes, as well as pain in muscles and joints. It is endemic in more than 100 countries (Figure 1) where an estimated 2.5 billion (10^9) people live,[1] more than one third of the world's population. Dengue has a strong potential to infect large portions of immunologically naïve human populations. For example, in 1972, 90% of the 4,600 people living on Niue Island in the South Pacific were infected after dengue was first introduced.[3] Deployed armed forces personnel represent another immunologically naïve population that would be highly susceptible to dengue exposure. Therefore, the insertion of US troops into a dengue endemic area could result in the infection of a significant number of personnel if effective countermeasures, such as personal protection and mosquito control, are not used.

Chikungunya is another mosquito-borne virus with flu-like symptoms. Infection is characterized by fever, headache, weakness, rash, and joint pain. While the febrile phase lasts from 2 to 5 days, the joint pain may persist for weeks or months in some individuals. Epidemics can impact large proportions of local populations. For example, on Reunion Island, an estimated 244,000 people, roughly 35% of the population, was infected from April 2005 to April 2006.[4] Chikungunya had been limited to 36 countries in sub-Saharan Africa and Southeast Asia; however, in 2006 after a massive outbreak in India, it appeared in Italy for the first time.[5] This recent range expansion has raised concerns that it could spread to many more countries in Europe and the Americas.

The primary global vector of dengue is the mosquito, *Aedes aegypti* (L.), known as the yellow fever mosquito. However, in a 2001 outbreak in Hawaii, a similar species, *Ae. albopictus* Skuse, known as the Asian tiger mosquito, was the predominant vector. The 2 species share several life history traits, including feeding and oviposition behaviors. Unlike many mosquitoes in the temperate regions, which primarily feed at dusk and dawn, both of these species readily bite people during the day. Despite many similarities, the

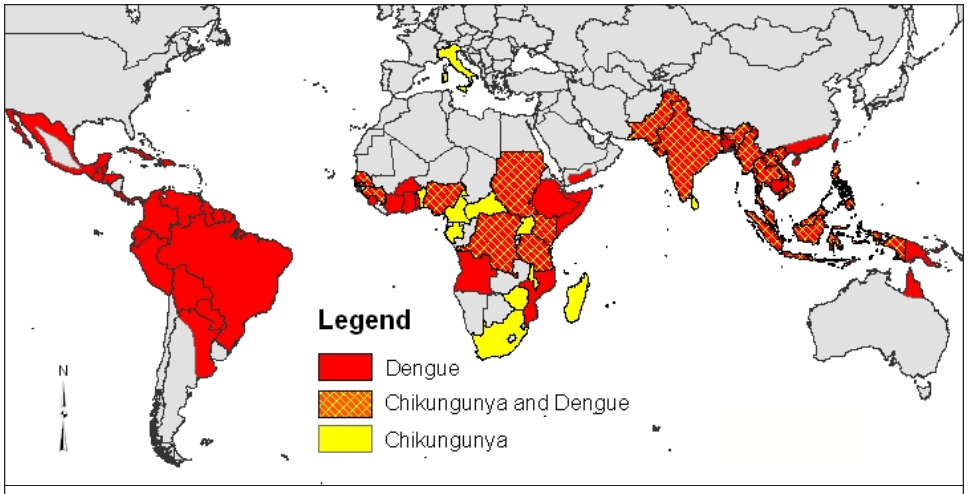

Figure 1. Approximate distribution of countries/areas at risk for dengue and chikungunya transmission. Dengue data (2006) from the World Health Organization.[1] Chikungunya data (2010) from the US Centers for Disease Control and Prevention.[2]

two can be distinguished from each other by the white scales on the front dorsal surface of the thorax. *Aedes aegypti* has a lyre-shaped pattern and 2 narrow bands of white scales , while *Ae. albopictus* lacks the lyre-shaped pattern and has one broad silvery-white stripe down the middle (Figures 2 and 3).

The Asian tiger mosquito was introduced into the United States in the 1980s and has since established itself in the southeastern region of the country. Today, the species infests an area holding almost two-thirds of the US population, where its habit of aggressive daytime biting has made it a major nuisance pest.[6] While *Ae. albopictus* does not currently vector diseases in the continental United States, its involvement in recent dengue and chikungunya outbreaks elsewhere demonstrates its potential threat to US citizens. Also, the continual expansion of its global range increases the likelihood that troops will encounter this species during deployment.

Disease Countermeasures

Currently no vaccines are available to prevent infection by either dengue or chikungunya. Therefore, prevention of mosquito bites is the most effective way to avoid contracting these diseases. Personal protective measures are a proven countermeasure system. In numerous studies, the Department of Defense Insect Repellent System*, consisting of N,N-diethyl-3-methylbenzamide (deet) for exposed skin and permethrin for clothing, has been shown to provide maximum personal protection against arthropod bites when applied according to instructions. Unfortunately, full compliance with repellent instructions is inadequate and, in hot humid environments where the disease threat is greatest, perspiration makes the application of repellents less desirable for the user and individuals are more inclined to expose bare skin to enhance cooling.[7] Therefore, mosquito control is an important countermeasure to prevent disease and annoyance from day-biting mosquitoes.

Mosquito control methods often target specific life stages (larvae or adults) or behaviors (host-seeking or resting). Larval control involves the treatment or removal of aquatic larval habitats. For mosquitoes that breed in pools of standing water, larval control can be very efficient when the pools are easy to identify and treat. However, *Ae. aegypti* and *Ae. albopictus* larvae develop in small containers such as discarded bottles, cans, cups, tires, flower pot saucers, cemetery urns, water storage jugs, upside-down trashcan lids, depressions in plastic tarps, clogged rain gutters, plant leaf axles (bromeliads are a popular horticultural plant that produces many potential breeding sites) and natural tree holes. In countries without running water, residents use many containers to store water around homes. While necessary for survival, this practice also augments the number of peridomestic breeding sites. In Thailand, for example, the mean number of potential breeding containers was 162 containers per house among 3 villages.[8] Clearly, effective larval control in such environments requires significant manpower and resident cooperation.

Adult mosquito control involves insecticide fogs or mists that can be applied by aircraft or truck-mounted equipment and are much less labor intensive per area than searching for and applying larvicides to small water containers. However, in order to be effective, the

*Information available at: http://phc.amedd.army.mil/PHC%20Resource%20Library/DODInsectRepellentSystemJustheFacts-June2007.pdf

Figure 2. Full view and closeup of *Aedes aegypti*. Note the lyre-shaped band of white scales on the thorax and the 2 narrow bands of white scales on the center of the thorax (right panel, red arrows).*

Figure 3. Full view and closeup of *Aedes albopictus*. Note the lack of a lyre-shaped band of white scales on the thorax and the broad band of white scales on the center of the thorax (right panel, red arrows).*

insecticide must impinge on the target mosquitoes. Consequently, if the adult mosquito is resting or in a sheltered location, such as within a dense bush or residential closet, it will not receive a lethal dose. For this reason, which has been demonstrated in numerous studies, the World Health Organization states that insecticide fogs and mists are costly, operationally difficult, and the "mosquito-killing effect is transient" and "variable in its effectiveness because the aerosol droplets may not penetrate indoors to microhabitats where adult mosquitoes are sequestered."[9]

In summary, there are significant shortcomings to the available larval and adult control strategies when targeting *Ae. aegypti* and *Ae. albopictus*. Accordingly, these species continue to expand their global ranges. Novel strategies must be incorporated to suppress these persistent disease vectors.

The Lethal Ovitrap

The lethal ovitrap (Figure 4) addresses the shortcomings of conventional control methods—trying to deliver insecticide to the mosquito—by having the potentially viremic female mosquito come to the insecticide. It is an extension of the surveillance ovitrap method, which uses artificial breeding containers to attract gravid (ready to lay eggs) female mosquitoes to lay eggs and reveal their presence. Surveillance ovitraps were first described in 1966 and have since been widely used around the world to monitor *Ae. aegypti* populations.[3,10] Therefore, the tendency of *Ae. aegypti* to visit them regularly is well established. Surveillance ovitraps consist of a black, smooth-walled, glass or plastic container partially filled with water and holding a rough wood, cloth, or paper strip at the water surface. Gravid female mos-

*Photographs by Graham Snodgrass, Army Institute of Public Health, Entomological Sciences Program, APHC(P), on a macro imaging device (patent pending) developed by the Entomological Sciences Program, APHC(P).

Figure 4. The Mosquito-Science prototype Trap-N-Kill lethal ovitrap. Photo courtesy of SpringStar, Inc.

quitoes visit the container and find the walls too smooth to deposit eggs. Therefore, their eggs are laid on the rough strip which can then be removed and placed under a microscope for counting.

In lethal ovitraps, the rough egg-laying strip is treated with an insecticide so that female mosquito will acquire a lethal insecticide dose when she lands on the strip to deposit eggs. Egg laying is not required to receive a lethal insecticide dose; if a mosquito spends as little as 10 seconds on the insecticide treated strip, she will acquire a lethal dose. Effectiveness of the lethal ovitrap in the field is enhanced by the female's predilection to not place all her eggs in one site, but to deposit them at numerous oviposition sites. This behavior, known as "skip oviposition," has been documented in numerous studies and it has been estimated that, on average, female *Ae. aegypti* lay eggs at 12 or more oviposition sites per egg laying cycle.[11] The exact number of oviposition sites visited is not known, but is undoubtedly greater than the number of those where eggs are deposited. To induce egg laying, a potential site must exhibit certain short-range chemical cues that verify both a sufficient food supply and a lack of overcrowding by other larvae. This tendency to visit multiple breeding containers increases the likelihood that a gravid female will visit a lethal ovitrap during her egg-laying cycle and die before she can transmit disease.

The lethal ovitrap technology circumvents the shortcomings of conventional control methods, broadcasting insecticides in hope that it will contact the mosquito, by luring the target mosquitoes to the insecticide. This reversal of the traditional control approach increases efficacy, while decreasing the amount of pesticide used, manpower requirements, and impact to nontarget organisms.

PROOF OF CONCEPT

Initial testing of the lethal ovitrap was conducted in the US Army Public Health Command laboratory. Heavyweight velour paper strips (2.54 cm by 11 cm) were used as an alternative to the wooden paddle normally used as a substrate for mosquito oviposition. The paper strips were pretreated with insecticide solutions and allowed to dry before being used in oviposition cups (473 ml). Insecticides tested were carbamates and pyrethroids known for their quick knock-down efficacy. Testing was conducted in cages 1 cu ft in size containing gravid female *Ae. aegypti* mosquitoes from a susceptible laboratory strain and 2 oviposition cups, one with an insecticide treated strip and one with an untreated strip (Figure 5). The synthetic pyrethroids proved to be the most effective, causing 98% to 100% adult mortality. Young larvae were added to the cups to test what would happen if any of the eggs hatched in the ovitrap. All larvae died within 2 hours of introduction to the traps, confirming that any eggs laid on the strips would not result in viable adult mosquitoes.[12]

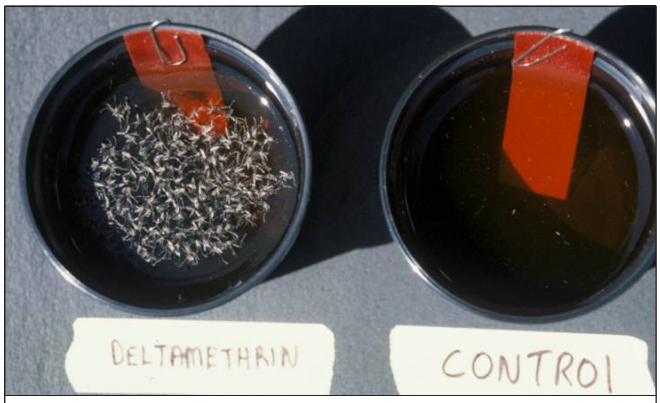

Figure 5. The left cup is a lethal ovitrap with the velour paper strip treated with the pyrethroid deltamethrin, which is toxic to adult mosquitoes. The right cup is a nonlethal ovitrap.

A later study in Australia tested ovistrips treated with the pyrethroid bifenthrin. The lethal ovitraps were placed outdoors in a shaded location for one month, and then placed in a cage with a pesticide-free ovitrap. A single gravid female was added to the cage and mortality was determined at 24 hours, and the ovitraps were checked for eggs. This was replicated 80 times. Of the 25 replications where eggs were found on the lethal ovistrip, 92% of the females died, while in the 55 replications where eggs were not found on the lethal ovistrip, 62% of the females died, confirming that visiting the lethal ovitrap without laying eggs can still be fatal to *Ae. aegypti* females.[13]

Four proof of concept field trials followed the successful laboratory evaluations. Deltamethrin, a synthetic pyrethroid insecticide, was selected as the active ingredient for these field trials. It was selected for the follow-

ing reasons: (*a*) it has been safely used around the world since 1978; (*b*) it is highly toxic to the target mosquitoes at small doses with just 1 mg per velour strip, enough to provide control for one month in the field; and (*c*) its solubility in water is low enough to maintain strip integrity in water (0.002 mg/L), but high enough to kill any larvae that may hatch from laid eggs. The toxicity to larval mosquitoes at low doses and the low solubility in water leaves a large safety margin for mammals. For instance, the no observable effect level (NOEL) in a dog feeding study was 1 mg/kg body weight/day. Therefore, a 10 kg dog would not exceed the NOEL by consuming the velour paper strips from up to 10 lethal ovitraps per day and could not physically drink enough ovitrap water to reach the NOEL.

The 4 field trials were conducted in Brazil, Peru, Bangladesh, and Thailand, each following the same protocol. The key points of the trials included:

- One group of homes received 10 lethal ovitraps for each home, 5 inside and 5 outside.
- An untreated reference area received no ovitraps.
- No additional mosquito control measures were taken in either control or treatment areas.
- Ten houses were sampled each week for *Ae. aegypti* abundance.
- The lethal ovitraps were deployed for 3 months with the lethal ovistrip component replaced monthly, except in Thailand where they were replaced every 2 weeks because mold grew on the surface, preventing the mosquito from contacting the insecticide.

When used alone in Brazil,[14] Peru (M. J. Perich, PhD, unpublished data, January 2001), and Bangladesh[15] field trials, the lethal ovitrap significantly reduced the number of *Ae. aegypti* adults per house, the number of containers with larva per house, and the number of pupae per house. The number of pupae per house is considered to be the most reliable measure of *Ae. aegypti* populations and can be correlated with dengue transmission risk.[16,17] The number of pupae per house before and after treatment in the untreated and treated sites is presented in Figure 6**.** While the number of pupae per house dramatically increased in the untreated sites in Brazil, the same metric fell below the threshold for dengue transmission in the treated areas. In Peru, the number of pupae per house dropped to zero. While the drop was not as dramatic in Bangladesh, it was statistically significant when compared to untreated areas.

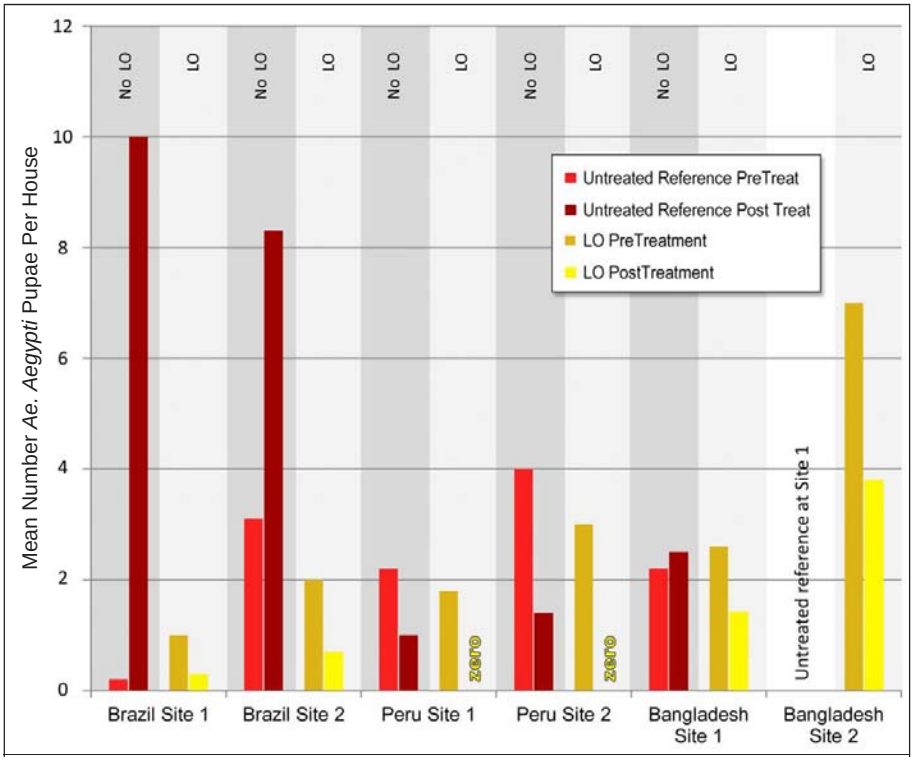

Figure 6. Number of pupae per house before and after placement of lethal ovitraps (LO) field trial in Brazil, Peru, and Bangladesh. Red bar is the untreated reference site one month before LO placement. Maroon bar is the untreated reference 3 months during LO placement. The gold bar is the LO treatment site one month before LO placement. The yellow bar is the LO treatment site 3 months during LO placement.

In the Thailand study area, there were a large number of breeding containers present. Some were very large, holding over 30 gallons of water, which made it difficult to count the number of pupae per household. Instead, the number of containers with larvae, ie, containers with pupae and adults collected in 10 minutes with a hand-held aspirator, were counted. The overall means of counts in untreated reference sites compared to lethal ovitrap sites from the 2000 study are shown in the Table.

The population reduction, as measured by these parameters, was not as large as what was seen in the Brazil and Peru studies. One possible explanation for the reduced effectiveness observed in the Thailand studies was the competition the lethal ovitrap had with the large number (mean 163±75 per house) and size of water containers around houses. Perhaps the placement of more than 10 lethal ovitraps per house would have been beneficial in this site to better compete with the existing containers. Another possible explanation is immigration of mosquitoes into the treatment sites from the untreated surrounding areas. There is increasing evidence that *Ae. aegypti* is capable of dispersing hundreds of meters, which could mean that the 250-meter separation between the untreated and treated sites in the trial may not have been sufficient to prevent migration between sites.[18]

LETHAL OVITRAP AS PART OF AN INTEGRATED VECTOR MANAGEMENT PROGRAM

Like the majority of pest management methods, the lethal ovitrap is more effective when used in an integrated vector management program that attacks the target pest with several control strategies. Researchers in Thailand and Australia have successfully used the lethal ovitrap as part of integrated management programs which controlled dengue transmission.

In Thailand, a community-based dengue control program was implemented. This program consisted of a preseason source reduction/cleanup campaign to remove potential breeding sites; application of a larvicide and copepods (which eat mosquito larvae) to non-drinking water containers; the distribution of mosquito-proof screens for drinking water containers; and placement, by volunteers, of 2 to 5 lethal ovitraps with the pyrethroid insecticide permethrin at each house.[19]

This undertaking proved to be a very successful dengue control program. Prior to the control measures, the dengue fever rates were 265 per 100,000 people in the community dengue control program, versus 217 per 100,000 in an untreated reference community. One year after the interventions, the dengue fever rates were zero in the community dengue control program versus 322 per 100,000 in an untreated reference community. The percentage of lethal ovitraps with eggs decreased from 66% to 10% in the integrated management program, indicating that the population of *Ae. aegypti* adult females was significantly reduced. Kittaypong et al[19] concluded that the lethal ovitrap "could successfully suppress populations of adult female *Ae. aegypti* for up to about 1 month" and "can successfully compete with other domestic oviposition sites."

Comparison of means of the counts of mosquito breeding in containers in the Thailand study area.*

	Overall Mean (±SD)	
	Untreated Reference Site	Lethal Ovitrap Site
Containers with larvae	16.8 (7.6)	8.5 (5.5)
Containers with pupae	5.4 (3.9)	2.4 (2.3)
Adult female *Ae. aegypti*	6.6 (7.8)	4.4 (6.9)

*Data from Sithiprasasna et al[8]

In 2004, Queensland Health (Queensland, Australia) responded to a dengue outbreak on Thursday Island in the Torres Strait. Their integrated control program consisted of residual insecticide spraying of the active dengue case houses and their nearest neighbors, yard inspections to remove breeding sites and treat nonremovable containers with larvicide or mosquito-proof screens, and the use of 780 locally produced lethal ovitraps with the pyrethroid insecticide bifenthrin. This approach successfully halted the dengue outbreak and the researchers stated "we believe that the sustained control provided by lethal ovitraps was an integral component to progressively removing female *Ae. aegypti* from the resident population."[20] Since then, the lethal ovitrap has become Queensland Health's principal means of adult control in dengue outbreaks. Adulticide sprays are now limited to houses with dengue infected people and lethal ovitraps are used elsewhere. As a result, the number of houses that can be serviced has doubled and the amount of pesticide used has decreased by 99%.[21,22] To ensure maximum coverage with lethal ovitraps, Australia has passed legislation authorizing public health workers to place lethal ovitraps around homes without the homeowner's consent.

The lethal ovitrap's contribution to the population reduction of *Ae. aegypti* in Australia when coupled with source reduction was documented in a 2007 study where the population of *Ae. aegypti* was monitored with sticky ovitraps in 3 areas. Each area received a different treatment: the first was an untreated reference area; the second, an area where larval control was done; and the third was an area where both larval control was done and lethal ovitraps were used for one month beginning April 2. There was no significant

difference in sticky ovitrap catches between the untreated reference and larval control area. However, there were significantly fewer *Ae. aegypti* in the area where lethal ovitraps were used, and, by week four, the decrease was 87% ($P < .05$).[23]

Future Use of the Lethal Ovitrap by the Military

The ease of use and long-term effectiveness of the lethal ovitrap make it a great tool for dengue and chikungunya vector control by deployed forces. However, before it can be made available for military use, it must be approved by the US Environmental Protection Agency (EPA) and a mass production facility be established to ensure that sufficient quantities can be produced as needed. Both of these developments are underway. To ensure that a manufacturer would be willing to invest in registering and establishing a production line, the US Army patented the lethal ovitrap technology in the United States (patents 5 983 557; 6 185 861; 6 389 740) and 6 other countries (Brazil, Mexico, Indonesia, Vietnam, Singapore, China). Subsequently, an exclusive licensing agreement has been negotiated with SpringStar, Inc (Woodinville, WA), which is in the process of submitting a registration packet to EPA and developing a production line. SpringStar has trademarked the name Trap-N-Kill for its lethal ovitrap product* and will apply for a Federal National Stock Number, which will simplify procurement by military units once production begins. The initial Trap-N-Kill product will be a permanent plastic unit labeled for use against *Ae. aegypti* and *Ae. albopictus*. The traps will require occasional maintenance of the treated strip as part of an overall integrated mosquito management program. In future product versions, the Trap-N-Kill will be configured so that the individual placing the cup will need to only add water and set it on the ground, preferably in a vegetated or shady area. SpringStar also plans to modify the Trap-N-Kill so that it will not hold water once the insecticide looses efficacy. This improvement will ensure that future generations of mosquitoes will not be able to breed in any cups left in the field beyond their useful life.

*Information available at: http://www.mosquitoscience.net

Summary

The patented lethal ovitrap is an effective, safe, environmentally sound, economical, and simple means of dengue and chikungunya vector control. It exploits the female mosquito's irrepressible urge to visit oviposition sites and deposit eggs to deliver a small but lethal insecticide dose. Its efficacy has been documented in laboratory and field studies by numerous researchers in 5 countries and reported in 9 peer-reviewed papers.[8,12-14,19-23] Control programs using the lethal ovitrap have been shown to halt dengue and chikungunya transmission. The impending EPA registration and mass manufacturing of the Trap-N-Kill product will ensure the availability of this technology for dengue and chikungunya vector control around the world.

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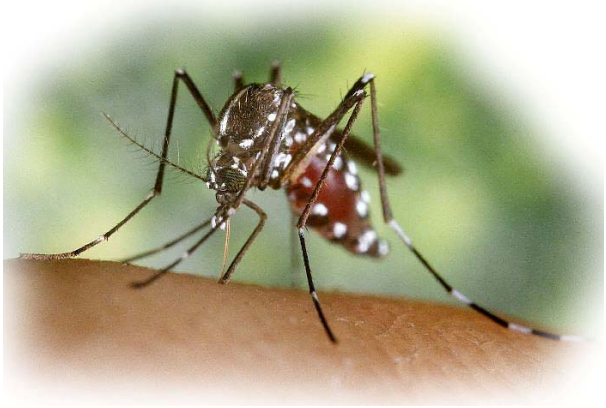

The Expanding Role of Military Entomologists in Stability and Counterinsurgency Operations

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Overview

Stability operations in Iraq and current counterinsurgency operations in Afghanistan present military entomologists with new and challenging skill requirements in addition to their traditional warfighting tasks. Coordination by military entomologists with the myriad of other actors in the health sector including multinational partners, host nation officials, other US agencies, and nongovernmental organizations is critical to success in stability and counterinsurgency operations. Also, entomologists in the field need an in-depth understanding of local power structures, organizations, and cultures. The ability to establish and maintain personal relationships will likely be the difference between success and failure of counterinsurgency programs on the ground. The contribution of military entomologists in counterinsurgency must always be balanced with and integrated into all other components of medical and civil-military operations. The overall effort at the national level must be fully integrated into local messages and priorities. The US military is still searching for ways to better train military servicemembers in the "whole-of-government" approach to winning at counterinsurgency.

Entomologists have served the military since World War I and have officially been part of the Army Medical Department since 1927 when they joined the Sanitary Corps. Since that time the role of military medical entomologists has evolved during conflicts, starting with World War II and continuing to the present day.[1] Their dedication and commitment to protect service members from pests and the diseases they transmit have contributed to significant reductions in disease and nonbattle injuries and increased operational readiness.

Military entomologists, working as part of the preventive medicine team, are primarily responsible for protecting the health of US military personnel and their families worldwide. They support these populations by planning, directing, and evaluating comprehensive integrated pest control programs to protect personnel and military property; conducting surveillance for medically important arthropods and rodents; identifying insects and other zoological specimens; providing technical advice; and providing disease vector risk assessments for geographical areas. These traditional roles of military entomologists are well documented and clearly defined by the Department of Defense[2] and the Armed Forces Pest Management Board*.

New Challenges of Stability Operations and Counterinsurgency

The principles and imperatives of stability operations and, more recently, counterinsurgency (COIN) present a complex and often unfamiliar set of missions and considerations. In many ways, the conduct of COIN is counterintuitive to the traditional US military view of war and the traditional roles assigned to military entomologists. The US Army Director of the Counterinsurgency Training Center in Afghanistan recently stated that military personnel must see counterinsurgency as a mindset, and not just a training event.[3] New missions in COIN have served to greatly expand the traditional roles of military entomologists of protecting military forces from rodent and vector-borne diseases.

Licina reviewed the role of Level III preventive medicine (PM) support in the counterinsurgency environment in Iraq.[4] Level III preventive medicine support was provided on an area basis with traditional, doctrinally-oriented tasks such as developing medical threat profiles, health hazard assessments, rodent and vector surveillance and control, reducing both acute

*Technical Guides available at http://www.afpmb.org/pubs/tims/tims.htm.

and chronic illness, and occupational environmental surveillance. However, the lack of support for and coordination with civil-military operations was noted. Preventive medicine assets in Iraq realized the opportunity to assist the host nation with essential services, providing legitimacy to the local government, and stimulate the economy through job creation. Local efforts were made to reach out to the Corps civil-military operations to support provincial reconstruction teams, agribusiness development teams, and civil affairs units that had no preventive medicine assets. Although civil affairs officers understood the synergy that could occur by PM assets providing basic water and sanitation services during the counterinsurgency, and conceptual agreement was made for support, strategic support was not provided due to competing priorities. This lack of preventive medicine integration during counterinsurgency exists for many reasons and is only partially within the control of the Department of Defense.

Current counterinsurgency operations in Afghanistan are focused on protection of the populace and expanding health services throughout the country, including rural communities, and are being supported by representatives from various indigenous populations and institutions, various US Government agencies, multinational partners, independent government organizations, host nation and nongovernmental organizations. Interacting with these representatives requires support from US military entomologists and an expanded set of professional skills that must be learned, inculcated and implemented to meet the additional demands of COIN operations.

One purpose of the COIN strategy in Afghanistan is to increase the capacity of the Afghan government to provide essential services to its people. Recent guidance from General David Petraeus, Commander, International Stabilization Force Afghanistan, declares that "the decisive terrain is the human terrain" and that the people are the center of gravity.[5] Military entomologists continue to play an important and ever-expanding role in this strategy, shifting from a focus on conventional military forces of rogue or rising states (terrain or enemy focused) to irregular challenges associated with the "long war" against transnational jihadism and counterinsurgency (people focused).

Entomologists play a critical role in contributing to medical civil-military operations in support of the counterinsurgency fight. For example, military entomologists have been important contributors in the development of the Afghan Ministry of Public Health National Malaria Strategic Plan, 2008–2013, and members of provincial reconstruction teams working to implement this plan to rebuild the nationwide Afghanistan malaria control infrastructure. These missions require an advanced knowledge of how other governmental agencies (ie, Department of State and US Agency for International Development), international governments, nongovernmental organizations, and private organizations operate in the COIN environment, and how to effectively interact with these diverse organizations. These types of skills are not learned in traditional military operational or training environments. In addition, a working knowledge of the host country's public health policy, capabilities and economic realities is essential (see inset below). This knowledge must be quickly garnered from whatever information sources are available and from previous personal experiences.

The provincial reconstruction teams partnering with the Afghan government to implement the Afghan Ministry of Public Health National Malaria Strategic Plan is an example of implementation of the planning

As part of the effort to reestablish the Afghanistan Malaria Mosquito Control Program, a basic vector control "train the trainer" course was initiated in Jalalabad with the assistance of both the Nangarhar Provincial Reconstruction Team and the Missouri Agribusiness Development Team. Students are taught using training aids in addition to receiving hands-on training with basic equipment. Some of the students had worked in mosquito control before the 1979 invasion by the Soviet Union. This was the final phase of a 2-year process working through the Afghanistan Ministry of Public Health and US funding processes.

considerations for foreign internal defense missions that also apply in current COIN operations in Afghanistan.[6] These planning considerations include making sure the plan is developed with the host nation's assistance, the plan enhances the nation's existing programs, the host nation can continue the program if US military support is curtailed or discontinued, the host nation receives the credit for the program, and the health service support goals and objectives are tailored for each region or province.

The COIN strategy in Afghanistan, recently updated by General Petraeus in 2010, has at its central theme the idea of "learn and adapt." A specific subset of General Petraeus' guidance is particularly applicable to military entomologists working in the COIN environment:

- Secure and serve the population.
- Foster lasting solutions.
- Be a good guest.
- Consult and build relationships, but not just with those who seek us out.
- Act as one team.
- Maintain continuity through unit transitions.
- Win the battle of wits.
- Exercise initiative.

This guidance should be applied to all essential tasks across all lines of effort to achieve the goal of transition from military-led to civilian-led efforts in essential services and increasing the legitimacy of the host nation government. However, some have criticized medical operations in COIN as "random acts of kindness," implying that they are not helpful, are not synchronized laterally, and are not nested with strategic plans.[7] To succeed, all medical operations must increase the respect the populace has for the host nation government and its agencies. These operations should also serve to increase the legitimacy of the government in the eyes of the population.

Expanded Skill Set Required for Military Entomologists

The new Army counterinsurgency manual[8] defines new military skill sets required, such as knowledge, cultural understanding, and appreciation of the host nation and region; functional skills needed for interagency and host nation coordination; language skills necessary for coordination with the host nation and multinational partners; and knowledge of host nation basic civic functions. This crucial knowledge and demanding skills must be learned before deployment, not ad hoc once on the ground.

Military entomologists have been individually learning and adapting during each rotation in Afghanistan. However, it is now time to "learn and adapt" in a more centralized and doctrinally correct manner as a profession, in a way that all military services can support and embrace. Changing our mindset is critical to future success in stability operations and COIN—we need to think and act very differently to be successful. The objective is the will of the people. Control of the population is the effective "offensive" operation in COIN because it is the one thing that insurgents cannot afford to lose. Counterinsurgency efforts must focus day-to-day operations on earning the support of the people. Every action, reaction, failure to act, and all that is said must be focused to this end. Holding routine meetings with community leaders that build trust and solve problems is critical to offensive operations. For military entomologists, this must be applied to health sector development as part of the overall preventive medicine and medical mission.

A major theme in Afghanistan's counterinsurgency training guidance is "embracing the people."[8] This requires building connections to and relationships with tribal, community, and religious leaders. Success in this area requires communication, collaboration, and cooperation taking place on a frequent (almost daily) basis. A thorough understanding of local grievances and problems that drive instability and subsequent actions that redress them is crucial. A rudimentary knowledge of the local language, if only a few conversational words, will strengthen trust with the local populace and be a positive force in the community.

Embracing the people also means understanding that the local government often sets priorities for community efforts and should have final approval on all reconstruction projects and new initiatives. It is imperative for military entomologists to work within their framework. New projects that tie-in with established, existing programs will increase credibility

and legitimacy of US and international efforts. Reconstruction efforts should emphasize and reinforce sustainable low-cost, and, ideally, locally produced projects.

NEW TRAINING REQUIREMENTS

The military skills required for medical operations in counterinsurgency are different from those of the past. Cross-training military entomologists in interagency coordination with other counterinsurgency assets such as civil affairs, provincial reconstruction teams, agribusiness development teams, US Agency for International Development, Department of State, nongovernmental organizations, and indigenous populations and institutions is critically important to success in current and future counterinsurgency operations. Military entomologists must possess a basic understanding of core competencies, basic organizational structures, and relationships, or potential relationships, of other US government agencies, independent government organizations, nongovernmental organizations, and regional organizations with the armed forces of the United States.[9] High quality individual and team training will manifest in better interagency support to operational forces. This new and enhanced training should start with initial military entry courses for PM officers such as the Principles of Military Preventive Medicine course (Course No. 6A-F5). This new training will require a significant investment in time and manpower as many programs of instruction will have to be updated or completely rewritten.

An increased emphasis on providing medical seminars to either supplement or replace the traditional medical civic action program in the counterinsurgency environment has recently gained favor among the medical[10] and special operations[11] communities. The medical seminars are composed of specific lectures and workshop topics to educate and train both US and indigenous peoples. US forces typically provide technical medical information and training while indigenous people train US forces about cultural aspects of medical care and geographically unique diseases. One of the side benefits of medical seminars is the face-to-face meetings between US and local officials that tend to reinforce the legitimacy of collaborative efforts.

Medical entomologists should pursue training in COIN and military stability operations courses to develop a foundational understanding of these challenging and complex military missions. While a number of courses are currently available to military personnel, both classroom and online, specific training to medical entomologists and their enlisted counterparts should be developed to focus consistent responses to support in-theater operational requirements. This training should be supplemented with annual symposia at professional conferences, medical seminars, and during the Armed Forces Pest Management Board's (AFPMB) Triennial Pest Management Workshop to maintain currency in policy changes and innovative ideas. A repository of previously developed materials reviewed and approved by the AFPMB and made readily available on their website should be implemented to expedite support requests, alleviate redundant development efforts and again ensure consistency.

SUMMARY

Military entomologists function as part of medical civil-military operations and are an essential combat multiplier directly supporting COIN operations. They not only directly support US and coalition military forces by performing their traditional wartime mission of protecting personnel from vector-borne and rodent-borne diseases but also enhance the legitimacy of medical services by the host nation government such as controlling diseases promulgated by food, water, vectors, and rodents.

These unique COIN missions demand a new skill set required of military entomologists that are not learned from existing training courses and programs. New training opportunities must be afforded military entomologists to familiarize them with how to interact with and synergize the efforts of host nation assets, other governmental agencies, nongovernmental organizations, and international military partners. Teamwork with previously unfamiliar groups and organizations is an essential component of working in the COIN environment and can present unfamiliar tasks for entomologists. This training should start with initial entry training and be a continual process throughout a military entomologist's career.

Current COIN operations require greater tactical and operational flexibility and diverse entomological expertise. The skills required for today's full spectrum medical operations are different from those of the past. Counterinsurgency medical operations demand greater

agility, rapid task-switching, and the ability to adequately address unfamiliar situations and challenges.

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Mosquitoes of Guam and the Northern Marianas: Distribution, Checklists, and Notes on Mosquito-Borne Pathogens

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Abstract

This report includes the distribution records and updated checklists of the mosquitoes known to occur in Guam and nearby selected islands (ie, Saipan, Tinian, Rota), based on our field collections from various localities during 2010, published reports, and accessioned specimens deposited in the US National Museum of Natural History, Smithsonian Institution, Washington, DC. The status of common and potential mosquito vectors and their borne-pathogens are also noted.

Introduction

The US territorial islands in the western Pacific Ocean have strategic and logistic military significance, particularly Guam and the Commonwealth of the Northern Mariana Islands (Saipan, Tinian, Rota) (Figure 1), in addition to their increasing importance to the tourism industry. Protecting military personnel and civilians against arthropod vectors and the diseases they transmit should be a high priority to both military commands and civilian administrators. In order to protect the human populations in these islands, proper surveillance of vectors and the diseases they carry must be regularly conducted or improved in order to develop effective prevention strategies. Vector surveillance and control programs would minimize, if not totally prevent, occurrence of mosquito-borne infectious diseases in target areas.

Geography, Climate, and Demographics

Guam

Guam is located at 13.28 N, 144.47 E, with an area of 544 km^2, and is the largest and southernmost of the 15 islands in the Mariana Islands archipelago.[1] The northern part of the island is a forested coral line limestone plateau while the south contains volcanic peaks covered in forest and grassland. The northern and central regions have more dense populations than other parts. The climate is a typical tropical marine, and the weather is generally hot and very humid with little seasonal temperature variation. The mean high temperature is 30°C and mean low, 24°C, with an average annual rainfall of 2,180 mm. The dry season runs from December through June, and the remaining months constitute the rainy season. January and February are considered the coolest months of the year, with night time temperatures in the mid to low 20s (°C) and generally lower humidity levels. The highest risk of typhoons is during October and November, however, they can occur year-round.[1]

Figure 1. Guam, Rota, Tinian, and Saipan, and their location in the Mariana Islands archipelago (inset).

Guam has military strategic and logistic importance. The US military maintains jurisdiction over its bases in Guam, which cover approximately 3,160 km^2, or 29% of the island's total land area. In the coming years, Guam will be experiencing a tremendous population growth as a result of the military buildup which has been described as one of the largest military-related operations since World War II. The US Marine Corps 3rd Marine Expeditionary Force, currently in Okinawa (approximately 8,600 Marines with 9,000 dependents), will be transferred to Guam by 2016. At the peak of the buildup in 2015, Guam is anticipating an increase of 52,000 people,[2] or 28% of the current population of approximately 183,000. The largest portion of those people will be temporary workers coming from regions where mosquito-borne diseases are endemic. With the increase in the island's population and its over 1.2 million annual visitors, there may also be a corresponding increase in vector-borne disease risks, particularly among thousands of US military personnel and their dependents stationed in Guam, as well as other Department of Defense (DoD) civilians.

Saipan

Saipan (15.25 N, 145.75 E), the capital of the US Commonwealth of the Northern Mariana Islands, is about 193 km north of Guam with a total area of 120.4 km², or about 20 km long and 9 km wide.[3] Ships of the US Maritime Prepositioning Force regularly anchor at Saipan,[4] and there are US military training sites on the island. It is a popular tourist destination in the Pacific, particularly for US military personnel and other DoD civilians. Additional descriptions of this island are provided by Savage et al.[5]

Tinian

Tinian (15.0 N, 145.6 E) is about 8 km southwest of its sister island, Saipan, from which it is separated by the Saipan Channel. It has a land area of about 102 km². Tinian's largest village is San Jose. The Island has a variety of flora and fauna, as well as limestone cliffs and caves. There is also a variety of marine life and coral reefs surrounding the island.[6]

Rota

Rota (14.2 N, 145.2 E), is the southernmost island of the US Mariana Islands and the second southernmost of the Marianas Archipelago.[7] A popular tourist destination, Rota is approximately 17 km long and 5 km wide, with a coastline about 62 km in length. The highest point is Mount Manira at 495 m. The island is 76 km north of Guam, 101 km south of Tinian, and 117 km south of Saipan. There have been proposals to use areas on Rota for new and continuing military training, consisting of the airport and sites within West Harbor.[8]

Mosquito Vectors and Mosquito-Borne Diseases

The common potential infectious diseases in Guam, that could be transmitted by mosquitoes include malaria, dengue fever, Chikungunya fever, dengue hemorrhagic fever, Japanese encephalitis, Murray Valley encephalitis, yellow fever, filariasis (Bancroftian, Brugian filariasis) and other viral diseases.[9] Multiple human malaria cases were reported in Guam in 1966, 1969,[10] 1975, and 1980-1986.[9] Several *Anopheles* species have been reported in Guam, however, *An. subpictus* Grassi and/or *An.* Barbirostris Group species could be vectors of malaria in the island, although their vector potential needs to be confirmed. Two *Anopheles* species, *An. sinensis* Wiedemann and *An. lesteri* Baisas and Hu, have also been previously reported from Guam,[11] but presently they are not as common as other mosquito species. *Anopheles sinensis*, a known malaria vector, also occurs in Asian countries, such as Japan,[12] North Korea,[13] South Korea,[14] and China.[15,16] *Anopheles lesteri*, the major vector of malaria in China (and previously known as *An. anthropophagus* Xu and Feng),[15,17] also occurs in South Korea,[14] Japan,[12] Hong Kong,[18] and the Philippines.[19] Presently, limited information is available on the distribution and habitats of these 2 different malaria mosquitoes in Guam and nearby islands. *Anopheles lesteri* was recollected recently from Guam (W.K.R., unpublished data, March 2010). *Anopheles sinensis* was also recollected during recent mosquito surveys conducted from 10 to 14 December 2007.[20] About 18 adults of *An. sinensis* were collected using Centers for Disease Control and Prevention (CDC) light traps (Figure 2) from Andersen AFB (Nimitz Hill Housing Area and other civilian areas).[20] In addition to *Anopheles*, other potential and known mosquito vectors on Guam belong to the genera *Aedes*, *Culex*, and *Mansonia*.

The historical accounts of the epidemics of mosquito-borne diseases in Guam have been noted by various authors.[21,22] Comprehensive lists of annotated bibliographies of Guam mosquitoes, including their associated infectious diseases, were previously prepared.[23-25] In addition to available internet/search

engines, comprehensive publications about mosquitoes of Guam and the Commonwealth of the Northern Mariana Islands can be searched and downloaded (in PDF format) from the Armed Forces Pest Management Board Literature Retrieval System* and the Walter Reed Biosystematics Unit (WRBU).[26] Taxonomic mosquito literature (in printed form), including old publications of species descriptions, are also available from the WRBU library.

Figure 2. CDC light trap used to collect mosquitoes, including *Anopheles sinensis*, from a housing area in Andersen AFB, Guam, December 2007.

In recent years, the threat of mosquito-borne diseases has been a serious public health concern with epidemics on neighboring islands and the constant introduction of infected people. However, epidemics were not identified on Guam. With expanding and very transient military and civilian populations, including tourists from Asian countries, the threat of mosquito-borne disease transmission is increasing. In the past, multiple travelers returning to Guam from other locations have brought back cases of dengue, malaria, Japanese encephalitis, and even filariasis.

Historically, some of these mosquito-borne diseases have been autochthonously transmitted on Guam. For example, dengue has been one of the most troublesome mosquito-borne diseases with epidemics usually occurring in late summer. The primary urban vector of dengue fever, *Aedes aegypti* (Linnaeus), has rarely been found on Guam over the last several decades. A World Health Organization report indicated that it was apparently eradicated from Guam.[27] Results of various surveys in Guam in 1995,[28] 2007,[27,29] and this study (2009-2010) yielded no *Ae. aegypti*. It is surmised that it was either totally eradicated or missed during the collecting efforts due to errors in sampling, seasonal occurrence variation, time and techniques used, immatures shifting to habitats other than artificial containers, and change of mosquito behavior. This may be due to competitive pressure from other species, inadequate larval collections from various breeding habitats, etc. In view of the transient populations on Guam, it is important to remember that the human is the main reservoir of dengue. Since *Ae. aegypti* is widely spread in Pacific areas where dengue is endemic, its dispersal is still occurring, and so its movement into and through the region is still of concern and should be prevented.[30] Therefore, once dengue is reintroduced or reestablished in Guam, it will take considerable time and diligent control efforts to eradicate the disease.[20,29] More than 14,000 mosquitoes collected on Guam from 2009-2011 were tested for Japanese encephalitis virus or malaria by the US Army Public Health Command Region–Pacific and no positive samples were detected (W.K.R., written communication, March 2011). Also, a recent outbreak of Zika virus on Yap Island, Micronesia[31] raised concern over its spread to Guam and other islands of the Marianas.

Reports on the number of mosquito species occurring on Guam and nearby islands are confusing and exact numbers are difficult to ascertain. About 32 species of mosquitoes were recorded on Guam, including 8 implicated disease vectors in 3 genera (*Aedes*, 3 spp; *Anopheles*, 4 spp, and *Culex*, 1 sp).[32] Although one report indicates about 40 species of mosquitoes on Guam,[23] other sources[26] recorded different species numbers. This may be due to inaccurate identifications of the species, incomplete surveillance data, unavailability of voucher specimens to confirm species identifications and occurrence, shortage of taxonomic experts involved in surveillance, etc. Considering that there has been an increase in international travel to and from Guam[27] involving thousands of passengers, mainly tourists and military personnel, the introduction of new mosquitoes (including potential vectors) from other countries/territories may be very common.

In addition to Guam, other islands with DoD high importance include Tinian, Rota, and Saipan. Tinian

*http://lrs.afpmb.org/rlgn_app/ar_login/guest/guest

will be used for training by Marine units moving to Guam from Okinawa between 2012 and 2016, while Saipan and Rota (also with training sites) are popular rest and recreation locations for many US military and DoD civilians, in addition to other tourists.[33,34] Little is known about the mosquito vectors and their borne infectious diseases in Tinian, Rota, and Saipan, as well as other surrounding islands. In 1983, larval collections were conducted from 42 habitats at 21 different sites on Saipan, with 9 species collected, including those with potential as vectors of human diseases.[5]

Although some mosquito identification keys[11,35,36] are available, they do not exclusively cover Guam and surrounding islands, or they have to be updated to include all species known to occur in Guam and nearby islands, particularly Tinian, Rota, and Saipan. It is essential to know where mosquitoes currently occur and where potentially they will be found on the islands. Also, knowledge of introduced species (or invasive species) on those islands is important for mosquito control.

In this article, we report the distribution records of mosquitoes and provide updated checklists of known mosquito species found in Guam and nearby islands, particularly Saipan, Rota, and Tinian. We also note the status of common and potential mosquito vectors and the diseases they transmit.

Materials and Methods

Adults were collected from various localities in Guam (Figure 3), with a modified miniature CDC light trap (Figure 2), baited with white or ultraviolet light with or without CO_2 and hung from a tree branch or from a wall of a building. Most adult specimens were killed in trap jars with insecticidal strip (2,2 dichlorovinyl dimethyl phosphate, 10%), frozen in a freezer, or placed in a container with dry ice. Larvae were collected from household junk, tires, tree holes, river and roadside side pools, and other water-filled containers with mosquito dippers, turkey basters, and plastic cups. Larvae were reared to adults in individual containers. Specimens were initially sorted and brought to the laboratory for further processing and identification. They were mounted on points on pins, examined, and identified using diagnostic morphological characters with the aid of keys and descriptions from pertinent literature.[11,35,36] The latitude and longitude of each location were recorded using a hand-held global positioning system unit (Garmin International, Olathe, KS) set to the WGS84 datum. For molecular species identification, DNA was isolated from individual adults (1 or 2 legs per adult). In addition, mosquito specimens deposited at the US National Museum of Natural History (USNMNH) were examined and identified, and their collection data recorded. Coordinates for localities or collection sites of museum specimens were recorded using gazetteers.[37,38]

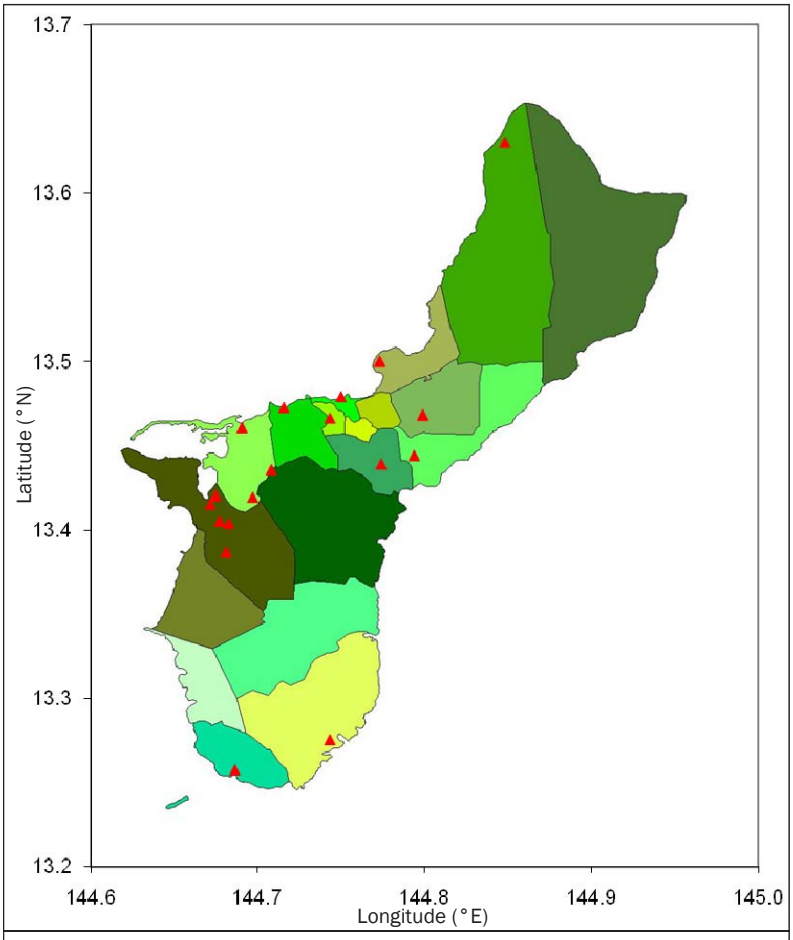

Figure 3. Mosquito collection sites in Guam.

Results and Discussion

A summary of collection localities of mosquitoes (based on observed specimens from field collected samples in 2010 and accessioned museum collections at the

USNMNH) is shown in Table 1. A total of 16 species in 6 genera and 8 subgenera were identified, with 15 species from Guam, 11 species from Saipan, 4 species from Rota, and 4 species from Tinian. The collection sites of the 2010 survey and those points of collection of previous surveys according to museum records are shown in Figure 3.

The updated checklists of mosquitoes reported from Guam, Saipan, Tinian, and Rota were based on combined records from selected literature and present observation, mainly from specimens deposited at USNMNH and our recent field collections (Table 2). For the 4 islands, we recorded 40 species (with 4 subspecies) representing 8 genera: *Aedeomyia* (1 subgenus), *Aedes* (3 subgenera), *Armigeres* (1 subgenus), *Anopheles* (2 subgenera), *Culex* (2 subgenera), *Lutzia* (1 subgenus), *Mansonia* (1 subgenus) and *Toxorhynchites* (1 subgenus). In our updated mosquito checklists, Guam has 40 species (including 3 subspecies in *Aedes* and 1 subspecies in *Culex*) while Saipan has 14 species; Rota, 9; and Tinian, 10. All species found on 3 islands (Saipan, Rota and Tinian) also occurred on Guam. Only a partial set of adult specimens from trap collections on Guam in 2009 and 2010 were processed, examined and identified. When completed, the collection data or occurrence records will be published in a separate article.

About 9 mosquito species were reported from Rota, representing 2 genera: *Aedes* (6 spp) and *Culex* (3 spp).[55] While *Ae. aegypti* was prominent during the early surveys on Guam and Saipan, the species declined rapidly following massive control programs during late 1940s. Only a single specimen of this species was discovered on a 1950 survey, for example, and the species was not recovered again until the 1970s. In 1980, a summary of the mosquito collection records of Southern Mariana Islands was reported.[39] *Culex (Cuc.) papuensis* were also reported on Guam,[11,56] however, it was not known to occur in the western Pacific islands,[26,56] and there is no voucher specimen of this species from Guam and other Mariana Islands in the USNMNH/Smithsonian national mosquito collections. About 39 species (with 2 subspecies) were recorded on Guam, but 16 of these species (including 1 subspecies) are no longer considered as occurring on Guam.[11]

Although several subspecies of *Ae. vexans*[57] (Meigen) were recorded, there is still a need to clarify the validity of these subspecies. While waiting for further studies to clarify the taxonomic identity of this species, we listed 3 subspecies of *Ae. vexans*, namely *vexans*, *nipponi* (Theobald) and *nocturnus* (Theobald), based on reviewed literature and observed specimens. *Aedes vexans nipponi*[40] was reported on Guam based on one collected larva, and it has not been reported since. This subspecies was not thought to occur on the Mariana Islands.[58] In 1984, Ward[40] excluded this subspecies from his list of Guam mosquitoes since it has not been reported or established subsequent to Reisen's article.[32] In 1973, Reinert[58] synonymized *nocturnus* with *vexans* from the Mariana Islands, but Lee et al[59] elevated *nocturnus* to species level in 1982. These authors considered all "*vexans*" from the Mariana Islands as "*vexans nocturnus*," probably because the specimens in the USNMNH national collections (prior to 1973 and after 1982) are mostly labeled as "*nocturnus*" or "*vexans nocturnus*." For *Culex* mosquitoes, the identity of *Cx.(Cux.) annulirostris marianae* Bohart and Ingram, should be studied to determine whether it should remain as a valid subspecies or be elevated to a distinct species. Several previous reports noted this subspecies as occurring only on the Mariana Islands.[35,41,42,55]

We recommend that intensive larval surveillance and collections from various breeding habitats be performed in Guam and nearby islands on a regular basis (weekly or monthly), in addition to adult light-trapping. Except for the larval and pupal collections conducted from September to October 1991 on Saipan,[5] very limited immature stage surveys were done in other islands. Past surveys in Guam using adult light traps might have missed those species of mosquitoes that are not attracted to light or other trap baits, or are not active during months when trappings were conducted. Adults of some species of *Aedes* and *Culex* are less attracted to lights or less collected from light traps. Therefore, in addition to adult surveillance, larval collections from different habitats (artificial containers, irrigation ditches, pools, marshes, etc) on a regular basis throughout the year are necessary to understand the larval ecology and population dynamics of mosquito species, particularly vectors, in target areas of various islands. With the ease with which exotic pathogens are transported between countries or even continents, there is an urgent need to have a strong surveillance program to detect the spread of vectors and the diseases they transmit. Proper adult and larval surveillance efforts are essential

Table 1. Summary of collection localities of mosquitoes (based on observed specimens) in Guam, Saipan, Tinian, and Rota.

Species	Island	Locality	Grid Coordinates	Collection Date	Number/ Stage	Collector	Remarks (Habitat)	Repository
Aedeomyia (Aedeomyia) catasticta Knab	Guam	Sta. Rita, Apra Landing, Navy housing and magazine areas	13.38688N/144.57828E (GU-004); 13.40386N/144.68299E (GU-006)	6, 10 Mar 2010	3F*	W.K. Reeves	LT	FC
	Guam		(ACC-522)	27 Aug 1975	3F, 3M		LC (pond-lake)	AC
Aedes (Aedimorphus) oakleyi Stone	Guam			3 Oct 1938	15F, 55M		LC (water drum)	AC
	Guam			1 Oct 1937; 6 Jun 1945; 26 May 1972	8M	W. Hull, R.G. Oakley	LC (coconut husk)	AC
	Saipan	Mt. Tabachan; Tanapag	15.23966N/145.75709E (TAN)	15 Jan 1949	1F, 9M			AC
	Saipan		(SAI-7)	19 Sep 1991	51M	H. Savage	LC (ground pool)	AC
Ae. (Adm.) vexans nocturnus (Theobald)	Guam	Pt. Oca; Pt. Ajayan	13.50018N/144.77308E (OC); 13.23333N/145.73333E (AJ)	23, 29 Jul 1951; 23 Aug 1951	14F,26M	W. H. Hull, J.L. Gressitt, R.M. Bohart	LC (ground pool)	AC
	Saipan	Charan Kanoa; Charan Ronoa; Charon;Tsutsuura; Hashigaro	15.20299N/145.71788E (CK);	2, 22, 23 Jul 1944; 22, 31 Aug 1944; 4 Sep 1944; 8-16 Oct 1944; 18 Jul 1945; 29 Jun 1951	16F, 64M	R.M. Bohart, J.L. Webb, C. Alley, 18th MLG	(swamp, tree hole in mangrove)	
	Saipan		(SAI-33)	23 Sep 1991	2F, 9M	H. Savage	(ground pool)	AC
	Tinian			23 Aug 1945	2M	Navy Medical School		AC
Ae. (Stegomyia) aegypti (Linnaeus)	Guam	Agana; Barrigada; Pt. Oca	13.47919N/144.75000E (AG); 13.46830N/144.79890E (BA); 13.50018N/144.77308E (OC)	27 May 1935; 27 Jun 1937; Sep 1945	24F, 40M	Navy Medical School	LC (water tank)	AC
	Guam				1F, 3M	C.P. Bagg		AC
	Rota			24 Oct 1945	1M		LC (artificial container)	AC
	Saipan	Charan Ronoa		25 Aug 1944	15F, 17M	D.G. Hall		AC
	Tinian			12 Jul 1944	2F, 5M	Navy Medical School		AC
Ae. (Stg.) albopictus (Skuse)	Guam	Merizo	13.25757N/144.68652E (GU-011)	6 Mar 2010	1F	W.K. Reeves	LT (mangrove swamp)	FC
	Guam		(ACC-512)	21Jul 1975	4F, 32M			AC
	Guam			4 Nov 1948; 11 Sep 1951	19F, 36M	W. Hull W.C. Reeves		AC
	Saipan	Charan Ronoa; Charan Taja; Garapan	15.20778N/145.72926E (GA)	22, 27 Aug 1944; 1 Sep 1944	11F, 10M			AC
	Saipan			Jun, Jul, Oct 1944; 4 Apr 1945	29F, 69M	D.G. Hall, J. Greenberh; D. Pashley; J.L. Webb; 18th MGL		AC
	Saipan		(SAI-10, 11, 13, 21, 22, 24, 61)	20 Sep 1991	33F, 31M	H. Savage	LC (refuse, toilet bowl, water barrel)	AC
	Tinian			19 Aug 1944	5F, 3M	Navy Medical School		AC
	Rota		14.19594N/145.24933	27 Feb 2010	3F	W.K. Reeves	AD (landing and biting)	FC
Ae. (Stg.) guamensis Farner and Bohart	Guam	Merizo	13.25757N/144.68652E (GU-011)	6 Mar 2010	1F	W.K. Reeves	LT (mangrove swamp)	FC
Ae. (Stg.) neopandani Bohart	Guam	Inarajan, Wolford Heights Road	13.27556N/144.68652E (GU-010)	6 Mar 2010	1F, 1M	W.K. Reeves	LT	FC
Ae. (Stg.) pandani Stone	Guam	Inarajan, Wolford Heights Road; Merizo; Sta. Rita, Apra landing, Navy housing and main gate areas; Yigo, Anderson AFB NW Field	13.42038N/144.67496E (GU-005); 13.40386N/144.68299E (GU-006); 13.27556N/144.68652E (GU-010); 13.25757N/144.68652E (GU-011); 13.63025N/144.84793E (GU-012)	6, 9, 10 Mar 2010	8F	W.K. Reeves	LT (mangrove swamp)	FC

ACC – museum accession code; AC – museum collection of the National Museum of Natural History (NMNH), Washington, DC; AD – adult collection, landing and biting; F – female; FC – field collected, deposited in the NMNH; LC – larval collection; LT – CDC light trap collections; M – male.

Table 1 continued on next page.

Table 1 (continued). Summary of collection localities of mosquitoes (based on observed specimens) in Guam, Saipan, Tinian, and Rota.

Species	Island	Locality	Grid Coordinates	Collection Date	Number/ Stage	Collector	Remarks (Habitat)	Repository
Ae. (Stg.) pandani Stone (continued)	Guam	Barrigada	13.46830N/144.79890E (BA)	27 Jul 1937	37M		LC (leaf axils of Pandanas dubius); type series	AC
	Guam	Inarajan; Mt. Tenjo; Mt. Chachao; Piti	13.44430N/144.79373E (IN); 13.41944N/144.69722E (TE); 13.43583N/144.70833E (CH); 13.46083N/144.69083E (PI)	2, 3 May 1936 7, 16 May 1936	1F, 16M			AC
	Guam			25 Jul 1938	23F, 29M		LC (leaf axils of Pandanas dubius); type series	AC
	Guam			25 Oct 1945	6M	L. Rozeboom	(coconut)	AC
	Guam			Jul, Aug 1951	10F	W.B. Hall		AC
	Guam	Fena Lake-Tolaeyuus R.		9 Sep 1975	23M		(bamboo grove; biting)	AC
	Rota	Hill 82			2F, 6M	D. Pashley		AC
An. (Cellia) indefinitus (Ludlow)	Saipan		(SAI-28)	21 Sep 1991	9F, 9M	H. Savage		AC
An. (Cel.) vagus Donitz	Guam	Agana Heights, Sta. Rita, Apra Landing, Navy housing and magazine areas	13.46646N/144.74339E (GU-001); 13.39364N/155.57828E (GU-003); 13.38688N/144.57828E (GU-004); 13.40386N/144.68299E (GU-006)	6, 7 Mar 2010 9, 11 Mar 2010	4F, 2M	T. Gutierrez, W.K. Reeves	LT	FC
	Guam			24 Sep 1951	1F, 2M	W.B. Hull		AC
	Guam	Naval magazine area		10 Feb 1971	7F, 8M			AC
Cx. (Cux.) annulirostris marianae Bohart and Ingram	Guam	Sta. Rita, Navy magazine main gate area	13.38688N/144.57828E (GU-004)	6 Mar 2010	1F	W.K. Reeves	LT	FC
	Guam	Agana; Pago R, Piti	13.47919N/144.75000E (AG); 13.4392N/144.77400E (PA); 13.46083N/144.69083E (PI)	13 Sep 1936; 5 Jul 1945; 4 Jun 1946	3M			AC
	Saipan	Charan Jiga, Charan Konoa, Charan Ronoa; Tsutsuura	15.20299N/145.71788E (CK)	24 Aug 1944; 31 Nov 1944	23F, 63M	D.G. Hall		AC
	Rota	Poniya; South and West Rota Is.	14.10000N/145.16667	25 Oct 1945	1F, 7M			AC
	Tinian			1944	3M			AC
Cx. (Cux.) litoralis Bohart	Guam	Pt. Oca		Sep 1945	1F			AC
	Rota	North Shore		26 Oct 1945	10F, 10M		(type series)	AC
Cx. (Cux.) quinquefasciatus Say	Guam	Sta. Rita, Navy Base, CB area; Yigo, Anderson AFB NW Field	13.41522N/144.67183E (GU-002); 13.63025N/144.84793E (GU-012)	4, 17 Mar 2010;	2F	P. Nuhn, W.K. Reeves	LT	FC
	Guam			Oct 1945	1F	L. Rozeboom		AC
	Guam			28, 29 July 1975	4F, 6M		(container on abandoned airfield)	AC
	Saipan		(SAI-9, 37, 40, 42, 47, 48, 59, 80)	Aug 1991	32F, 85M	H. Savage	LC (flooded terrestial grasses, ground pool, water barrel, Phragmites marsh); biting pigs	AC
	Saipan			Sep 1944; Nov. 1982	6M	J.L. Webb, D. Pashley		AC
	Saipan	Charan Ronoa; Jija		Aug 1944	4M			AC
	Saipan			18 Jul 1944	1F, 1M		treehole, mangrove	AC
	Tinian			Aug 1944		Navy Medical School		

AC – museum collection of the National Museum of Natural History (NMNH), Washington, DC; F – female; FC – field collected, deposited in the NMNH; LC – larval collection; LT – CDC light trap collections; M – male.

Table 1 continued on next page.

Table 1 (continued). Summary of collection localities of mosquitoes (based on observed specimens) in Guam, Saipan, Tinian, and Rota.

Species	Island	Locality	Grid Coordinates	Collection Date	Number/ Stage	Collector	Remarks (Habitat)	Repository
*Cx. (Cux.) tritaeniorhynchus*Giles	Guam	Sta. Rita, Apra Navy landing, housing and magazine areas	13.42038N/144.67496E (GU-005); 13.40386N/144.67735E (GU-007)	9, 10 Mar 2010	5F	W.K. Reeves	LT (deer pen)	FC
	Guam	NAVSTA, Pt. Apaca		Aug, Sep 1975	16F, 12M			AC
	Guam			3 Oct 1975; 24 Dec 1975; 5 Jan 1976	3F, 4M		(ground pool, ditch)	AC
	Saipan		(SAI-7, 9)	15-25 Aug 1991	7F, 36M	H. Savage	(Phragmites marsh, ground pool; biting pigs	AC
*Lutzia (Metalutzia) fuscana*Wiedemann	Saipan			Jan 1972	2M	N. Siren		AC
Mansonia (Mansonoides) uniformis (Theobald)	Guam	Sta. Rita, Apra Navy landing, housing and magazine areas	13.42038N/144.67496E (GU-005); 13.40386N/144.67735E (GU-007)	9, 10 Mar 2010	2F	W.K. Reeves	LT	FC

AC – museum collection of the National Museum of Natural History (NMNH), Washington, DC; F – female; FC – field collected, deposited in the NMNH; LT – CDC light trap collections; M – male.

components in developing effective strategies for the prevention and control of mosquito vectors and their borne-infectious diseases.

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Table 2. Updated checklists of mosquito species from Guam and neighboring islands.

Species	Guam	Rota	Saipan	Tinian
Aedeomyia (Aedeomyia) catastictaKnab	B2, R1, W1, X			
Aedes (Aedimorphus) oakleyiStone	B2, R1, X		B3, S1, X	
Aedes (Adm.) vexans nipponi(Theobald)	R1			
Ae. (Adm.) vexans nocturnus(Theobald)	B2, X		B3, B4, S1, X	X
Ae. (Adm.) vexans vexans(Meigen)	B2, K1, P2, R1		N2	V
Ae. (Stegomyia) aegypti(Linnaeus)	K1, R1, R2, X	N1, X	B3, E, K2, X	N2, X
Ae. (Stg.) albopictus(Skuse)	B2, K1, P2, R3, X	N1, N3, X	B3, B4,K2, P1,S1, X	V, X
Ae. (Stg.) burnsiBasio and Reisen	B1, R1			
Ae. (Stg.) dybasiBohart	B1, R1			
Ae. (Stg.) guamensisFarner and Bohart	B2, R1, R3, X	N1, N3	B3, S3	N2
Ae. (Stg.) hensilliFarner	B2, R1			
Ae. (Stg.) marshallensisStone and Bohart	B2, R1			
Ae. (Stg.) neopandani Bohart	B3, P2, X	N1, N3	B3, S1, W3	B3, N2
Ae. (Stg.) pandaniStone	B2, P2, R1, R2, X	N1, N3, X		
Ae. (Stg.) rotanus Bohart and Ingram	B2, B3, P2, R1, R2	B3, R2, N1, N3, X		
Ae. (Stg.) saipanensisStone	B2, B3, P2, R1		B3, B4, P1, S2, W3, X	B3, V
Ae. (Stg.) scutellaris(Walker)	B2, R1, R2			
Armigeres (Armigeres) subalbatus (Coquillett)	R1, W1			
Anopheles (Anopheles) baezaiGater	B1, R1, R2, W3			
An. (Ano.) barbirostrisVan der Wulp	K1, R1, W1, W2			
An. (Ano.) lesteri aisas and Hu	B1, R1			
An. (Ano.) sinensisWiedemann	B2, R1, X			
An. (Cellia) indefinitus(Ludlow)	B2, D1, R1, W1		P3, S1, X	V
An. (Cel.) litoralisKing	R1, W1			
An. (Cel.) subpictusGrassi	B3, D1, D2, P2, K1, R1			V
An. (Cel.) tessellatusTheobald	B1, R1			
An. (Cel.) vagus Donitz	D1, D2, K1, R1, W1, X			
Cx. (Cux.) annulirostris marianae Bohart and Ingram	R1, X	N1, N3, X	B3, B4, W3, X	
Cx. (Cux.) fuscocephala Theobald	R1, W1			
Cx. (Cux.) hutchinsoni Barraud	R1			
Cx. (Cux.) litoralisBohart	B3, R1, X	N1, W3, X	B3	N2
Cx. (Cux.) quinquefasciatusSay	K1, P2, R1, X	N1, N3	B3, E, K2, S1, X	V, X
Cx. (Cux.) pseudovishnuiColless	R1			
Cx. (Cux.) sinensisTheobald	R1			
Cx. (Cux.) sitiensWiedemann	B3, R1		S1	
Cx. (Cux.) tritaeniorhynchusGiles	B3, K1, P2, R1, X		S1, X	
Cx. (Cux.) vagansWiedemann	R1			
Cx. (Culiciomyia) papuensis(Taylor)	N2			
Lutzia (Metalutzia) fuscanaWiedemann	B3, P2,R1		S1, X	
Mansonia (Mansonoides) uniformis (Theobald)	W1, X			
Toxorhynchites (Toxorhynchites) amboinensis(Doleschall)	R1			
Tx. (Tox.) brevipalpisTheobald	R1			
Total Number of Species	40 (4 subspecies)	9 (1 subspecies)	14 (3 subspecies)	10 (1 subspecies)

Species Reported	Reference
B1	43
B2	21
B3	35
B4	41
D1	44
D2	45
E	46
K1	9
K2	47
N1	27
N2	39
N3	42
P1	48
P2	22
P3	49
R1	11
R2	32
R3	50
S1	5
S2	51
S3	52
V	53
W1	40
W2	54
W3	26
X	This Survey

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Online Spatial Database of US Army Public Health Command Region-West Mosquito Surveillance Records: 1947-2009

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ABSTRACT

Mosquito surveillance records from the US Army Public Health Command Region-West (APHCR-W) were georeferenced and made available online via the database mapping application MosquitoMap (www.mosquitomap.org). This article briefly reviews the history of the APHCR-W surveillance program and some characteristics of the resulting dataset, which numbers over 100,000 records mainly from US Department of Defense (DoD) facilities in the western United States from 1947 to 2009. The value of past and future DoD mosquito surveillance efforts can be increased by reporting the location of collection data in online spatial databases such as MosquitoMap.

INTRODUCTION

Mosquito surveillance of military installations has been conducted and reported by the US Army since the early years of World War II. Baseline mosquito species collection data, standardized by trap index, have been reported annually, allowing comparisons between years and within a single year. For example, the report for 2006[1] reported 46 mosquito species in 8 genera, which were collected from 24 installations, subinstallations, and other facilities within the 20 states comprising what is now the Army Public Health Command Region-West (APHCR-W) area of responsibility, including US Army (9), Army Reserve (2), National Guard (2), US Navy (6) and one from the National Park system.

Britch et al[2] explored relationships between the Normalized Difference Vegetation Index* and 2003-2005 APHCR-W mosquito surveillance data, for a subset of mosquito species and locations, including Fort Riley, Kansas, Fort Lewis, Washington, and Yuma Proving Ground, Arizona. They sought to identify instances of population patterns that suggested a response to climate, and concluded that the mosquito surveillance data could be useful for future climate-based models developed to forecast population dynamics of medically important mosquitoes.

Mosquito surveillance is seen as important intelligence to support the planning of effective mosquito control programs. Mosquito trap data at the APHCR-W dates from 1947, making this one of the longest running mosquito surveillance programs in the world, and providing a unique resource for understanding changes in mosquito occurrence and abundance in the United States. These data were available via the APHCR-W website†, but georeferencing, which allows collection locations to be mapped for spatial analyses, was lacking. This article discusses a project to georeference these data and make them available online in a geographical information systems setting.

SURVEILLANCE PROGRAM HISTORY

The US Army Public Health Command (APHC) lineage can be traced back over 70 years to the Army Industrial Hygiene Laboratory (AIHL) which was established at the beginning of World War II under the direct jurisdiction of The Army Surgeon General. It was originally located at the Johns Hopkins School of Hygiene and Public Health, with a staff of three and an annual budget that did not exceed $3,000. Its mission was to conduct occupational health surveys of Army operated industrial plants, arsenals, and depots. These surveys were aimed at identifying and eliminating occupational health hazards within the Department of

*http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php
†http://phc.amedd.army.mil/topics/phcrspecific/west/Pages/default.aspx

Defense's (DoD) industrial production base and proved to be beneficial to the nation's war effort. In 1960, the AIHL became known as the US Army Environmental Hygiene Agency (AEHA). Its mission was expanded to support the worldwide preventive medicine programs of the Army, DoD, and other federal agencies through consultations, supportive services, investigations, and training. It was redesignated the US Army Center for Health Promotion and Preventive Medicine (CHPPM) in 1995 with the mission to provide worldwide technical support for implementing preventive medicine and public health and health promotion/wellness services into all aspects of America's Army and the Army Community, as well as anticipating and rapidly responding to operational needs and adapting to a changing world environment. In 2009, CHPPM was reorganized and became the Army Public Health Command.

The need for entomologists and pest surveillance, particularly for the southeastern United States where malaria was a threat, became apparent with the establishment of Army training camps during the mobilization program of World War II.[3] Weekly collection of mosquitoes from set collecting stations and reporting the species caught and their abundance was instituted by most of the Army posts in the 4th Service Command during this time.[3] Surveillance and control efforts in the United States was seen as necessary training for the job of controlling insects of medical importance in overseas theaters of operation.[3] After the war, the 9th Service Command Medical Laboratory, located at Fort Baker, California, began keeping records of mosquitoes captured on military installations along the US west coast. Colonel Stanley J. Carpenter, a noted Army Entomologist, cowrote the landmark book, *The Mosquitoes of North America,* while stationed at Fort Baker.[4] This handbook remains an indispensable guide to mosquito identification, and his identifications of mosquitoes are still recorded in the current APHCR-W mosquito database. Colonel Carpenter was later reassigned to Fort Baker to the renamed 6th Army Area Medical Laboratory, where he worked until his retirement in 1960.[5] In 1974, the health and environmental resources of the 6th Army Laboratory were transferred to the Fitzsimons Army Medical Center, Colorado, and designated as a subordinate command under AEHA. During the transition, records of mosquito collections in the western United States were transferred to the new subordinate command. In addition, mosquito surveillance was expanded to include Army installations in 23 western states, including Alaska. In 1999, the subordinate command moved from Fitzsimons to Fort Lewis, Washington, and in 2009 was redesignated the Army Public Health Command Region-West. Mosquito surveillance data have been maintained from 1947 until today. This command currently identifies mosquitoes from all Army installations in 20 western states. All mosquito collections have been transcribed from archived record cards and placed into a database.

Materials and Methods

The task of georeferencing the APHCR-W data presented numerous challenges due to base closures and lack of access to maps that detailed the sites mentioned in collection data. In early 2010, 294 files comprising individual base files and yearly files from 1947-1951 through 2009 were obtained (F.A.M. unpublished data, 2010), which allowed inclusion of these data on the database mapping application MosquitoMap*.

Surveillance data from different years were combined into one Microsoft Excel spreadsheet. In the absence of maps detailing individual sites, we opted to summarize their location by defining the centroid of the base and estimating uncertainty using published information about the area of the base. The internet provided particularly useful information, including general information lists of bases, and links to some specific base information which sometimes included map coordinates. For estimating spatial uncertainty, we used area data that is publicly available on the internet, and *The Base Structure Report*.[6] When area was given in acres, uncertainty in meters was calculated in Excel using the formula

$$=SQRT((Acres\times4046.85642)/3.1416)$$

Batch georeferences for street addresses were obtained using GPS Visualizer†, with Google set as the source. Input data were first edited to remove nonessential information, and arranged in a standard order to minimize geocoding errors. Output addresses were checked against input to identify discrepancies, and results that had a low precision level (to street or city, for example) were flagged to be further checked. Discrepancies were usually resolved through a

*http://www.mosquitomap.org
†http://www.gpsvisualizer.com/geocoder/

combination of internet searches for key terms and orientation with Google Earth*. Use of the historical imagery, altitude, distance along a path, street view, and the link to Google Maps in Google Earth, were found to be particularly useful for resolving problematic collection sites. When georeferences could not be resolved to street level, the township where the collection was made was georeferenced using Biogeomancer Workbench 1.2.4†.

A small minority of records had georeference information, either various geodetic formats or military grid reference system (MGRS). The MGRS grid zone identifier and 100,000 meter square identifier information was missing, so approximate location, as determined in Google Earth, was used to obtain a first approximation in the program GeoTrans V2.4.1‡, then the northing and easting information entered to obtain the precise decimal degrees georeference. In most cases, these coordinates were checked in Google Earth to see if the location corresponded with any text information that was recorded for the collection site. The point radius method portrays uncertainty or error as a radius around a geocoordinate.[7,8] Uncertainty was estimated in the Manis Georeferencing Calculator§ from Biogeomancer, or estimated by visual assessment of the extent in Google Earth, or as the radius of a circle described by the calculated area.

Data were filtered in Excel for unique locations, and these point data were converted to shape files for mapping in DIVA-GIS 5.2**. Further data cleaning was undertaken by the "check coordinates" option of DIVA-GIS, a "point-in-polygon" method,[9] which identifies points located outside all polygons and points that did not match relations for the country and state names. Data were imported into ARCVIEW GIS 3.3 (Environmental Systems Research Institute, Inc, Redlands, CA) for graphical display.

We composited yearly files into one Excel sheet, with a sequence number added to recreate the original order. A new column was added with genus, subgenus, species, and author information taken from the MosquitoMap collection form, which is based on the online Systematic Catalog of Culicidae.[10] The mosquito species recorded were checked for current taxonomic status. The geolocations of records were checked in DIVA-GIS for agreement with the country and state of occurrence. The location of each species was mapped and this checked against known records for these species. Records with trap catches labeled "Not operated," "Negative," "Misc. Culicidae," "Aedini" (n=18,269), and one record labeled "*Ochlerotatus atlanticus/tormentor*" were placed in a separate Excel sheet. Those records that could not be georeferenced (n=267), and anomalous records, the distribution of which did not agree with established knowledge (n=15), were also separated. This left 100,610 georeferenced and quality controlled records. Data fields were rendered into the MosquitoMap format, and records were uploaded into MosquitoMap in November 2010.

SPECIES ACCUMULATION CURVES

The application EstimateS 7.5.1†† was used to investigate under-sampling and spatial aggregation in the data. EstimateS calculates randomized species accumulation curves (also known as sample-based rarefaction curves) and computes a variety of species richness indicators. For an idealized complete inventory for an area, the species accumulation curve will form an asymptote near the true species richness, and taxa that are *rare* will be observed more than once. The expected richness function in EstimateS is called Sobs (Mao Tau). A Coleman curve is calculated by randomly reassigning specimens to samples and then recalculating the species accumulation curve, thus removing any clumping in the data. The present study used the EstimateS incidence-based coverage estimator (ICE), which depends on the presence and distribution of rare taxa, to estimate the lower bounds of species richness and to assess the degree of undersampling. The present study used the default values in EstimateS, that is, 50 randomizations for estimators and 10 for the upper abundance limit for rare taxa. The yearly presence (1) or absence (0) of each species was the input for EstimateS.

RESULTS

There were 858 unique location points (Figure 1), for 100,610 records, representing 201,905 male and 1,198,281 female specimens. The mean radius of geographic uncertainty was 7,970.8 m (SD=7542.0), with a range of 88 m to 80,547 m. Of these, 21% had

*http://www.google.com/earth/index.html
†http://bg.berkeley.edu/latest/
‡http://geoengine.nga.mil/geospatial/SW_TOOLS/NIMAMUSE/webinter/geotrans.html
§http://manisnet.org/search.shtml
**http://www.diva-gis.org/
††http://viceroy.eeb.uconn.edu/estimates

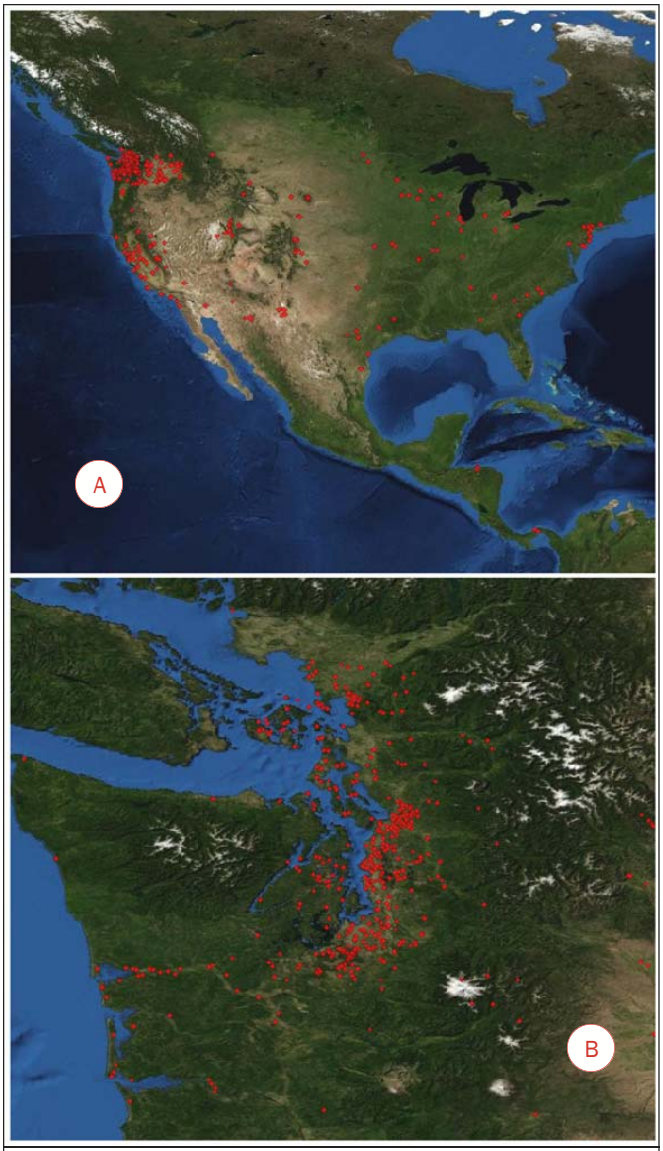

Figure 1. Geographical distribution of surveillance records from the PHCR-W dataset for the 48 US states (panel A), and a close-up of Puget Sound area of Washington state (panel B).

Breakdown of the mosquito surveillance records in the PHCR-W dataset by state.

State	No. Years	No. Records	No. Species
AK	14	273	20
AL	1	22	8
AZ	49	17313	31
CA	49	9144	34
CO	49	11389	26
CT	1	2	2
GA	1	190	17
HI	1	6	2
IA	1	1	1
ID	1	6	3
IL	24	7759	38
IN	6	38	7
KS	35	30197	38
MD	1	2	2
MI	8	135	19
MN	12	437	20
MO	27	8497	41
MT	2	2	2
ND	3	112	14
NJ	2	21	8
NM	15	631	17
NV	6	50	9
NY	1	3	3
OH	2	21	9
OK	1	68	13
OR	7	45	10
SC	1	26	10
SD	1	3	3
TX	19	2874	26
UT	22	631	16
WA	36	9039	40
WI	20	1098	30
WY	7	446	15

an uncertainty of 2,000 m or less, 56% were 8,000 m or less, and 85% were 12,000 m or less.

The majority of locations were from the state of Washington, but, as shown in the Table, more records came from Kansas, Arizona, and Colorado. In all, 33 US states were sampled. Figure 2 shows yearly changes in species (number of species, species accumulation) and sampling effort (logarithm of the number of records, logarithm of the number of US states that were sampled). A change in the early to mid 1970s and in the 2000s can be seen from the data. This effect, broken down by state, is shown in Figure 3, and the number of species by state in Figure 4.

There are 105 species names; 14% of species were caught in only one year, and 26% in one or two years. The singleton species were: *Aedes burgeri* Zavortink, *Ae. dupreei* (Coquillett), *Ae. euplocamus* Dyar and Knab, *Ae. provocans* (Walker), *Ae. pullatus* (Coquillett), *Ae. varipalpus* (Coquillett), *Ae. washinoi* Lanzaro and Eldridge, *Anopheles judithae* Zavortink, *An. vestitipennis* Dyar and Knab, *Coquillettidia venezuelensis* (Theobald), *Culex arizonensis* Bohart, *Mansonia titillans* (Walker), *Psorophora mathesoni* Belkin and Heinemann, *Uranotaenia anhydor syntheta* Dyar and Shannon, *Ur. lowii* Theobald. Four out of the 15 singleton species were caught in 1996, and a majority of the other infrequently found species were caught in

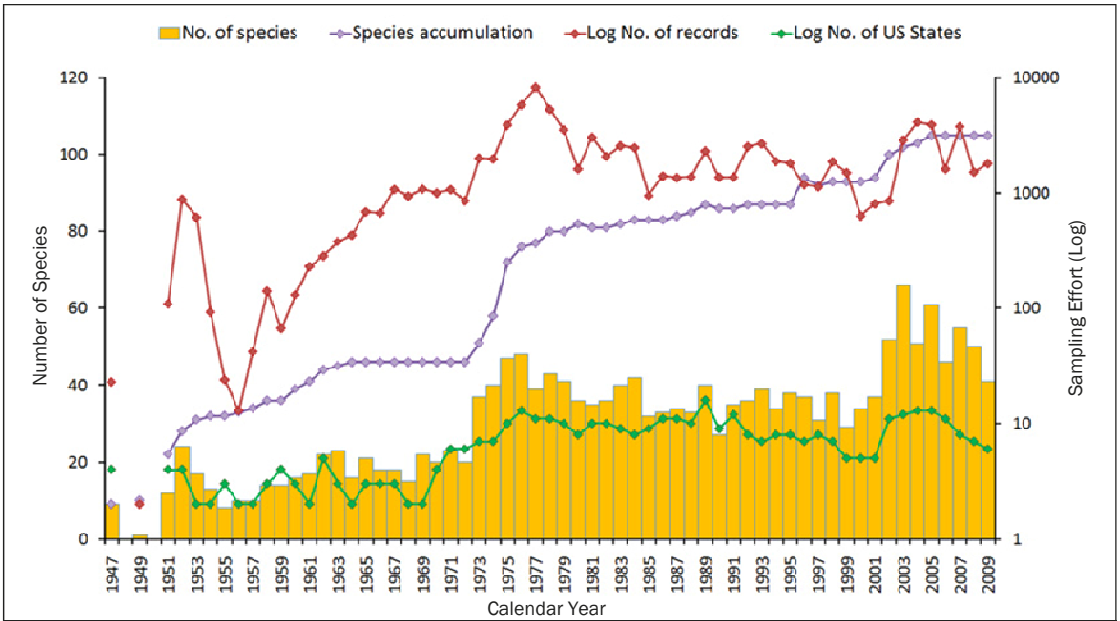

Figure 2. Yearly changes in species (number of species, species accumulation) and sampling effort (log plot of the number of records, log plot of the number of US states that were sampled) from the PHCR-W mosquito surveillance dataset. Note the change in the early to mid 1970s, and in the 2000s.

1973-1978, and 2002-2005, when many new US states were surveyed. The 10 most frequently collected species (lowest to highest) were: *Cx. quinquefasciatus* Say, *Ae. vexans* (Meigen), *Culiseta incidens* (Thomson), *Ps. columbiae* (Dyar and Knab), *Cx. erythrothorax* Dyar, *An. franciscanus* McCracken, *Cx. pipiens* Linnaeus, *Ae. dorsalis* (Meigen), *Cx. tarsalis* Coquillett, *Cs. inornata* (Williston). New state records arising from the APHCR-W surveillance program comprised *Ae. fulvus pallens* Ross in Missouri,[11] *Ur. sapphirina* (Osten Sachen) in Colorado,[12] and *Ae. thelcter* Dyar in Arizona.[13]

The results using all years resulted in very high estimates of species numbers using EstimateS. Because of this, and the clear difference between pre- and post-1975 collection data, we report analysis of post-1975 results. Post-1975 data comprised 101 of the 105 species collected over the 1947-2009 period. The curves resulting from the EstimateS analysis are shown in Figure 5. EstimateS advised that the coefficient of variation was >0.5, so the Classic option was used and reporting was limited to the ICE estimate for incidence-based richness. The largest ICE mean estimate was 112 species and Sobs was 97 species, being very close to the total number recorded, 105 species. According to the Online Mosquito Catalog,[10] 166 species occur in the US, but a subset of these occur in the geographic area sampled by the APHCR-W surveillance program. Thus, species recorded from the APHCR-W data may be approaching the total number of species actually present within the area of surveillance.

Most records pertain to collections on US military facilities, but this was not always the case. Other locations included National Parks, water and sewage treatment plants, roadside collections, food processing factories, and private residences. For example, in 2003 and 2007, many residents in Washington cooperated in a mosquito survey that was a collaboration between APHCR-W and the Washington Department of Health.

DISCUSSION

According to Heyer et al,[15] for a complete inventory of species, the estimators and Sobs coincide and asymptote together, whereas for a relatively undersampled fauna, the estimator curves are much higher (65%) than the observed curves. In the most undersampled taxa, the Sobs curve may also be linear,[15] but this was not observed in the present study. A general coincidence of the Coleman (not shown) and Sobs curves in Figure 5 is evidence against patchiness in the distribution of data points, especially for rare species.

Compared with the arthropod, vertebrate, and plant species analyzed in Heyer et al,[15] the mosquito curves in Figure 5 suggests an inventory, for the area under

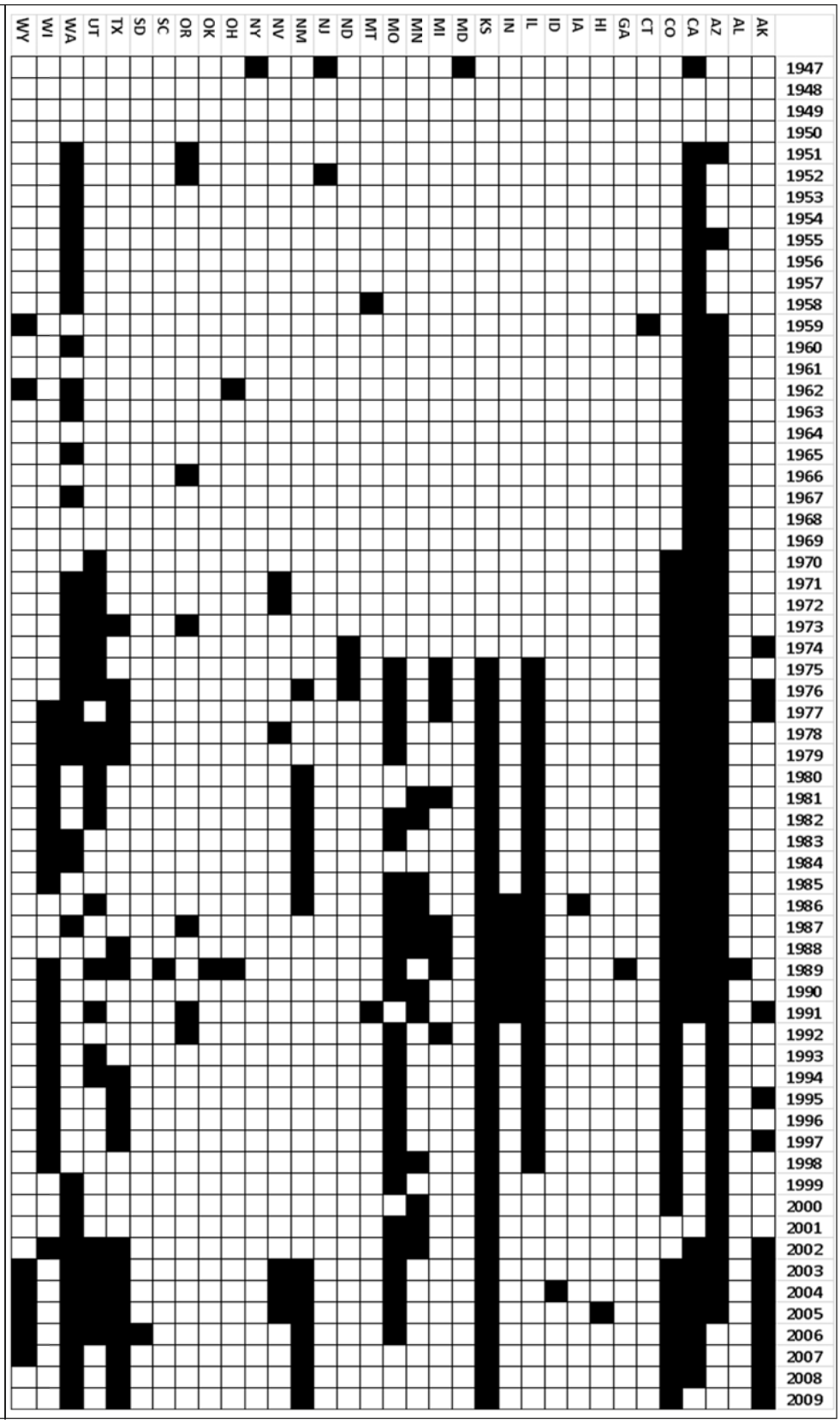

Figure 3. Presence (solid fill) or absence (no fill) of mosquito surveillance records from the PHCR-W dataset by state for years 1947 through 2009.

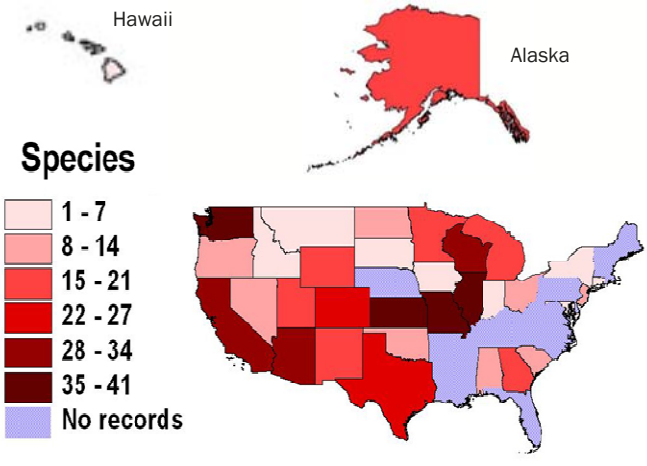

Figure 4. Total number of species recorded in the PHCR-W dataset for each state.

study, that is approaching completeness. For a complete inventory, values for uniques tend toward zero, as they will have been observed multiple times. Values for Sobs and ICE appear to be reaching an asymptote and the uniques curve is starting to decline. It is possible that the rarity of many mosquito species is an artifact, perhaps by nonrandom sampling, which distorts the results. Occasional introductions of species that do not become established may inflate the number of species, whereas climate change may make the environment more or less suitable for different species, thereby having unpredictable effects on total species number.

The geographical range of APHCR-W surveillance in the continental United States has changed over the years (Figure 3), and the Base Realignment and Closure cycle is one possible factor among many that may affect surveillance coverage in the future. The current primary focus of DoD vector surveillance appears to be at the level of the military installation rather than statewide or nationwide. However, it is a synthesis of information and a coordinated response at these coarser spatial granularities that the effect of climate change and spread of invasive species and emerging vector-borne diseases will most profitably be addressed. This was demonstrated most forcefully following the emergence of West Nile virus (WNV) in the United States in 1999, when the Army Surgeon General directed the creation and implementation of a WNV Surveillance and Control Program for Army installations.[16] A multiagency collaboration and the formation of an ad hoc WNV committee of the Armed Forces Pest Management Board enabled Army, Navy, Marine, and Air Force installations to use mosquito surveillance and control, dead bird surveillance, and human case monitoring to minimize the risk of WNV to personnel on military installations.[16] The WNV threat also resulted in a collaboration between APHCR-W and the Washington [state] Department of Health regarding training, mosquito identification, and exchange of mosquito surveillance data, including data from APHCR-W for 1973-2005, which resulted in a checklist and distribution records for mosquitoes of the state of Washington.[17]

Furthermore, longer term surveillance datasets are more valuable for identifying permanent rather than short-term perturbations in vector populations, and for establishing action thresholds or control decision rules. As surveillance data are made more accessible, and tools to assist their analysis are made available online, the utility of these data for decision makers such as health planners and integrated pest management personnel will increase. According to Debboun et al,[16]

> …carefully planned surveillance plays a critical role in assessing vector-borne disease threats because the information gained can influence decisions on the use of medical preventive interventions, such as chemoprophylaxis, and pesticide usage.

According to Britch et al,[2] mosquito surveillance at military installations should be continued or even augmented, to improve and automate the ability to fore-

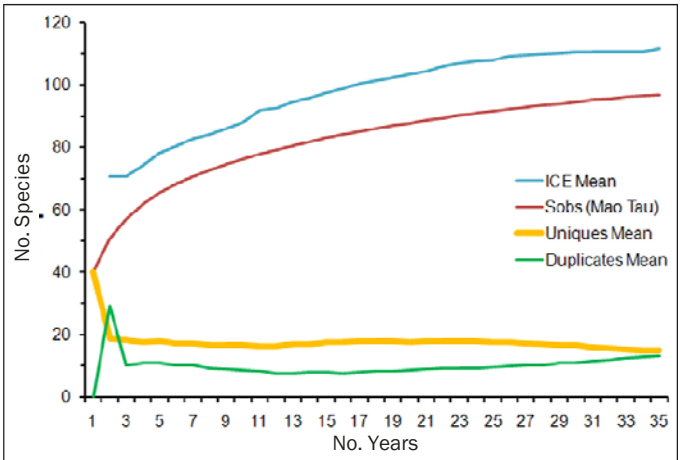

Figure 5. Species richness estimators and patchiness indicators for mosquito species from the PHCR-W database calculated with the program EstimateS.

ICE indicates incidence-based coverage estimator.[14]

Sobs (Mao Tau) [mean] indicates empirical species accumulation curve.

Uniques mean indicates number of species occurring in only one year.

Duplicates mean indicates number of species occurring in only 2 years.

cast mosquito population changes favorable for mosquito-borne diseases. We agree, and would add that uniform adoption of georeferencing standards for recording the location of mosquito collections would add value to these data.

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Reliability of Lower Quarter Physical Performance Measures in Healthy Service Members

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ABSTRACT

Introduction: Measures of endurance, flexibility, strength, and power may be of value in predicting injury risk, but application to the military setting has been limited. The purpose of this study was to assess the reliability and precision of lower quarter physical performance measures among novice raters.

Methods: Sixty-four (53 male, 11 female) healthy active duty Soldiers (aged 25.2±3.8 years, 25.1±3.1 kg/m^2) were recruited while in training at Fort Sam Houston, Texas. Subjects completed 13 lower quarter physical performance measures in a counterbalanced order. Measures included indicators of lumbopelvic endurance (trunk flexion, trunk extension, and trunk lateral flexion), lower extremity flexibility (gastrocnemius, soleus, iliotibial band, hamstring, and quadriceps), hip strength (hip external rotation, hip abduction), quality of movement (lateral step down), and lower extremity power (timed hop test and crossover hop test). Interrater test-retest reliability was assessed between baseline scores and those obtained 48 hours later using intraclass correlation coefficients (ICC) and standard errors of measurements (SEM).

Results: Measures of lumbopelvic endurance had ICC(2,1) values ranging from 0.77 to 0.79 with SEM ranging from 18.3 to 24.5 seconds. Measures of flexibility had ICC(2,2) values ranging from 0.27 to 0.59 with SEM ranging from 4.1° to 9.9°. Measures of hip strength had ICC(2,3) values ranging from 0.61 to 0.82 with SEM ranging from 1.3 kg to 3.0 kg. Measures of power had ICC(2,3) values ranging from 0.78 to 0.93 with SEM values of 0.2 seconds and 27.4 cm.

Conclusions: The majority of measures assessed had adequate reliability in this sample of uniformed service members assessed by novice raters. The measures of strength and power had moderate to good reliability with small measurement error, indicating the possibility of these measures to detect change over time. Although the measures of lumbopelvic endurance had good reliability, they were associated with relatively large SEM values compared to the group mean, thus limiting the ability of these tests to detect change over time. The measures of flexibility had limited reliability which may be associated with a restriction in range of the underlying scores that could artificially underestimate reliability. These results can help inform which physical performance measures should be used in future research to assess injury prediction and human performance optimization among uniformed service members.

INTRODUCTION

Musculoskeletal injuries are a primary source of disability in the US military.[1,2] In 2007, musculoskeletal injuries resulted in approximately 2.4 million medical visits to military treatment facilities and accounted for $548 million in direct patient care costs.* In 2004, lower extremity injuries, both traumatic (eg, noncontact anterior cruciate ligament tears and ankle sprains) and overuse (eg, anterior knee pain, medial tibial stress syndrome, and plantar fasciitis), accounted for over 4.8 million of the 11 million limited duty days related to injury, second only to spine disorders.† At this time there is no efficient and cost effective way to screen Soldiers to determine their risk of sustaining such an injury. There is, however, preliminary evidence suggesting that a neuromuscular and strength training program may be beneficial for preventing the incidence of lower extremity injuries.[3-9] A first step towards efficiently and effectively screening service members to determine their response to such a training program is to examine the reliability and precision of measures used to assess their fitness level, lumbo-

*Data source: Department of Defense Medical Metrics database, not directly accessible by the general public.
†Data source: US Army Medical Surveillance Activity compilation (2004), not directly accessible by the general public.

pelvic strength and stability, flexibility, balance, and neuromuscular control. The specific focus of this study is trunk endurance, flexibility, strength, quality of movement, and power measures.

Poor lumbopelvic stability, to include strength and endurance deficits of the trunk, pelvic, and hip musculature, has been associated with lower extremity injuries in physical therapy patients, middle and long distance runners, collegiate level gymnasts, and young female athletes.[10-15] Waddell et al[16] demonstrated moderate to good reliability of the trunk flexor endurance test (intraclass correlation coefficient (ICC) 0.95 and kappa value of 0.48) in patients with low back pain. Similarly, good reliability of the trunk lateral flexion and extensor endurance tests has been demonstrated by McGill et al[17] in a group of young healthy subjects (ICC 0.96 for right trunk lateral flexion, ICC 0.99 for left trunk lateral flexion, and ICC 0.99 for trunk extensor endurance). Studying effects of preseason trunk muscle training on low back pain occurrence in women collegiate gymnasts, Durall et al[18] reported good reliability for both the trunk extensor and right lateral flexion endurance tests (ICC 0.89), as well as the left lateral flexion endurance test (ICC 0.91).

Researchers have associated inadequate flexibility in various athletes with the development of anterior knee pain and lower extremity injuries.[19-26] Specifically, soft tissue tightness of the gastrocnemius, quadriceps, hamstring muscles, and iliotibial band/tensor fascia latae has been suggested to influence such injuries.[11,19-21,27-31] Piva et al[32] demonstrated good reliability when measuring flexibility of the hamstrings (ICC 0.92), quadriceps (ICC 0.91), gastrocnemius (ICC 0.92), soleus (ICC 0.86), and iliotibial band/tensor fascia latae (ICC 0.97) in patients diagnosed with patellofemoral pain syndrome (PFPS). Lesher et al[31] reported good reliability for gastrocnemius flexibility (ICC 0.84) while studying therapeutic taping for patients with PFPS. Gastrocnemius and soleus muscle flexibility are important to ankle joint range of motion. Using ankle dorsiflexion as a measure for gastrocnemius length, some studies report lower interrater reliability with these measures.[33,34] Elveru et al[35] and Youdas et al[34] have both reported moderate reliability (ICC 0.50 and 0.58, respectively) in measuring gastrocnemius length in patients with neurological and/or orthopedic problems.

Hip musculature strength, with specific emphasis on hip flexion, external rotation, and abduction, has been associated with lower extremity overuse injuries in runners sustaining knee pain.[11,36-40] Piva et al[32] demonstrated good reliability for hip abduction strength (ICC 0.85) and external rotation strength (ICC 0.79) in patients sustaining PFPS. Similarly, Fredericson et al[38] reported good reliability in testing hip abductor strength (ICC 0.96) in 24 collegiate male and female runners with iliotibial band syndrome. Impaired neuromuscular control during step down has also been theorized to increase risk for lower extremity injury.[41] To date, data are conflicted regarding the reliability of the lateral step down test. Piva et al[32] reported moderate reliability (ICC 0.67) in patients with PFPS, while Weir et al[42] has reported poor reliability (ICC 0.39) in a group of 40 male athletes.

The triple hop test for distance has been shown to be a strong predictor of lower limb power and strength in healthy collegiate soccer players, supporting the test's clinical use as a preseason screening test in this population.[43] The score of the triple hop test for distance has been found to be strongly associated with the scores of the timed hop and cross-over hop tests, both of which have been useful for predicting return to function after an injury.[43,44] Researchers have found these tests to be sufficiently reliable with ICCs that range from 0.70 to 0.96 across different studies.[42]

Although a review of the literature demonstrates that the aforementioned tests are largely reliable in populations of healthy adults and athletes, their reliability and precision in a population of active duty service members has not been validated. Before efficient and cost effective screening of service members can take place, it is necessary to demonstrate that our evaluation and measurement tools can be consistently used and interpreted. Therefore, the primary purpose of our study is to determine the reliability and precision of lumbopelvic endurance, flexibility, strength, quality of movement and power measures in young healthy service members using novice raters.

METHODS

Participants

Subjects were recruited over an 8-week period from service members participating in physical training at Fort Sam Houston. Subjects were eligible for inclusion

if they were aged 18 through 35 years or an emancipated minor, fluent in English, and had no current complaint of lower extremity pain, spine pain, or other medical or neuromusculoskeletal disorder that limited participation in work or exercise in the last 6 months. Service members were excluded if they were currently seeking medical care for lower extremity injuries, or had previous medical history that included any surgery for lower extremity injuries. Service members were also excluded if they were unable to participate in unit physical training due to other musculoskeletal injuries, if they had a history of fracture (stress or traumatic) in the femur, pelvis, tibia, fibula, talus, or calcaneus, or were pregnant. All participants signed consent forms approved by the Brooke Army Medical Center Institutional Review Board.

Examiners

Examiners used in this study were all novice raters. The study staff included 4 research physical therapists, one research assistant and 29 physical therapy students enrolled in a doctor of physical therapy training program. Before testing, all examiners underwent 20 hours of hands-on training led by one of the physical therapists on the techniques and equipment for each test using this specific study's protocol. To minimize bias, raters were randomly assigned to each data collection station. The raters for day two were blinded to the raters' measurements on day one.

Performance Tests

This analysis represents a convenience sample of the 64 participants (53 male, 11 female) who were evaluated at baseline and again 48 hours later for the purposes of establishing intrarater reliability. The physical examination included assessment of lumbopelvic endurance (flexion, extension, and lateral flexion), lower extremity flexibility (gastrocnemius, soleus, iliotibial band, hamstring, and quadriceps), muscular strength (hip external rotation and hip abduction), quality of movement (lateral step down test), and power (timed hop test, cross-over hop test). For tests that assessed the dominant leg, we defined leg dominance as the leg the subject would naturally use to kick a ball.

Lumbopelvic Endurance

Trunk flexor endurance (Figure 1) was assessed with the subject positioned supine and arms at sides, palms flat on table.[16] Subjects were instructed not to push down with their arms during testing. The subject's feet were passively positioned 15 cm (6 in) above the table to demonstrate the starting position and passively moved to the 20 cm (8 in) and 10 cm (4 in) marks to ensure the subject was aware of the boundaries at which the test would be terminated. The examiner then placed the subject's legs at the 15 cm (6 in) mark and instructed them to hold and began timing. Feedback on foot position was provided every 20 seconds. If the subject's feet went above the 20 cm (8 in) mark or below the 10 cm (4 in) mark, instructions were provided to return to the 15 cm (6 in) mark. If the subject went outside the zone a second time, the test was terminated. The test ended when the subject was unable to keep the feet within the target zone, the feet went out of the zone twice, or 240 seconds elapsed.

Trunk extensor endurance (Figure 2) was assessed with the subject positioned prone and their anterior superior iliac spine positioned near the edge of the testing table and their upper body supported by a stool.[17,45,46] A single pillow was placed under the subject's feet and ankles. Three adjustable straps secured the subject at the proximal ankle, popliteal fossa, and greater trochanters. Timing began when the subject released his or her hands from the resting position and folded the arms across the chest. The inclinometer was immediately placed between the inferior borders of the scapula and the subjects were instructed to position the upper body so that the

Figure 1. Trunk flexion endurance test.

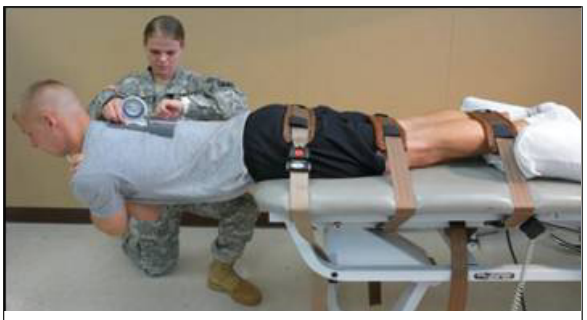

Figure 2. Trunk extension endurance test.

inclinometer read zero. The subject was informed when the correct position was attained. Feedback was provided every 20 seconds. If the subject deviated greater than ±10°, they were instructed to return to the test position. The test was terminated upon the second deviation, if the subject rested the body or hands on a supporting surface/stool, or 240 seconds had elapsed.

Trunk lateral flexor endurance (Figure 3) was assessed with the subject in side lying supported on the elbow of the dominant arm and the legs extended.[17,45,46] The top foot was placed in front of the lower foot for support and the opposite arm was placed on the shoulder of the dominant arm. Subjects were instructed on how to support themselves by lifting their hips off the surface to maintain a straight line over their full body length while supporting themselves over the top of the dominant elbow and the sides of the feet. Timing began when the subject moved into the testing position and feedback was given every 20 seconds. If subjects deviated from the test position due to fatigue, they were given one correction. The test was terminated if the subject deviated a second time, could not return to testing position after first deviation, or 240 seconds had elapsed.

Flexibility

Gastrocnemius flexibility (Figure 4) was assessed with the subject positioned in prone and ankles resting just off the edge of the plinth. The foot was positioned in subtalar neutral at 90° and the subject was cued to move their toes towards their nose from that position. Two measurements were taken with a standard goniometer as the subject actively dorsiflexed at the ankle.[27,32]

Figure 3. Trunk lateral flexion endurance test.

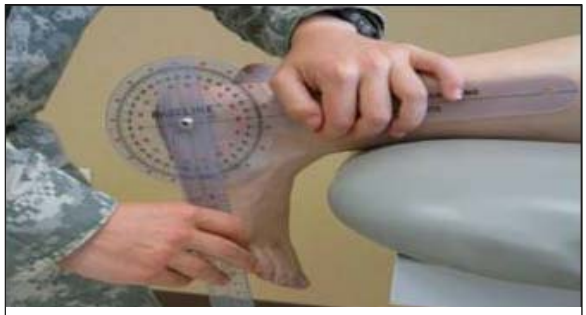

Figure 4. Gastrocnemius flexibility test.

Figure 5. Soleus flexibility test.

Soleus flexibility (Figure 5) was assessed with the subject positioned in prone and the knee of the leg being tested bent at 90°.[27,35] The foot was positioned in subtalar neutral at 90° and the subject was cued to move the toes towards the table from that position. Two measurements were taken with a standard goniometer as subjects actively dorsiflexed the ankle.

Iliotibial band flexibility (Figure 6) was assessed with the subject positioned in side-lying.[30,32,47,48] The tested leg was on top and the nontested leg was bent slightly to restrain body rotation. A bubble inclinometer was

Figure 6. Iliotibial band flexibility test.

Figure 7. Hamstring flexibility test.

used to measure the angle between the thigh and the horizontal plane. A single measurement was recorded in the modified Ober's position.

Hamstring flexibility (Figure 7) was assessed with the subject supine and the head, arms, and back flat against the plinth.[49,50] The leg not tested was fully relaxed in terminal extension while the hip of the tested leg was passively flexed until the subject's thigh was vertical. The vertical position was verified with a bubble inclinometer. Subjects interlocked their fingers around their thighs to help maintain vertical alignment while the leg was passively stretched into knee extension. Measurements were taken with the inclinometer just distal to the tibia tuberosity at first resistance. Two measurements per limb were recorded.

Figure 8. Quadriceps flexibility test.

Quadriceps flexibility (Figure 8) was assessed with the subject prone and the legs positioned midline.[32,51] Stabilizing the pelvis with one hand, the examiner flexed the subject's dominant knee to first resistance. Two measurements were taken with an inclinometer on the distal anterior tibia.

Strength

Hip external rotation strength (Figure 9) was assessed with the subject prone and the knee of the dominant leg flexed to 90°, hips neutral, the opposite knee in full extension, and the thighs of both legs kept closely together.[32] Belts were used at the level of the posterior superior iliac spines and over the distal posterior thighs to minimize substitutions. The examiner stood on the side of the flexed leg and placed the hand held dynamometer (HHD) just proximal to the medial malleolus of the subject. The HHD was fitted with a concave pad and set at zero. The subject was cued to push into the examiner's hands with maximal effort for approximately 3 to 5 seconds with 1 to 2 seconds to ramp-up force. Two trials were performed on the dominant leg with 1 minute rest between trials. A third trial was performed if the first 2 trials varied by more than 10%.

Figure 9. Hip external rotation strength test.

Hip abductor strength (Figure 10) was assessed with the subjects in side lying on their nondominant side with the bottom knee bent for support.[32,38] The subject's position was standardized by placing foam pads under the abducted dominant leg (the heel was in the middle of the pad) until a bubble inclinometer measurement taken at the mid tibia read 20°±5°. Tested legs were positioned at 20° of hip abduction, 5° of hip extension, and slight external rotation. A belt was positioned just proximal and slightly posterior to the lateral malleolus. Force was recorded with a HHD fitted with a concave pad and attached to the belt. Two trials were performed in the same manner as the hip external rotation strength. A third trial was performed if the first 2 trials varied by more than 10%.

Figure 10. Hip abduction strength test.

Quality of Movement

Quality of movement was assessed using the lateral step down test (Figure 11).[32] This test assesses the ability of a subject to maintain good alignment and biomechanics according to a set of criteria during a single leg step down. Each subject was asked to stand in single-leg stance with knee straight on a 20 cm (8 in) high step. The examiner marked each subject's tibial tuberosity and traced a line bisecting the second toe to assist visualization of movement. With hands

positioned on waist, subjects then bent the knee of the stance leg until their opposite heel gently contacted the floor, then re-extended the stance knee. Each subject performed 5 repetitions of the lateral step down test. Each repetition was scored based on 4 criteria: (1) arm strategy, (2) amount of trunk movement/lean, (3) pelvic position, and (4) amount of knee deviation. A single point was added for each of the following deviations: the use of an arm strategy, a trunk lean to either side, or pelvis rotation or elevation. If the knee deviated medial to the second toe, a single point was added to the score. If the knee deviates medial so that the lateral border of the knee is medial to the second toe, 2 points were added to the score. The quality of movement score ranged from 0 to 5, with zero indicating good quality of movement and 5 indicating poor quality of movement.

Power

For the 6 m timed hop test, 9 m (30 ft) of tape measure was secured to the floor with a start and finish line marked 6 m (20 ft) apart.[44,52] The tested leg was chosen at random and positioned behind the starting tape with toes close to the line. Each subject was instructed to hop on a single leg past the finish line as quickly as possible for 3 trials on each leg (Figure 12). The examiner recorded both time and the number of hops for the 6 trials.

For the cross-over hop test, 9 m (30 ft) of tape measure was secured to the floor. The tested leg was chosen at random and positioned behind the starting tape with toes close to the starting line. Each subject was instructed to hop 3 times on a single leg and cross over the line created by the measuring tape on each hop (Figure 13).[44,52] The examiner recorded the distance from the starting line to the heel of the third heel strike. Three trials were performed for each leg.

Figure 11. Lateral step down test .

Data Analysis

Descriptive statistics were calculated to summarize the demographic characteristics and the results of the tests. Reliability was analyzed with intraclass correlation coefficients (ICC(2,k)). For the ICC values, k was determined based on the number of repetitions analyzed. For endurance tests and iliotibial band flexibility k=1, for hamstring, quadriceps, gastrocnemius, and soleus flexibility k=2, for hip abduction and external rotation strength k=3, and for lateral step down k=5.[53] Good reliability is defined as 0.75 or higher, moderate as 0.50 to 0.74, and poor as less than 0.49.[53] Response stability and precision were analyzed by calculating both standard error of measurement (SEM) and the minimal detectable change (MDC) values. Statistical analyses were conducted using SPSS for Windows, Version 12.0 (SPSS Inc, Chicago, IL).

Results

Sixty-four participants (53 male, 11 female) met the inclusion and exclusion criteria and completed the study (Table 1). On average, the subjects were aged 25.2±3.8 years and had a body mass index of 25.1±3.1 kg/m^2. No subjects were excluded from the analysis.

Lumbopelvic Endurance

The mean values for the trunk extension, flexion, and lateral flexion endurance tests varied from 97.2 to 120.1 seconds with relatively wide ranges (Table 2).

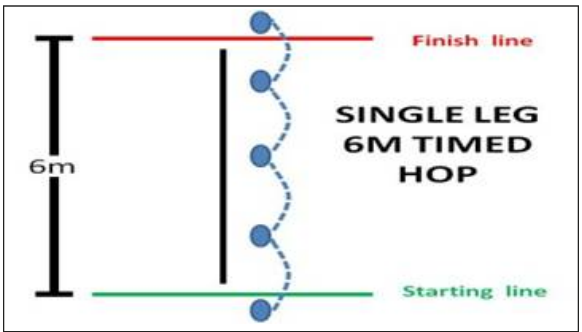

Figure 12. Timed hop test.

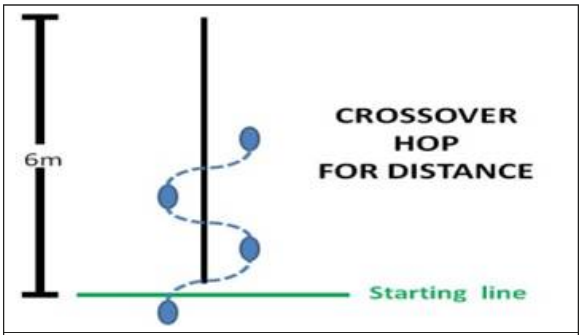

Figure 13. Cross-over hop test.

Of the 64 subjects, only 2 subjects maintained the posture for the maximal time (240 seconds) during the trunk extension test, while 3 subjects maintained the postures for the maximal time during the trunk flexion and trunk lateral flexion endurance tests. Overall, the measures of trunk endurance demonstrated good reliability in our sample tested with novice raters. The point estimates of the ICC(2,1) values ranged from 0.77 to 0.79. However, the MDCs ranged from 50.8 to 60.7 seconds.

Flexibility

Descriptive data regarding the available range of motion are provided in Table 2. The ICC values ranged from 0.27 to 0.59, demonstrating poor reliability for the gastrocnemius muscle and moderate reliability for the other measures. The SEM ranged from 4.1° to 9.9°, while the MDC ranged from 11.3° to 27.4°.

Strength

Mean measures of hip strength included hip external rotation (15.7±3.2 kg) and hip abduction (18.3±4.7 kg). Hip strength measures had moderate to good reliability with relatively small measurement error (Table 2). The ICC(2,3) was good for hip external rotation (ICC point estimate of 0.82) and moderate for hip abduction (ICC point estimate of 0.65) with SEM ranging from 1.3 to 3.0 kg.

Table 1. Test subject demographics.

	Mean±SD	95% CI
Age, years	25.2±3.8	24.3 to 26.2
Height, cm	175.5±9.6	173.1 to 177.9
Weight, kg	77.5±12.5	74.4 to 80.7
Body mass index, kg/m^2	25.1±3.1	24.3 to 25.9
Limb length, cm	92.2±5.9	90.8 to 93.7

SD – standard deviation. CI – confidence interval

Table 2. Descriptive and reliability data.

Measure	Mean (SD)	Range	ICC (95% CI)	SEM	MDC
Lumbopelvic endurance, seconds					
Extension	108.6 (39.6)	49.0, 240.0	0.79 (0.67,0.87)	18.3	50.8
Flexion	120.1 (49.6)	5.4, 240.0	0.78 (0.58,0.88)	24.5	67.8
Lateral flexion	97.2 (42.8)	29.4, 240.0	0.77 (0.64,0.85)	21.9	60.7
Flexibility, degrees					
Hamstring	48.4 (9.6)	10, 70	0.54 (0.25,0.72)	7.9	21.9
Quadriceps	98.5 (13.4)	53, 129	0.57 (0.17,0.76)	9.9	27.4
Gastrocnemius	8.8 (5.3)	-1, 19	0.27 (-0.24,0.57)	4.1	11.3
Soleus	16.3 (5.9)	-1, 35	0.59 (0.28,0.77)	7.4	20.4
Iliotibial band	11.4 (6.1)	1, 29	0.57 (0.38,0.72)	4.2	11.6
Strength, kg					
Hip abduction	18.3 (4.7)	8.5, 32	0.65 (0.17,0.83)	3.0	8.2
Hip external rotation	15.7 (3.2)	9.5, 23.6	0.82 (0.68,0.89)	1.3	3.6
Quality of Movement					
Lateral step down, points	1.9 (1.0)	0, 4	0.61 (0.30,0.79)	0.6	1.5
Power					
Cross-over hop test, cm	427.5 (101.4)	197.0, 680.7	0.93 (0.80,0.97)	27.4	75.9
Timed Hop Test, seconds	2.1 (0.4)	1.3, 3.5	0.78 (0.64,0.87)	0.2	0.5
Timed Hop Test, No. hops	4.9 (1.06)	3, 11	0.90 (0.84,0.94)	0.3	0.9

ICC indicates intraclass correlation coefficient.
Model 2,1: Trunk endurance - flexion, extension, lateral flexion; Flexibility - iliotibial band
Model 2,2: Flexibility - hamstring, quadriceps, gastrocnemius, soleus
Model 2,3: Strength - Hip abduction, hip external rotation
Model 2,5: Lateral step down (statistics above are based on "average score" of 5 trials, not best score).
SD indicates standard deviation. SEM indicates standard error of measurement. MDC indicates minimal detectable change

Quality of Movement

The lateral step down test had a mean score of 1.9±1.0 points. The ICC(2,5) point estimate of 0.61 demonstrated moderate reliability. The SEM was low (0.6 points).

Power

The average service member was able to hop 6 meters in 2.1 seconds and used approximately 5 hops to cover the 6 m distance (Table 2). In regards to the cross-over hop test, the average service member was able to cover 427.5 cm in the 3 hops. These measures had good reliability with ICC(2,3) values ranging from 0.78 to 0.93 and SEM values of 0.2 seconds and 27.4 cm.

DISCUSSION

The majority of measures were adequately reliable in this sample of uniformed service members assessed by novice raters. Although the measures of lumbopelvic endurance had good reliability, they were associated with relatively large SEM values compared to the group mean, thus possibly limiting the ability of these tests to detect change over time. The measures of flexibility had limited reliability. This may be associated with a restriction in range of the underlying scores that could artificially underestimate reliability. The measures of strength and power had moderate to good reliability with small measurement error, indicating the possibility for these measures to detect change over time.

Lumbopelvic Endurance

The mean values for trunk extensor and trunk lateral flexion endurance were similar to those reported by Chan et al[46] in collegiate rowers. However, the mean values reported in this study are approximately 20 to 30 seconds lower than those reported by McGill et al[17] who assessed trunk extension and flexion endurance in a young, healthy sample. Previous reports by Biering-Sorensen[54] suggested that trunk extensor time of 4 minutes (240 seconds) was associated with less risk for developing low back pain. The mean values of our subjects was much lower (97 to 120 seconds). Additionally, only 2 subjects maintained the posture for the maximal time (240 seconds) during the trunk extension endurance test, while 3 subjects maintained the maximal time during the trunk flexion and lateral flexion endurance tests. Potential confounding factors which may have decreased performance in our sample include the specificity of subjects' personal and unit physical training, the time of day these tests were administered, level of motivation, and subject comfort during the test. Further research should be conducted to determine how to improve lumbopelvic endurance of uniformed service members.

The overall reliability of lumbopelvic endurance measures in our study were good and similar to those reported by Chan et al[46] in collegiate rowers (ICC range: 0.76 to 0.93). Although the ICC values are considered good, the MDC ranged from 50.8 to 67.8 seconds. These values indicate that individuals would need to improve by approximately 1 minute to be 95% confident that the improvements noted were not due to chance. Although the lumbopelvic endurance tests may be a reliable screening tool to predict those at risk for injury, these tests lack the ability to detect change over time and may not be a good outcome measure when assessing the impact of interventions on lumbopelvic endurance.

Flexibility

The descriptive values for flexibility measurements are similar to those previously reported by Piva et al[32] and Kendall et al,[47] excluding quadriceps and hamstring flexibility. Our sample lacked a mean of 48.4° to full knee extension during the 90-90 test for hamstring flexibility, indicating a significant lack of passive motion. Quadriceps length during prone knee bend averaged only 98.5°of knee flexion as compared to 138° reported by Piva et al.[32] Many factors influence flexibility including chronic postures, exercise routines, and muscle temperature. In our unique sample, flexibility may be limited due to the influence of daily physical training or sustained postures, the early morning hours in which we obtained our measurements, as well as the interpretation of end range.

Limited ankle dorsiflexion has been suggested as a predictor of future injury,[55] however, assessment of gastrocnemius muscle flexibility has the lowest value for reliability. All other flexibility measurements have moderate reliability. These lower reliability values for assessing flexibility are in general agreement with prior publications,[33,34] but are in disagreement with ICC(2,2) values reported by Piva et al[32] that ranged from 0.86 to 0.97. The lower reliability values reported in this study may be associated with the use of more pairs of raters, use of novice raters, or a restriction in

ankle dorsiflexion in this sample of healthy active duty service members. The low ICC values and the relatively high SEM values in relation to the available range of motion at the ankle joint suggest the test may not be stable enough to accurately assess improvements in motion over time. The technique we used was nonweight bearing and required the determination of subtalar neutral prior to measurement of ankle dorsiflexion. The reliability of finding subtalar neutral has been reported as low.[33] Weight-bearing techniques to assess dorsiflexion that do not require the determination of subtalar neutral have demonstrated excellent reliability in previous studies. Denegar et al[56] reported ICC(3,1) of 0.98 to 0.99, while Vicenzino et al[57] reported ICC(3,3) of 0.95. Future research may find this strategy more reliable than the technique used in this study.

Strength

The mean strength value for hip external rotation in our subjects (15.8 kg) is equivalent to those reported in previous research, while the mean strength value for hip abduction (18.3 kg) exceeds those previously reported.[32,58,59] Thorborg et al[58] reported a mean hip external rotation strength value of 13.3 kg and hip abduction mean strength of 12.8 kg in a study of 8 healthy subjects with an age range similar to our subjects. Piva et al[11] reported a mean hip external rotation strength of 16.9 kg and hip abduction strength of 13.8 kg in subjects with PFPS, while subjects without PFPS had a mean hip external rotation strength of 15.8 kg and hip abduction of strength of 14.4 kg. Both of these differences in means showed no statistical significance. More recent studies contradict these findings by demonstrating significant strength deficits for hip external rotation and hip abduction in subjects with PFPS as compared to those without this diagnosis.[59,60] These findings may indicate that those with hip strength deficits in comparison to a similar population may be at a greater risk for developing PFPS or those with PFPS may develop hip strength deficits. For both tests, our values are similar to or exceed those reported for subjects with PFPS and subjects without PFPS, as would be expected given that we excluded those with PFPS from participation. Though we make no comparisons, based on the research cited above, the large means found in our subjects for hip external rotation and hip abduction strength may be a factor that contributed to them being injury free at the time of data collection.

We found good reliability of hip external rotation strength with an ICC(2,3) of 0.82. Our values were higher than those reported by Malliaras et al[61] who reported an ICC(2,1) for the right and left hip ranging from 0.60 and 0.63 (n=12). At the same time, our interrater values were equivalent to the interrater reliability values reported by Piva et al,[32] an ICC(2,2) of 0.79 in a sample of 30 subjects. As expected, our value is lower than the intrarater reliability values reported in another study by Piva et al,[11] ICC(3,2) of 0.96 for 15 subjects graded by experienced raters. A more recent study showed that when intrarater reliability of hip external rotation strength of 8 healthy subjects was measured by one experienced physiotherapist, the value achieved exceeded that of this study with an ICC (2,1) ranging from 0.92 to 0.99 for measurements with subjects positioned in both prone and sitting.[58] SEM values for hip external rotation have been reported by Piva et al[32] as 2.4 kg and by Thorberg et al[58] as 0.5 kg. The SEM value in our study for hip external rotation is 1.3 kg. The MDC value reported in a study by Thorborg et al[58] was 1.4 kg, our MDC was 3.6 kg. The slight differences in reliability values may be attributed to measurement techniques, sample size, and experience of raters. Overall, the high reliability values accompanied by the low SEM and MDC values support the use of these tests in identifying those at risk for injury due to decreased hip external rotation strength as well as accurately assessing change over time.

We found moderate reliability of the hip abduction test with an ICC(2,3) of 0.65. These values are equivalent to those published by Malliaras et al.[61] In their assessment of 13 male football players, interrater reliability ICC(2,1) values ranged from 0.58 to 0.73 for the right and left hip, while intrarater reliability values ICC(3,1) were good and ranged from 0.81 and 0.84.[61] All of these values are lower than those reported by Piva et al[32] who reported an interrater reliability ICC(2,2) of 0.85 when using experienced raters. SEM values reported in previous research are similar to those of our study.[32,61] Our MDC value for hip abduction was high at 8.2 kg in comparison to 3.0 kg reported by Thorborg et al.[58] The precision of hip abduction strength measurement demonstrates it may be accurate enough to detect change over time but more research is required.

Quality of Movement

Piva et al[32] found the reliability (kappa) of the lateral step down to be 0.67 with 80% agreement. However,

Weir et al[42] reported lower intrarater (ICC(2,1): 0.49) and lower interrater reliability (ICC(2,1): 0.39) when performed by 6 experienced observers. Our results demonstrated moderate reliability for the lateral step down with an ICC(2,5) of 0.61. Additionally, the SEM was only 0.6 on a 5 point scale, which suggests the lateral step down test may have the necessary response stability to detect change over time. However, the narrow scale (5 points) may limit its clinical and predictive utility if the variability of scores is limited.[42]

Power

The mean distance for the cross-over hop test in our study was 427.5 cm, the mean value for the timed hop test was 2.1 seconds, and the average number of hops taken for the timed hop test was 4.9 hops. In previous research of 20 subjects (5 male, 15 female) of the same age group as our subjects, mean values were reported for both testing days one and two.[62] The combined mean value for days one and two for the cross-over hop test was 369.85 cm; combined mean value for the timed hop test was 2.62 seconds.[62] Differences may be attributed to the physical condition of active duty military subjects in our study compared to the physical condition of the subjects in the study reported above; no information was reported regarding the subjects' levels of athleticism.[62] Gender differences between the 2 samples may also explain the difference in means. In a review of the research on hop tests; Fitzgerald et al[44] suggest that future research look specifically at gender-specific performance of landing and hopping. It is implied that there may be differences between men and women that contribute to functional stability.

In the clinical commentary mentioned above, Fitzgerald et al[44] reviewed the research that established hop tests as a physical performance measure of function, and specifically looked at the ability of these tests to predict dynamic knee stability. Based on previous research, they reported ICC values for the cross-over hop test for distance from 0.90 to 0.96 and reliability values for the 6 m timed hop test that ranged from 0.66 to 0.92. Amongst novice raters, we achieved good reliability for both of these tests with an ICC(2,3) of 0.93 for the cross-over hop test and 0.78 for the timed hop test. These high reliability values are also associated with low SEM values (eg, 0.19 seconds for the timed hop test), making it an appropriate test for determining change over time as it has the response stability required to detect change amongst a population.

Conclusion

Reliability measures can help guide which performance measures should be used in a military setting. Those tests with good reliability that may prove useful for measuring performance include all tests of trunk endurance, hip external rotation strength, the timed hop test, and the cross-over hop test. Those tests with moderate reliability that may prove less useful amongst our population include hip abduction strength, lateral step down, and flexibility of the hamstrings, quadriceps, soleus, and iliotibial band. The only measurement showing poor reliability was gastrocnemius flexibility, which could be attributable to a restriction in range of the underlying scores that could artificially underestimate reliability or the need to further standardize the assessment technique.

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Reducing the Public Health Risk of Cryptosporidiosis by Optimizing Treatment Processes at a Military Water System

Steven H. Clarke, PE

ABSTRACT

Safe drinking water supplies are critical to public health and mission success. One of the primary goals of water treatment is to effectively reduce the acute health risks posed by pathogenic microorganisms present in our raw, untreated water supplies. As a result of recent drinking water regulations, a military water system identified significant levels of *Cryptosporidium* in their raw water supply requiring additional or improved treatment to remove. *Cryptosporidium*, the pathogenic microorganism that causes Cryptosporidiosis, has been indicated in numerous waterborne outbreaks worldwide, including the United States. The US Army Public Health Command conducted a year-long study evaluating the ability of the water system to provide improved treatment by optimizing the existing treatment processes. Study results show that optimizing existing treatment processes and switching to an alternative coagulant chemical will achieve the *Cryptosporidium* removal required to comply with drinking water regulations, with subsequent reduction in the risk of Cryptosporidiosis. These improvements will also ensure effective treatment in all raw water quality conditions and reduce overall chemical costs without increasing operational and maintenance burdens. The optimization evaluation and techniques used for this water system can be applied to all military-owned water systems to help ensure the protection of public health and mission success.

INTRODUCTION

The microbial pathogen *Cryptosporidium* presents a significant public health threat. *Cryptosporidium* causes Cryptosporidiosis, a diarrheal disease with symptoms of dehydration, weight loss, abdominal pain, fever, nausea, and vomiting lasting up to 2 weeks.[1] While not usually fatal in healthy individuals, the disease can be incapacitating, preventing those sickened from performing their duties. In addition to being a public health threat, *Cryptosporidium* represents a significant threat to mission readiness.

The protozoan *Cryptosporidium* is found in waters throughout the United States and worldwide. It is more commonly found in untreated surface waters (rivers, streams, lakes), but has been found in groundwater (well water), mostly as a result of poorly constructed or damaged wells allowing the entrance of contaminated surface water.[2] Numerous drinking-water associated cryptosporidiosis outbreaks have been documented. The Centers for Disease Control and Prevention reported that *Cryptosporidium* has caused 13 drinking-water associated outbreaks in the US since 1988.[3] In the United Kingdom, 25 drinking-water disease outbreaks were attributed to *Cryptosporidium* from 1988 through 1998.[4] Most recently, in November 2010, the Swedish town of Ostersund suffered a drinking-water–associated outbreak caused by *Cryptosporidium*, reportedly sickening at least 160 people.[5] The most well known is the largest *Cryptosporidium* outbreak in US history; Milwaukee, Wisconsin, 1993. Over 400,000 persons were sickened and approximately 100 deaths were attributed to this outbreak.[2,6]

The 1993 Milwaukee outbreak was caused by inadequate drinking water treatment in conjunction with significant rainfall and subsequent runoff leading to increased levels of *Cryptosporidium* in the source (raw) water.[7] Drinking water treatment for microbial pathogens, including *Cryptosporidium*, generally consists of disinfection and filtration. Disinfection using chlorine is the most common drinking water treatment process used for controlling pathogens in both surface and groundwaters. The majority of military water systems use chlorine for disinfection. While chlorine disinfection is effective against most microbial pathogens, it is not effective against *Cryptosporidium*. Alternative disinfectants, such as ultraviolet light (UV), ozone, and chlorine dioxide are generally effective, but are not as widely used. The

filtration process typically used in treating surface waters involves several steps: coagulation, flocculation, sedimentation, and filtration.[2] Coagulation is the process of conditioning the particles (eg, dirt, microbes) in the water to more easily remove them. Coagulation is accomplished by rapidly mixing a coagulant chemical such as aluminum sulfate (alum) into the water. Flocculation is the process of producing large clumps of conditioned particles called "floc." This is accomplished in basins with stirring equipment (eg, paddles or blades) that provide slow, gentle mixing which allows the conditioned particles to collide and stick together to form floc. Sedimentation is the stage during which the resulting floc settles out of suspension. This is accomplished in large basins with slow water velocities that allow the floc to sink. The final stage is filtration during which any remaining small floc is removed. Filters typically consist of a granular media such as sand or a dual media of sand and anthracite coal.

Determination of the effectiveness of filtration treatment for *Cryptosporidium* is not based on testing treated water specifically for *Cryptosporidium*. *Cryptosporidium* analysis requires the collection and shipment of samples to an approved laboratory for analysis at a cost of about $500 per sample. Because of the time and cost involved, an alternative measurement is necessary to continuously ensure water is adequately treated. This is done by measuring turbidity, the level of opaqueness of the water. It is measured in Nephelometric Turbidity Units (NTUs). To provide a perspective, 5 NTU water is generally clear to the naked eye, while 20 NTU water is slightly cloudy. Measuring turbidity is easily accomplished at a water treatment plant and can be performed instantaneously. Research has shown that treating water to very low turbidities (ie, less than 1 NTU) correlates to increased microbial pathogen removal (ie, cysts, viruses).[8] Thus, measurement of turbidity is an effective surrogate test and is used to determine the effectiveness of filtration treatment for *Cryptosporidium*.

The 1993 Milwaukee outbreak was a major event that prompted the regulation of *Cryptosporidium* in drinking water in the United States. The Safe Drinking Water Act of 1974 (42 USC §300f) governs regulated drinking water systems in the United States. The law required the US Environmental Protection Agency (EPA) to develop regulations to reduce the likelihood of a cryptosporidiosis outbreak. In response, the EPA developed a series of regulations to control *Cryptosporidium*, culminating with the most recent Long Term 2 Enhanced Surface Water Treatment Rule (LT2 rule). The LT2 rule specifies the amount of treatment or other protective action necessary for a water system to reduce the risk of an outbreak. Water systems must conduct monitoring of their source water for *Cryptosporidium* and, depending on how much is detected, must provide a certain level of treatment or implement other protective actions to minimize the risk of an outbreak. The improvement of existing treatment processes to provide very low turbidity water (0.15 NTU or less), additional treatment processes such as UV light or ozone, and the implementation of source water protection activities are some of the treatment and protective actions available which reduce the risk of an outbreak.

The US military has numerous water systems that must comply with the LT2 rule. In the United States, the Army has 19 water systems that must be in compliance. While that is not very many systems, they serve over 300,000 persons on a daily basis. With so many Warfighters, family members, and civilians who could be potentially exposed, controlling *Cryptosporidium* in drinking water is a significant public health and mission-readiness issue. This article describes the process of addressing the risk of *Cryptosporidium* to an existing military water system serving an Army facility in the United States. It details the discovery of problem levels in the source water for that system, the examination of the various treatment process options available to address the risk, and the evaluation of those options against the existing equipment and facilities from the perspectives of cost effectiveness and, most important, reduction of the health risk to the water consumers.

BACKGROUND

In compliance with the LT2 rule, the US Army Public Health Command (APHC) conducted source water monitoring for *Cryptosporidium* from 2007 through 2009. The survey detected the presence of *Cryptosporidium* in river water which is the source for a military water system in the United States. The levels were such that additional treatment or other actions by the water system were required to reduce the risk of an outbreak. Of all the options available under the LT2 rule to reduce the *Cryptosporidium* risk, two were immediately chosen for evaluation as the least costly

options, as well as not imparting any significant additional operational burdens, and not posing any increased safety risk to the WTP operators. These options were optimized combined filter performance and optimized individual filter performance. To comply with the LT2 rule, the water system would have to consistently meet both options. Meeting these options required the WTP to produce very low filtered-water turbidity levels. Providing optimized combined filter performance requires the combined filter effluent (the measured effluent turbidity of all operating filters) to be less than or equal to 0.15 NTU at least 95% of the time each month. Two criteria must be met to successfully provide optimized individual filter performance: individual filter effluent turbidity (the measured effluent turbidity of each operating filter) must be less than 0.15 NTU in at least 95% of the maximum daily turbidity values for each filter every month; and no individual filter may have a measured turbidity greater than 0.3 NTU in 2 consecutive 15-minute measurements each month.[9] These are stringent criteria. Effectively meeting the optimized filter performance options not only requires that the WTP filters be optimally operated, but that all upstream treatment processes are also performing optimally (ie, coagulation, flocculation, and sedimentation). Filtration performance is directly affected by the performance of the upstream treatment processes. If any of those processes are functioning poorly, filtration performance will be adversely affected.

The concerned military water system was originally constructed in the late 1940s and modified over the next 3 decades. The system's water treatment plant (WTP) is capable of producing 4.25 million gallons per day (MGD) and currently produces an average of just over one MGD. Treatment consists of coagulation, flocculation, sedimentation, filtration, disinfection with chlorine, fluoridation for reducing dental caries, and corrosion control to minimize lead and copper leaching. Prechlorination (addition of chlorine to the raw source water) is practiced to control algae. Powdered activated carbon is added to control adverse tastes and odors, and alum and sodium aluminate are used for coagulation. During winter months, a polymer is added to improve coagulation and flocculation of the cold water. Lime is added to adjust pH and add alkalinity for effective corrosion control. Figure 1 presents a schematic of the WTP.

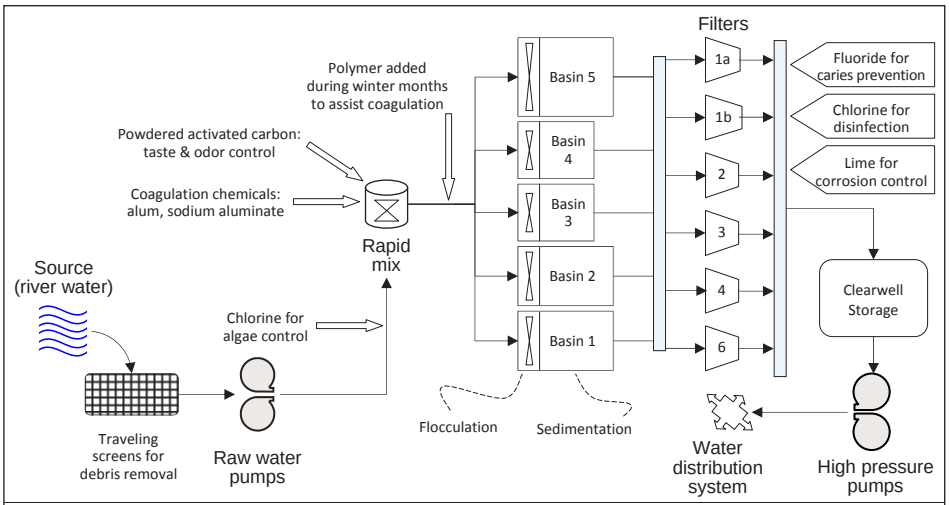

Figure 1. Functional schematic of the flow path and treatment stages of the water treatment plant.

To evaluate the feasibility of complying with the 2 selected treatment options, existing WTP turbidity data from 2008 and 2009 was compared to optimized filter performance criteria. Figure 2 shows how the WTP currently compares to the combined filter performance criteria. Table 1 and Figure 3 show how the WTP currently compares to the individual filter performance criteria. The data show that the WTP as currently operated is meeting the optimized filter performance criteria most of the time, but not on the consistent basis necessary for compliance. The data shows that consistently meeting the criteria can be a feasible approach for LT2 rule compliance.

Table 1. Months (red tint) during which tests indicated that individual filter turbidity performance exceeded the maximum filter criteria (samples taken during the month must not exceed 0.3 NTU in 2 consecutive measurements).

January 2008	July 2008	January 2009	July 2009
February 2008	August 2008	February 2009	August 2009
March 2008	September 2008	March 2009	September 2009
April 2008	October 2008	April 2009	October 2009
May 2008	November 2008	May 2009	November 2009
June 2008	December 2008	June 2009	December 2009

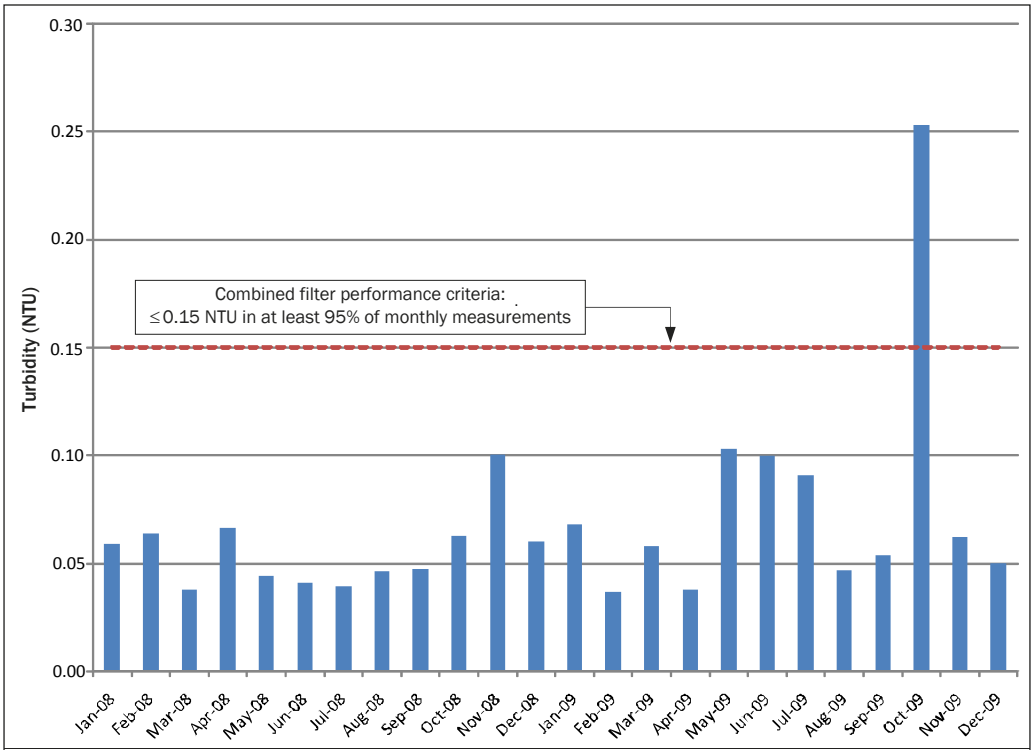

Figure 2. Combined filter turbidity performance plotted against combined filter turbidity criteria.

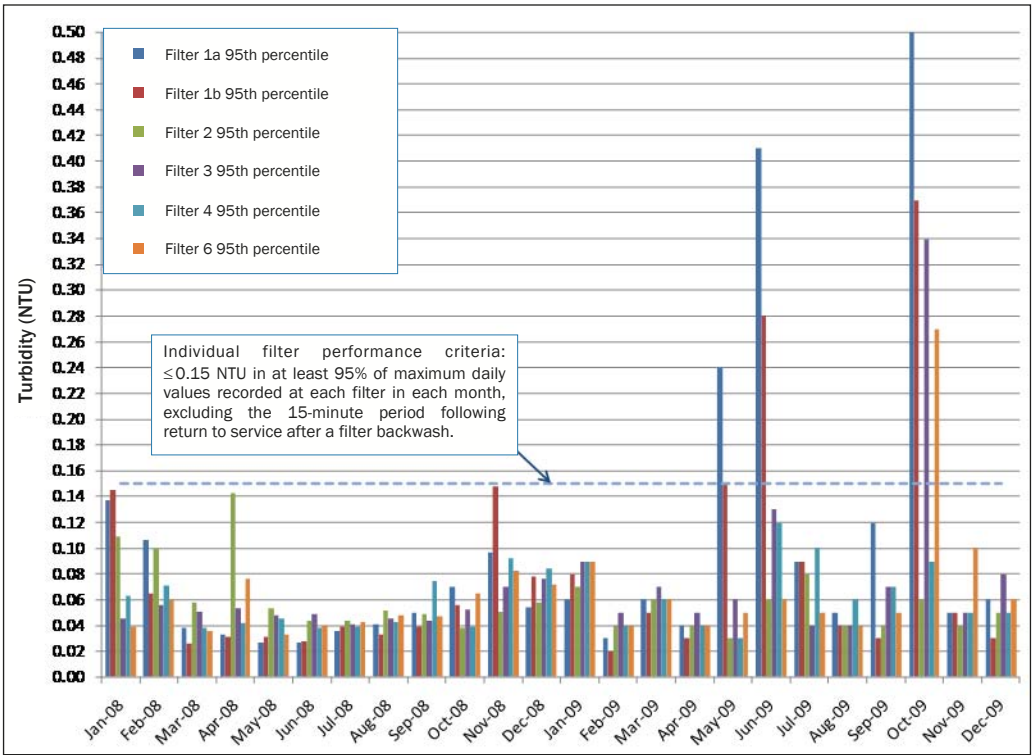

Figure 3. Individual filter turbidity performance plotted against 95th percentile individual filter turbidity criteria.

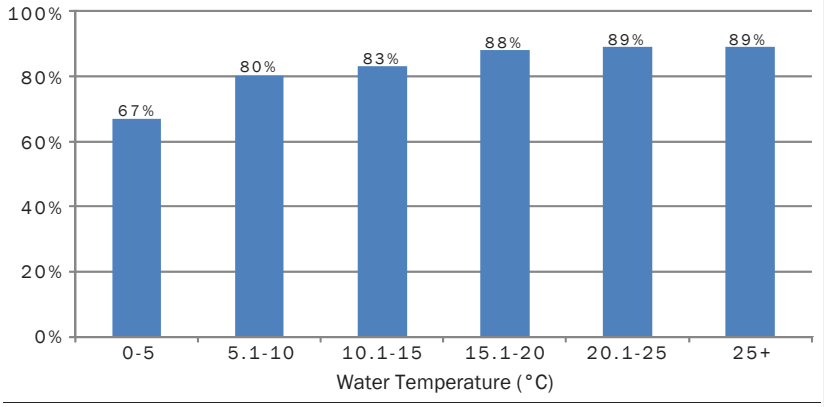

Figure 4. Water treatment plant turbidity removal efficiency at various water temperatures.

A significant secondary benefit that can be realized by meeting these filter performance options is improved treatment of very cold water. The WTP has a history of difficulty in treating very cold water. The frequency distribution chart in Figure 4 shows reduced treatment efficiency when water is very cold. In the 0°C to 5°C range, turbidity removal averaged only 67% through coagulation, flocculation, and sedimentation treatment processes, versus 80% to 89% turbidity removal when treating warmer water. Optimizing the WTP to meet the filter performance options to comply with the LT2 rule will also improve cold water performance.

Treatment Process Optimization

The APHC evaluated the WTP to identify deficiencies in the design or operation of the treatment processes and provided recommendations to optimize their performance. The APHC project officers used a water system performance evaluation (WSPE) protocol developed by APHC. The WSPE protocol is based on the EPA's Composite Correction Program, used by regulatory agencies and water systems to ensure compliance with microbial pathogen-related regulations.[10] The WSPE protocol contains procedures to evaluate treatment processes and a water system's ability to comply with existing and even future regulations (ie, the LT2 rule). Any recommendations for correcting identified deficiencies and optimize treatment performance are prioritized according to the health risk to consumers. Recommendations ensuring the greatest benefit for health protection receive the highest priority. The WSPE protocol can be applied to any water system.

With a focus on compliance with the LT2 rule and minimizing the risk of *Cryptosporidium* in the drinking water, the APHC project officers identified 2 main treatment deficiencies among other minor findings that hindered optimal performance of the WTP. They were the flocculation treatment process and flow distribution through the WTP.

Flocculation

The WTP has 5 combined flocculation and sedimentation basins in 3 different sizes: two small basins, each about 100,000 gal in volume (basins 3 and 4 in Figure 1); two larger 200,000 gal basins (basins 1 and 2); and one 250,000 gal basin (basin 5). The flocculation treatment process in each basin is

Figure 5. Flocculation chamber of basin 1.

Figure 6. Sedimentation chamber of basin 2.

separated from the sedimentation treatment process by a baffle wall made of either brick or fiberglass planks. Figures 5 and 6 show emptied flocculation and sedimentation portions of basins 1 and 2, respectively. The WTP operators have long known that sedimentation effluent turbidities from one of the two larger flocculation and sedimentation basins (basin 2 in Figure 1) were always higher than effluent turbidities from other flocculation and sedimentation basins. Sedimentation effluent turbidity samples were taken and showed turbidities in the poorly performing basin 48% to 71% higher than the other basin turbidities. The higher turbidities indicate inadequate performance of the sedimentation and/or the flocculation process. Since the sedimentation process for the poorly performing basin was identical to its twin 200,000 gal basin, the focus shifted to the flocculation treatment process.

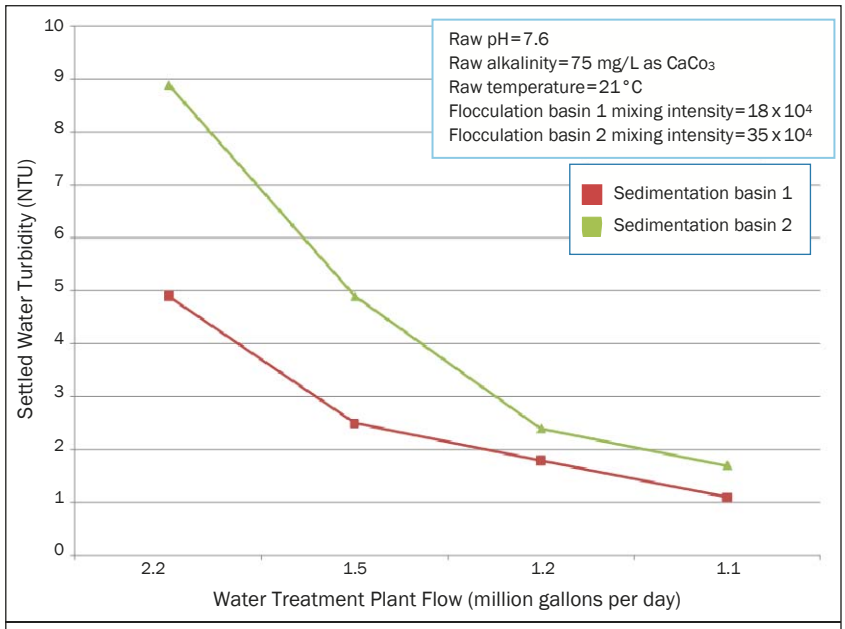

Figure 8. Jar test simulating basin 1 and basin 2 turbidity removal performance.

The single major factor distinguishing the flocculation process of the poorly performing basin was the amount, or intensity, of mixing occurring. The rotational speed of the mixing equipment in the flocculation basin was 44% faster than the other flocculation basins (3.6 rpm, versus 2.5 rpm). The mixing energy, or mixing intensity provided by this faster rotation is well above the industry recommended range. Mixing intensity is expressed in terms of energy input by the stirring equipment (G, seconds$\times 10^{-1}$) multiplied by the amount of time water remains in the basin (ie, detention time (t), seconds). The recommended mixing intensity range (G$\times$t, unitless) for optimal floc formation is 3×10^4 to 20×10^4.[11] The mixing intensity provided by the poorly performing basin was 35×10^4 compared to the other basins mixing intensities of 16×10^4 to 20×10^4. The higher mixing intensity results in poor floc formation and subsequent poor sedimentation as evidenced by the higher sedimentation effluent turbidities.

Figure 7. A jar tester assembly.

Bench-scale jar testing was conducted to verify that mixing intensity was the cause of the poorly performing basin. Jar testing is an effective method of optimizing treatment operations.[12] A jar test is designed to simulate the coagulation, flocculation, and sedimentation treatment processes at a WTP. Figure 7 is a picture of the jar test apparatus used for this project. Water samples were collected from the rapid mix basin and 2 tests were performed simultaneously to simulate flocculation and sedimentation in the 2 large 200,000 gal basins at the different mixing intensities (basins 1 and 2 in Figure 1). The test was designed to simulate the WTP at a flow of 1.5 MGD (the flow through the WTP at the time of jar testing). Jar test samples were collected after various periods of settling to reflect not only the current WTP flow (1.5 MGD), but also to reflect performance at other flowrates. Results are shown in Figure 8. For each flowrate the settled water turbidities (representing sedimentation effluent turbidity) are consistently higher in the basin 2 samples, indicating poorer

performance. This confirms that the higher mixing intensity is excessive and creates floc that does not easily settle. Not only does this degrade sedimentation performance, it can degrade filtration performance due to increased solids loading.

Reducing mixing intensity will improve flocculation and sedimentation performance in the poorly performing basin. The easiest and least costly way to accomplish this is to slow down the rotational speed of the mixing equipment by installing a variable frequency drive (VFD) on the flocculator motor. At a cost of about $1,200, this is a minor expense that will improve treatment. Going further, installing VFDs on all basin flocculator motors will improve overall treatment. Recommended mixing intensities will change depending on water temperature. The availability of infinitely adjustable rotational speeds allows WTP operators to fine-tune flocculation performance.

Flow Distribution

Proper flow distribution helps ensure optimal performance for all treatment processes. Flow distribution through the WTP is difficult to maintain. Proper flow distribution requires proportional flow splitting to the flocculation/sedimentation basins and filters to help provide optimal treatment. There are 3 separate inlet pipes, one leading to basins 1 and 2, one leading to basins 3 and 4, and one leading to basin 5 (see Figure 1). Operators must manually adjust valves in these pipes to regulate flows to each basin with the goal of maintaining equal water levels, providing proportional flow to each basin and thus, proper flow distribution. Adding to this difficulty is filter operation practices. Effluent from the sedimentation basins is combined into a common pipe with multiple outlets, one to each filter. Depending on which filters are operating, the greatest amount of flow to the operating filters will be from the basins closest to those filters. The basins furthest away from the operating filters will back up and flood the outlet weir, adversely affecting performance, causing greater floc carryover and higher settled water turbidities.[12] An expensive capital upgrade would be necessary to modify the inlet design to the basins and improve flow distribution. Instead, to improve flow distribution and overall treatment, filter operational practices should be modified to spread out filter operation, depending on which basins are operating.

Alternative Coagulant Evaluation

Addressing the 2 major and other minor findings will improve treatment. However, it may not be enough to provide consistent compliance with the LT2 rule *Cryptosporidium* removal requirements and provide effective treatment of very cold water. Switching to an alternative coagulant may help further optimize treatment, ensuring consistent compliance. There are several coagulants that are proven to be more effective than alum (the primary coagulant in use) at reducing turbidity in different water qualities including very cold water. A more effective coagulant in conjunction with optimizing existing treatment processes would certainly ensure consistent LT2 rule compliance and treatment in very cold water.

Selected Evaluation Coagulants

Polyaluminum chloride (PACl), ferric chloride ($FeCl_3$), and ferric sulfate ($FeSO_4$) were the chemical coagulants chosen for evaluation. Coagulant samples were obtained from regional vendors. The 2 main criteria used for choosing which coagulants to evaluate were: the coagulant should perform well by itself when treating very cold water (ie, no secondary coagulant or polymer addition); and the coagulant should perform well when treating the range of raw water quality experienced throughout the year. The iron-based coagulants, ferric chloride and ferric sulfate, are well-known to be effective in treating very cold water as well as a wide range of water qualities.[13,14] PACl is also effective in treating very cold water, however, depending on the particular PACl product, its effectiveness is limited at higher pH.[13] PACl is also used by the majority of surface water treatment plants in the region where the military water system is located. One regional surface water WTP supervisor reiterated PACl's ability to perform well in very cold water and its reduced effectiveness at higher pH.

Coagulant Evaluation Procedure

Bench-scale jar testing was done to evaluate the alternative coagulants. Jar testing was performed throughout fiscal year 2010 to encompass seasonable water qualities including very cold water. Week-long onsite visits were made each month between February and August. Jar test conditions for coagulation, flocculation, and settling times were derived from current WTP operation. Jar tests were conducted to simulate WTP operation at 3 different flow scenarios:

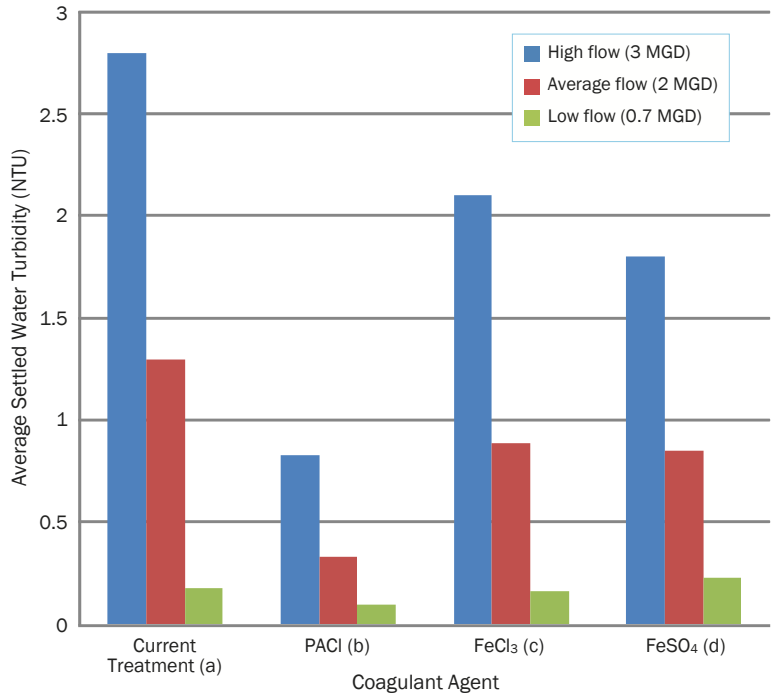

Figure 9. Results of cold water jar tests of coagulant agents at different flow rates.

Notes: Raw turbidity, 4.1-4.9 NTU
Raw pH, 7.7-7.8
Raw alkalinity, 82-89 mg/L as $CaCO_3$
Water temperature, 1°C-12°C
(a) Average=0.19 mmole Al
(b) Average=0.083 mmole Al
(c) Average=0.12 mmole Fe
(d) Average=0.18 mmole Fe

MGD indicates million gal/day. PACL indicates polyaluminum chloride. $FeCl_3$ indicates ferric chloride. $FeSO_4$ indicates ferric sulfate.

Table 2. The average turbidity removal percentages for the lab jar tests of coagulant agents. Specific data are provided in Figures 9 and 10.

	High Flow	Average Flow	Low Flow
Cold Water (a)			
Current Treatment	32%	46%	96%
PACl	83%	93%	98%
$FeCl_3$	53%	86%	97%
$FeSO_4$	59%	82%	95%
Seasonable Water (b)			
Current Treatment	53%	64%	94%
PACl	94%	97%	98%
$FeCl_3$	92%	93%	97%
$FeSO_4$	88%	89%	97%

(a) See Figure 9.
(b) See Figure 10.

0.7 MGD (estimated low flow), 2 MGD (estimated future average flow), and 3 MGD (estimated high flow). Alternative coagulant dosages were determined by conducting jar tests to identify optimum dosages for turbidity removal based on raw water quality at the time of testing. Alum, sodium aluminate, and polymer dosages were based on current WTP dosages. Cold water jar tests were conducted in February and March when water temperatures were below 6°C. During warmer months, raw water samples were iced down to about 1°C to 2°C for the beginning of each jar test.

Coagulant Performance Treating Cold Water

The PACl consistently performed best in the cold water jar tests. Figure 9 shows the average turbidities at the end of the jar tests representing settled water turbidities. Table 2 presents the average turbidity removal percentage for each flow scenario. Higher settled water turbidities correspond to lower percentage turbidity removal indicating poorer coagulant performance. All the alternative coagulants performed better than current treatment (ie, alum, sodium aluminate, and polymer addition) in the cold water tests, while PACl performed best in all scenarios, consistently producing the lowest settled water turbidities and removing the greatest percentage of turbidity. These results show that PACl is highly effective in treating very cold water and its use would enable the WTP to consistently achieve compliance with the LT2 rule filter performance criteria during the times of the year when the water is cold. Average coagulant dosages are also shown in Figure 9. Coagulant dosages are reported in molar concentration (mmole) of metal (either aluminum or iron) to allow equivalent comparison of dosages. Thus, a 1 mmole Al (aluminum) dosage is equivalent to 1 mmole Fe (iron) dosage. The PACl consistently performed better than all coagulants at about half the dosage; 0.083 mmole Al compared to 0.19 mmole Al for current treatment, 0.12 mmole Fe for ferric chloride, and 0.18 mmole Fe for ferric sulfate. In addition to improving turbidity removal, switching to PACl would result in less coagulant chemical use and less sludge production (discussed later).

Coagulant Performance Treating Seasonable Waters

All the alternative coagulants performed better than alum and sodium aluminate in treating warmer raw waters of different quality throughout the fiscal year (polymer is not added to warmer waters). PACl consistently performed best in the seasonal performance jar tests. Figure 10 shows the average settled water turbidities, and Table 2 presents the average percent turbidity removal for each flow scenario. Again, PACl produced the lowest settled water turbidities and removed the greatest percentage of turbidity in all flow scenarios. Switching to PACl would likely ensure filtered water turbidities would be well within both the LT2 rule combined and individual filter performance criteria when treating the different raw water qualities experienced at the WTP throughout the year.

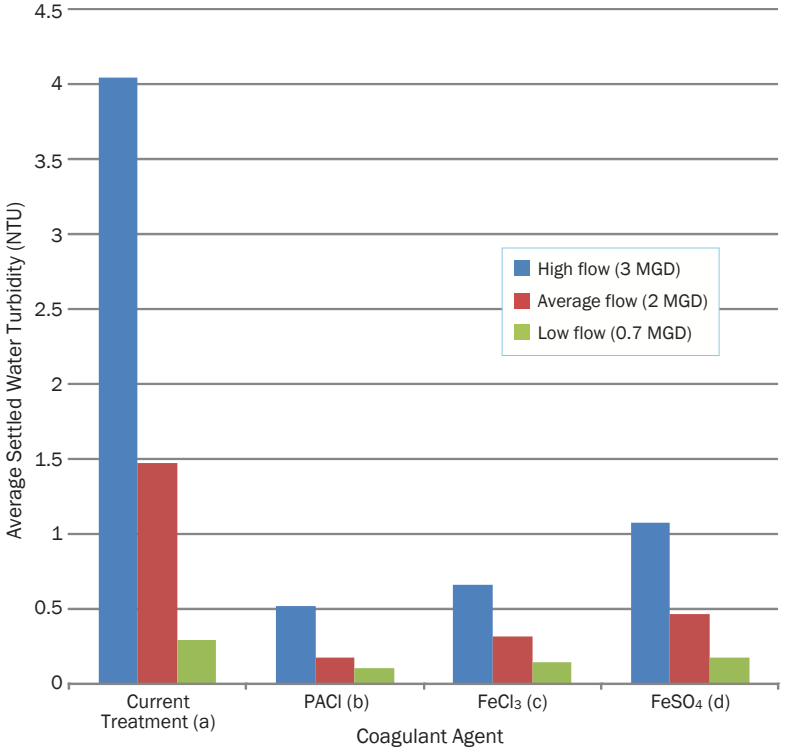

Figure 10. Results of seasonable water jar tests of coagulant agents at different flow rates.
Notes: Raw turbidity, 3.1-8.9 NTU
Raw pH, 7.6-8.5
Raw alkalinity, 76-94 mg/L as $CaCO_3$
Water temperature, 13°C-28°C
(a) Average=0.19 mmole Al
(b) Average=0.083 mmole Al
(c) Average=0.12 mmole Fe
(d) Average=0.18 mmole Fe
MGD indicates million gal/day. PACL indicates polyaluminum chloride. $FeCl_3$ indicates ferric chloride. $FeSO_4$ indicates ferric sulfate.

Effect of pH on Coagulant Performance

The pH of the water can affect the performance of all the coagulants evaluated. Typically alum performs best in the pH range of 5.5 to 8.0, while the iron-based coagulants perform best in a wider pH range of 4 to 9.[15] The effective range of PACl varies depending on the product formula—there are many different PACl formulations that have varying effective pH ranges. While some references describe the effective pH range of PACl as being 4.5 to 9.5, the regional manufacturer of the PACl product evaluated for this project indicated an effective pH range of 4 to 8.[13]. Experience at a regional WTP with a slightly different PACl product from the same manufacturer indicated PACl performance degradation above pH 8.0 to 8.2. The pH range of the WTP's source water is 6.8 to 9.1 based on daily records over the past 4 years. However, anecdotal evidence from the WTP operators indicates the pH range of the source water to be about 6.5 to 9.5. The primary reason for the high raw water pH is algal activity. Jar testing was conducted to evaluate the effect of pH on performance of the coagulants. Jar tests were conducted at pH levels of 6.5, 8.5, 9.0, 9.5, and 10. The pH of the water was increased using sodium hydroxide (NaOH) or decreased using sulfuric acid (H_2SO_4). Jar tests were conducted under the average flow scenario (2 MGD) conditions. Figure 11 shows the effect of pH on the chemical coagulants. The iron-based coagulants consistently reduced turbidity levels (less than 0.41 NTU) across the entire pH range. However, PACl generally reduced turbidity to even lower levels (less than 0.27 NTU), but only up to a pH of 9.0. Above 9.0, PACl settled water turbidities increased. Switching to PACl would require the addition of an acid to lower pH when raw water pH levels are greater than 9.0 to ensure adequate turbidity removal and subsequent compliance with the LT2 rule under all raw water quality conditions.

Addition of Carbon Dioxide

Acid addition at a WTP can be a significant operator safety issue. For example, sulfuric acid, a commonly

used acid for pH control, is extremely corrosive, which presents a safety issue to WTP operators and requirements for special storage and handling materials. For these reasons, sulfuric acid was not considered. Carbon dioxide was considered instead because it is safer to use than other acids and requires no special storage and handling materials. The dissolution of carbon dioxide into water and its subsequent hydration produces carbonic acid, a fairly strong acid.[16] Thus, carbon dioxide acts as an acid when added to water. A jar test was conducted to determine the effectiveness of carbon dioxide addition on pH adjustment and PACl performance. Figure 12 demonstrates the ability of carbon dioxide to adjust pH and shows PACl performance at different pH levels. Raw water samples were adjusted by adding sodium hydroxide (NaOH) to increase the pH to about 9.5, followed by carbon dioxide addition to achieve a starting pH of 7.5, 8.0, 9.0, or 9.5. The pH 9.5 sample had no carbon dioxide addition (it was only NaOH adjusted). Results show that carbon dioxide effectively reduced pH and PACl performance was similar to other jar tests (Figure 11) showing degraded performance only above a pH of 9.0. This indicates that carbon dioxide addition can be an effective way to lower pH in raw water when using PACl. Adding carbon dioxide at this WTP simply requires a storage tank, an injection point in the raw water pipes, and online flow and pH metering equipment to allow instantaneous, automated dosing. This process is safer than adding sulfuric acid and would add little additional operational burden for the WTP operators.

Sludge Production

Sludge consists of turbidity-causing materials (eg, microbial pathogens, organic and inorganic solids, algae) and the precipitated coagulant chemical. Generally, the use of chemical coagulants produces a significant amount of sludge (ie, tons per year), mostly due to the chemical coagulant itself. The quantity of sludge produced must be considered for each coagulant as they produce different amounts of sludge. Table 3 shows the estimated amounts of dry sludge produced by each coagulant, based on a flow of 2 MGD and an average raw water turbidity of 15 NTU from WTP records over the past 4 years. Average coagulant dosages for alum are based on WTP records and the alternative coagulant dosages are based on jar test data. PACl is estimated to produce the least amount of sludge, about 13 tons/year less than what current treatment (alum) produces. The iron-based coagulants would produce significantly more sludge. In addition to consistently outperforming the other chemical coagulants, another benefit of switching to PACl would be significantly less sludge production.

Annual Chemical Costs

Estimated annual chemical costs are shown in Table 4. Chemical costs for current treatment were based on actual usage and cost information. Post-lime feed costs for the alternative coagulants were based on estimated lime usage determined using the Rothberg, Tamburini, & Winsor Model for Water Process and Corrosion Chemistry, version 4.0 (RTW4) and average water quality conditions.[17] The PACl, compared to the other coagulants, has a minimal effect on pH and alkalinity (chemical coagulants act like acids depressing the pH and consuming alkalinity), thus requiring less lime to

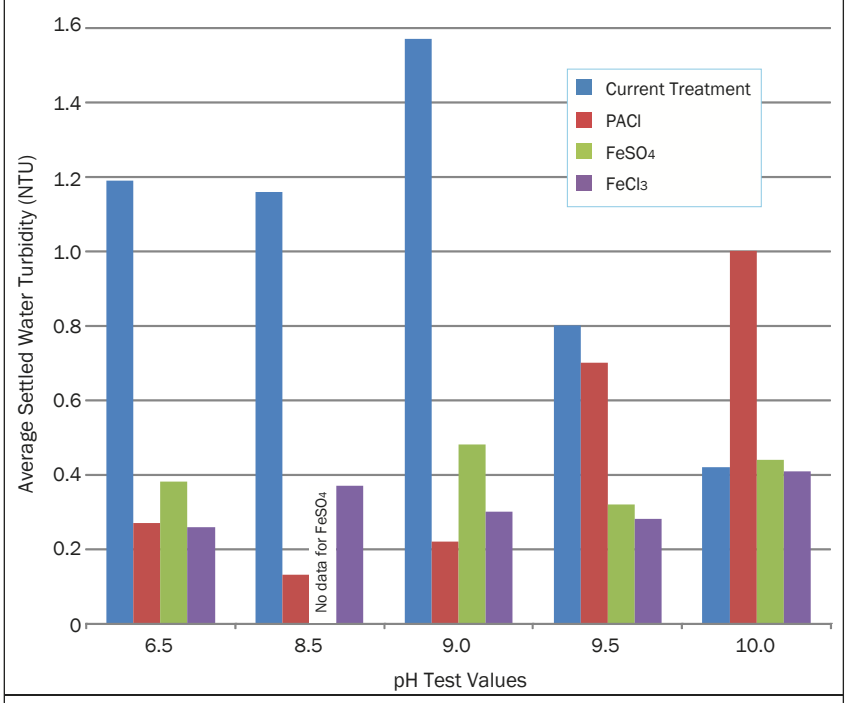

Figure 11. Effect of pH on coagulant performance.
Notes: Raw turbidity, 2.7-10 NTU
Raw alkalinity, 68-81 mg/L as $CaCO_3$
Water temperature, 14°C-29°C

achieve the desired finished water pH range of 7.8 to 8.0 necessary to minimize corrosion in the distribution system. Carbon dioxide costs are based on estimated annual usage (about 4,000 lb) determined using the RTW4 model. In addition to performing better than all coagulants tested and producing the least amount of sludge, switching to PACl would also result in an overall chemical cost savings.

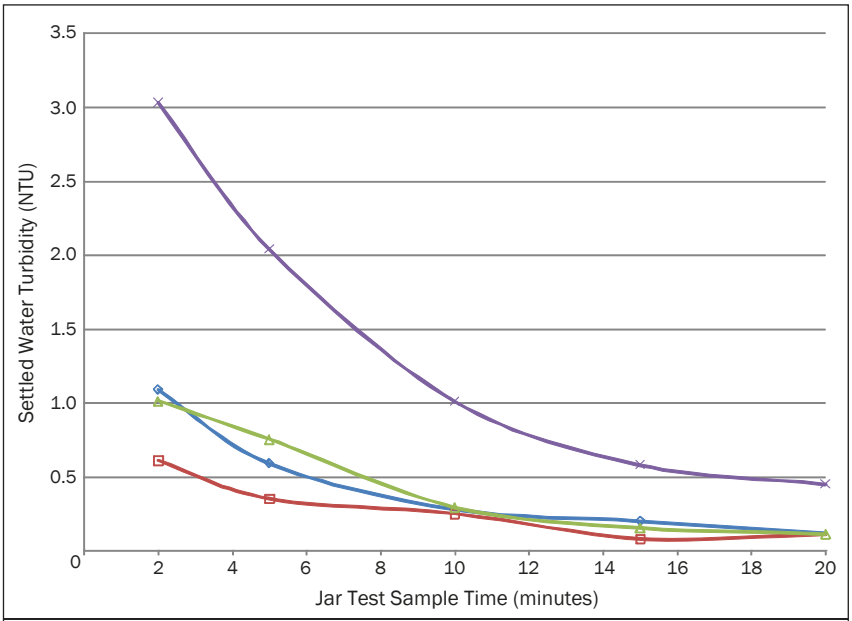

Figure 12. Effect of CO_2 on pH adjustment and PACl performance.
Notes: Raw turbidity, 2.8 NTU
PACl dosage, 0.073 mmole Al (35 mg/L PACl product)

Conclusions and Recommendations

Reducing the risk of a Cryptosporidiosis outbreak at this military installation requires compliance with the LT2 rule. To comply, the installation WTP must provide additional or improved treatment, or implement other specified protective actions. Additionally, treatment of very cold water must be improved. Optimizing existing treatment processes at the WTP will improve treatment. Using the WSPE protocol developed by the Army Public Health Command (Provisional), project officers identified several findings and recommendations to optimize existing treatment processes, including improving flocculation mixing intensities and flow distribution throughout the WTP. However, optimizing the existing treatment processes may not allow for consistent compliance with the LT2 rule as well as provide consistent cold water treatment. Three alternative coagulants were evaluated to determine if they might improve overall treatment allowing the WTP to consistently comply with the LT2 rule and provide consistent cold water treatment. The coagulants PACl, ferric chloride, and ferric sulfate were evaluated because of their generally recognized ability to perform better than alum in a wide variety of water qualities including very cold water. Jar test results showed that PACl performed the best, consistently removing the greatest percentage of turbidity and producing the lowest settled water turbidities. PACl's performance is degraded at higher pH (>9.0) in which case acid addition would be necessary to use it. Carbon dioxide was shown to be an effective acid. It is estimated that PACl would produce the least amount of sludge and would reduce annual chemical costs, even with the addition of carbon dioxide. These combined factors indicate that PACl is the best alternative coagulant and it is recommended that the WTP should switch to PACl. Replacing the 3 coagulants currently used (alum, sodium aluminate, and polymer) with PACl and carbon dioxide will result in improved performance, enabling consistent treatment and compliance, and ultimately further reduction in the risk of *Cryptosporidium* in the drinking water.

Table 3. Estimated sludge production of each coagulant.

Coagulant	Average Coagulant Dose (mg/L)	Coagulant Sludge Produced (tons/year)	Turbidity Sludge Produced (tons/year)	Total Sludge Produced (tons/year)
Current Treatment	46	46	60	106
PACl	40	33	60	93
$FeCl_3$	50	73	60	133
$FeSO_4$	50	90	60	150

Table 4. Estimated annual chemical costs ($ per year).

	Current Treatment	PACl	$FeCl_3$	$FeSO_4$
Coagulant	$70,000	$49,000	$43,000	$76,000
Post-Lime Addition	$13,000	$4,000	$11,000	$9,000
CO_2 Addition	NA	$4,000	NA	NA
TOTAL	$83,000	$57,000	$54,000	$85,000

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Adapting Military Field Water Supplies To The Asymmetric Battlefield

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Introduction

Since the initiation of Operation Iraqi Freedom (OIF) the US Army has rapidly transformed from a division-centric force designed to fight 2 major theater wars concurrently, to a brigade-centric force, expeditionary in nature, and ready to respond simultaneously to many conflicts worldwide. Our forces have become more agile and battlefield operations more asymmetric. This remarkable transformation has created appreciable gaps in both doctrine and materiel essential to adequately address the needs of our Warfighters on the battlefield. The typical longitudinal methods for timely and adequate provision and medical surveillance of life-sustaining drinking water must be reconsidered in light of the changed battlefield. The preventive medicine (PM) community, and specifically military field water sanitary control and surveillance, is focused on adapting to minimize the gaps between theater needs and PM support.

The increased and expansive use of commercial bottled water notwithstanding, from the early 1980s, potable field water producers have relied on large, over-engineered water purification systems based on the principle that employing a single robust technology that could turn any water, anywhere, including seawater, into safe drinking water, was the best solution. That mindset has continued with the recent development and deployment of more agile, state-of-the-art materiel using better technologies to produce greater volumes of safe water from similar or reduced footprints. Preventive medicine responsibilities for the surveillance and certification of field water prior to consumption, as presented in current doctrine[1] has been adapted to keep pace with emerging bulk water materiel. As such, bulk water continues to be safe, and most often, plentiful on the battlefield.

The focus of this article is on what lies ahead. Army transformation has distributed Warfighters into smaller numbers across more locations than ever. The PM community is responding to these challenges through a change towards a quasi–risk-based approach where, while bulk water production and doctrine-based surveillance will remain the norm, smaller-scale, decentralized water production will emerge, incorporating less robust treatment technologies and new deployment strategies.

Lifeblood of the Warfighter

Safe drinking water is an absolute necessity for health and well being, yet it is a scarce commodity in desert environments. Warfighters conducting operations in hot desert environments may need to drink 15 L or more of water a day to maintain acceptable levels of hydration. Without sufficient quantities of safe water, dehydration will quickly lead to loss of physical and mental capacity and degrade or create a total loss of mission performance. Individual requirements differ among personnel, and are affected by a number of variables. The time of day and related ambient temperature, the uniforms they wear, the amount of gear they must carry, their levels of activity, and acclimatization all play roles in the amount of water needed to stay hydrated. The US Army Combined Arms Support Command Water Planning Guide[2] specifies the need for over 15 gal (57 L) of potable water per person per day to sustain the force in arid environments. This quantity comes at great expense on personnel, transportation and logistics, and monetary expenditures.

A Brief History of US Army Field Water Supplies

In all of the wars in which the US was engaged up to and through the Spanish American War (1898), each Soldier was responsible for obtaining his own water in

the field.[3] In World War I (1914-1918), as many as 400,000 men occupied an area of 20 to 25 square miles, making local supplies insufficient. As a result, the first military field water treatment systems were developed. Engineer water supply regiments were formed and given the responsibility to procure water from the rear and haul it forward to the troops in 110-gal mule-drawn carts. Unit-level water treatment equipment at the time consisted of "Lyster bags," heavy canvas bags that were hung off the ground using timber tripods as shown in Figure 1.[4] The open top of the bag allowed Soldiers to add calcium hypochlorite powder for disinfection, and instructions suggested finding a clean stick to stir the disinfectant into the water.

By 1949, the Army began developing mobile water treatment systems to be mounted on trailers and trucks to meet the needs of the modern mobile field Army. The work resulted in the production of the Army mobile water purification unit series of equipment with treatment consisting of coagulation, filtration, and disinfection (Figure 2). Later purification units employed a novel upflow clarifier, colloquially dubbed the "ERDL-ator" (Engineering Research and Development Laboratory -ator), that included a suspended sludge blanket for particulate matter reduction. They were the primary equipment sets used by the Army during the Korean and Vietnam conflicts.

Figure 1. WWI-era Army unit-level Lyster bags.

The uncertainty associated with military operations and the types of water sources that might be encountered in future operations in diverse areas of the world made it difficult to preselect which water purification equipment to take on a particular deployment. In response, the Army began investigating other technologies, looking for a single system that could treat any water source that might be encountered anywhere in the world.[5] This led to the development of the Army's reverse osmosis water purification units (ROWPUs) which continue to be the standard for Army field water treatment systems.

Current US Army Reverse Osmosis Water Purification Units

The first Army tactical ROWPU was designed to produce treated water at the rate of 600 gal per hour (gph) from seawater or 900 gph from fresh water. The model, shown in Figure 3, was first produced in 1979, and, with some modifications, is still in use today. The unit package is mounted on a 5-ton trailer, powered by a 30 kW generator, and includes three 3,000-gal collapsible fabric tanks. Treatment centers around coagulation and prefiltration followed by high pressure reverse osmosis membranes and calcium hypochlorite solution injection. The system over-pack includes add-on activated carbon and ion exchange filters for use when chemical, biological, or radiological warfare agent contamination is suspected. A 3,000-gph (fresh water) ROWPU (2000-gph seawater) was introduced in 1987. It is essentially a larger version of the 600-gph ROWPU and was the most commonly used military water treatment unit at large base camps in Iraq.

Two newer systems recently brought into the inventory incorporate semiautomated operation, energy recovery, and membrane prefiltration in an effort to provide better quality feed water to the reverse osmosis elements. The state-of-the-art tactical water purification system (Figure 4) produces 1500 gph from freshwater, 1200 gph from seawater, and is being fielded as a 1-for-2 replacement for the 600-gph ROWPUs. The smaller 4-module lightweight water purifier (Figure 5) can be packed in the back of a

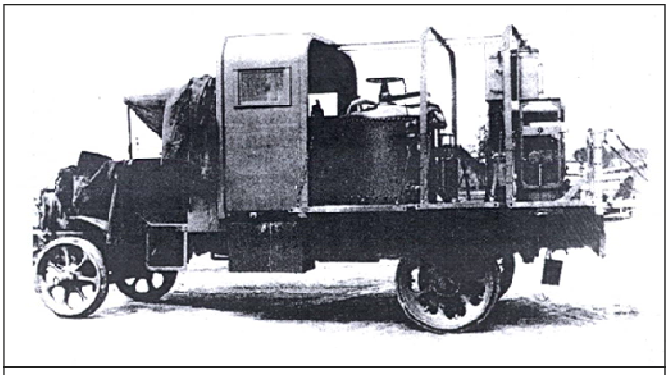

Figure 2. Early Army mobile water purification unit.

Figure 3. Army 600-gph trailer-mounted ROWPU.

HMMWV (high mobility multipurpose wheeled vehicle), and hand carried and set up by 4 strong Soldiers. It produces 125 gph from freshwater, 75 gph from seawater. Correctly maintained, Quartermaster-operated, and PM-surveyed, the Army's ROWPUs produce high quality drinking water that meets the Department of Defense (DoD) Military Field Water Standards and ensures Warfighters will not become sick as a result of consuming microorganisms or chemicals in the water they drink.

Water Storage and Distribution

Once water is produced on the battlefield, storage and distribution equipment maintain water quality after production and prior to consumption, and allow transport of water from production points to forward locations.

The US Army fields multiple bulk-water storage containers and tanks ranging in capacity from 5 to 50,000 gal. Larger storage tanks from the potable water storage and distribution system may consist of a combination of 20,000- and 50,000-gal fabric bags connected with fabric piping at potable water production points to form a "tank farm." The forward area water point supply system (FAWPSS) is a portable, self contained gas- or diesel-powered system consisting of 500-gal storage drums and a 125-gal/minute pump. Designed for various contingency operations, combining the FAWPSS with the tactical water distribution system, a highly mobile fabric piping water distribution system, creates complete, forward-deployable water storage and distribution.

Figure 5. Army lightweight water purifier.

Figure 4. Army tactical water purification system.

Transporting water to other bases and smaller tactical locations is accomplished using tank trucks and water trailers. Older semitrailer-mounted fabric tanks requiring transport either completely full or empty are being replaced by next generation, hard-sided, baffled tanks such as the load handling system water tank rack (hippo). The hippo is a 2,000 gal stainless steel tank, transportable filled, partially filled, or empty, and contains a recirculation pump. Replacing the 400-gal unit-sized trailers, termed "water buffaloes," are 900-gal unit water pod systems (camels) mounted on M1095 trailers for better road and off-road transportability. Under development is an integrated thermal regulating capability for the camel which will heat water to prevent freezing, and chill water to improve its palatability in hot environments.

Field Water Doctrine

Preventive medicine is doctrinally mandated to "provide the medical oversight of field water supply operations for the prevention of waterborne diseases".[6] *Technical Bulletin MED 577*[1] describes current doctrinal requirements for the PM oversight of all aspects and components of field water including source, production, storage, distribution, and point of use.

The primary concept employed by the military to provide safe field water is termed a "multiple barrier" approach. The approach consists of 5 barriers to water contaminants that could cause adverse health effects if they are consumed:

1. source water selection and protection,
2. water treatment,
3. disinfection,
4. proper operation and maintenance of storage and distribution systems, and
5. operational water quality monitoring.

While PM assets primarily focus on barrier 5, all are critical and PM may have involvement and oversight of all 5 barriers.

Through robust water treatment technology and routine monitoring, the bulk water produced on the battlefield rivals municipal supplies in the United States. Army Engineers support the development of water sources, such as well drilling; highly-trained Quartermaster personnel (Military Occupational Specialty 92W) operate military ROWPUs and monitor the water quality and disinfection residuals during water production; and PM personnel provide oversight to the entire field water production, storage, and distribution process. Vital to PM oversight are the unit-level field sanitation teams (FSTs), non-PM assets that provide daily disinfectant residual monitoring and equipment oversight. The integration of Engineers, Quartermaster, PM, and FST assets has been the approach used for safe water production since the 1970s, and has proven itself as an effective collaborative effort.

PREVENTIVE MEDICINE RESPONSIBILITIES

Preventive medicine personnel must have a good understanding of what a field water supply system comprises (from source to tap) in order to provide effective water quality surveillance and the understanding to solve problems when they arise. Preventive medicine personnel and Army Engineers are involved in the evaluation and selection of a water source. Whether ground, surface, or host nation, potential water sources are assessed and their quality analyzed to select those with the lowest health risk. When conditions allow, waters deemed contaminated or vulnerable to threats, intentional or otherwise, may be passed over for lower risk sources. Once the source is selected, Quartermaster personnel prepare and operate the ROWPU, then PM certifies potability prior to distribution for consumption. The multitude of PM surveillance responsibilities is shown in the Table. Routine inspections cover water production, storage and distribution, bottled water, shower points, and advanced testing of untreated and treated water.

Inspection Frequencies During Deployments.

Equipment or Activity	Responsible Agent	Frequency	Notes
Raw water sources	PM	Initial only	annual sanitary survey, annual advanced water testing (AWT)
Water purification points*	PM	Monthly	semiannual AWT
Storage and distribution facilities	PM	Monthly	inspect and confirm free available chlorine (FAC) ≥ 1 mg/L
	FST†	Daily	confirm FAC ≥ 1 mg/L, semiannual disinfection
Bottled water storage	PM	Monthly	bacteriological testing of 10 bottles/lot until lot is exhausted
Unit potable water containers	PM	Monthly	inspect and confirm FAC ≥ 0.2 mg/L
	FST	Twice daily	confirm min FAC ≥ 0.2 mg/L, semiannual disinfection
Showers and personal sanitation points	PM	Monthly	inspect and confirm FAC ≥ 1 mg/L
	FST	Twice daily	inspect and confirm FAC ≥ 1 mg/L

*Military/contract water treatment operators monitor hourly for FAC (≥ 2 mg/L) and pH (5-9).
†FST duties may also be performed by trained contract owner/operator.

It is easy to imagine the strain that only routine water inspections place on PM assets, especially when added to other medical oversight responsibilities. A single PM team may have multiple water production points, dozens of shower points, each with storage tank and some with recycle systems, and hundreds of potable water tanks throughout their area of responsibility, all geographically dispersed throughout the battlefield. Despite the intense effort required by PM to successfully conduct doctrine-based water surveillance, Army transformation has created additional materiel gaps requiring PM evaluation and/or oversight to minimize health risks. The PM community is adapting to these changes at all support levels.

THE CHANGING BATTLEFIELD

Many current military operations lack the centralized characteristic of conventional warfare. The transformation to a more agile fighting force where Warfighters inhabit tactical, unit-sized forward operating bases (FOBs), smaller command outposts

(COPs), and safe-houses creates unique, never-before-encountered requirements for field water operations and surveillance. Both materiel and doctrinal requirements have failed to keep pace with the creation of distributed operations. Current medical assets on the battlefield are already stretched thin providing oversight on well-established bases, and are not able to monitor the production and distribution of field water operations at the unit level or in ultradistributed operations where several Warfighters consume local municipal supplies in safe houses. Many of the challenges facing "big Army" today were only relevant to Special Operations Forces during past conflicts.

Fielded water purification systems produce safe water from virtually any source, however, they require a large footprint, dedicated operators, and lack overall portability. The smallest, the HMMWV transportable, lightweight water purifier with a 125-gph production rate, is too large for many FOBs and COPs and, while mobile, is designed to be set up and operated at one location for extended periods of time. Mobile military units have had to rely on bottled water resupply to meet hydration and sanitation needs. Resupply of bottled water is expensive, convoys are often targeted by the enemy, and is counter to the creation of a sustainable force.

To date, water treatment at the individual level has been reserved primarily for emergency situations under SERE (survival, evasion, resistance, and escape) environments. To counter waterborne pathogen threats, iodine tablets have been fielded by the US military since the 1960s, and Chlor-floc, a flocculent and chlorine-based disinfectant, since the 1990s. These products provide limited efficacy against certain known pathogens and have been surpassed on the commercial market by newer treatment innovations, including membrane filtration, granular media sorbents, and ion exchange resins.

Commercial manufacturers noticed the materiel gap of small-scale water treatment devices and moved full-force to capture the military market. Currently, individuals and military units are purchasing nondoctrinally-approved water treatment equipment for individual and multiuser (10 to 50 personnel) operation, but have little more than manufacturer marketing materials on which to base purchasing decisions. The US Army Public Health Command (USAPHC) identified the need for oversight and proposed 2 projects to the Army Studies Program Management Office to survey and evaluate the ability of these commercial products to fill military materiel gaps. The USAPHC's position is that the mission-critical need to provide water treatment at the smaller scale must not create unnecessary health risks to the Warfighter.

Preventive Medicine Evaluation of the Commercial Water Treatment Market

To evaluate commercial individual water purifiers, the USAPHC convened user and technical subject matter expert panels to develop and score devices against evaluation criteria. While no formal laboratory testing was conducted, devices were researched and procured for hands-on evaluation. In most cases device technologies were well understood and evaluations were based on industry-standard technology capabilities. Incorporating the help of the Edgewood Chemical Biological Center Decision Analysis Team, a multiple-attribute decision model was created to score devices against weighted criteria, providing a summed hierarchy of devices. Accepted shortcomings of the model include an ever-changing commercial market of devices and criteria weights that may vary based on mission-specific needs. However, objective review of device capabilities laid the framework for further evaluation, leading to several valuable findings from the study:

- Within the commercial market, there is complete lack of oversight of device capability claims made by device manufacturers.
- Evaluating device capabilities based on manufacturer-stated technology alone will often lead to inaccurate conclusions.
- Laboratory testing of devices is paramount to understanding the true capabilities of devices and necessary to protect the health of Warfighters.

Mirroring the lessons learned for commercial individual water purification devices, USAPHC developed model criteria and evaluated the next size-class, small unit water purifiers (SUWPs), designed for unit-level deployment and ranging from suitcase to pallet-sized. The operation and quality oversight mission concept for SUWPs diverges from individual Warfighter responsibility to one parallel to that of military ROWPU operations. Only in this instance, the

unit lacks a qualified operator and programmed public health oversight.

PREVENTIVE MEDICINE DEVELOPMENT OF A SINGLE YARDSTICK

Burrows[7] highlighted the need for efficacy testing of water purification devices for individual Soldier use and the lack of a "suitable health-based protocol for such testing." As part of the original Army Studies project for individual water purifiers, it was proposed that a single testing "yardstick," similar to those of the American National Standards Institute or military standards, be developed to objectively evaluate the capabilities of water treatment devices. Previous testing protocols relevant to small-scale water treatment devices included those published by the US Environmental Protection Agency[8] (EPA) and NSF International (Ann Arbor, MI).[9] However, neither protocol met military evaluation needs, and, surprisingly, commercial products were often marketed as having passed the EPA protocol with absolutely no government oversight.

The USAPHC, in collaboration with NSF International, developed NSF Protocol P248,[10] which borrows heavily from the previous protocols for microbiological reduction performance criteria, then builds in important military specifications such as minimum treatment capacity and flow rate. Then, to provide strict control of protocol use, NSF P248 requires testing oversight by a government review agency who works with the test sponsor and laboratory to ensure testing sufficiently challenges device technology and demonstrates device capabilities. The USAPHC, currently acting as the government review agency, provides the final determination of compliance with NSF P248 to eliminate the loose interpretation and inaccurate compliance statements associated with previous testing protocols. NSF P248 has been adopted by US Army and Marine Corps combat developers as minimum performance criteria for waterborne pathogen reduction, and is endorsed by the Joint Medical Field Water Subgroup, a subgroup to the Joint Environmental Surveillance Working Group, which advises DoD Health Affairs.

PREVENTIVE MEDICINE SUPPORT TO FIELD WATER PACKAGING

Since the first Gulf War in 1990, bottled water has been provided to deployed personnel in increasing quantities from the US and from countries in and near areas of operations. Prior to that, virtually all the drinking water consumed by deployed personnel was produced in the field. This transition has occurred at great monetary cost and with a severe impact on transportation assets which must haul the bottles of water in competition with other important equipment, parts, and supplies. During current operations, at any given time, as much as 50 percent of transportation assets may be delivering bottled water. In an effort to continue the desirable use of bottled water, yet reduce the logistical impact and increase sustainability, the Army is turning to in-theater portable water bottling facilities to allow the military to produce, package, and distribute its own bottled water in areas of operations much closer to the consumers.

Commercial bottled water plants producing product for military use are inspected and approved by Army Veterinary Service (VS) personnel before being placed on an approved sources list. Periodic onsite sanitary inspections and sample analysis are performed by VS and approved sources lists are updated daily. Once bottled water is delivered, PM responsibilities begin. In contrast to commercial bottled water, bulk water produced and packaged in the field is termed "packaged field water," regardless of whether the container is a bottle or bag. It is the responsibility of PM to survey the bulk water production point that feeds the packaging system, as well as the packaging equipment and product water quality.

Packaged field water, or the expeditionary water packaging system (EWPS) as the materiel solution has been coined, remains in the development stages

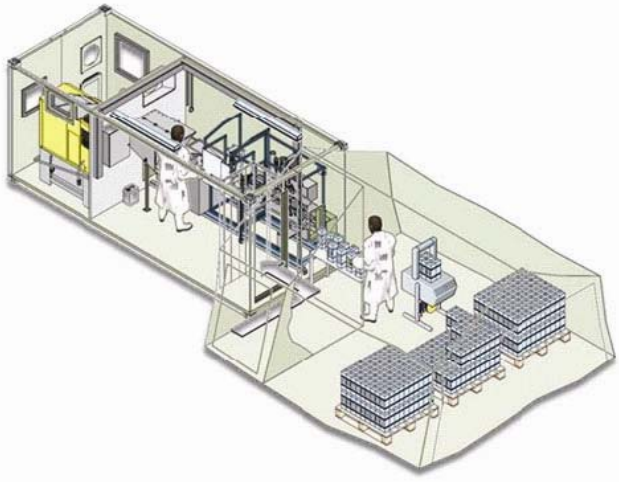

Figure 6. Concept of expeditionary water packaging system.

(Figure 6) in terms of the Army concept of employment and program of record materiel. The US Army Combined Arms Support Command (CASCOM) is currently developing requirements and, in a coordinated effort, the Army's Tank Automotive Research, Development, and Engineering Center (TARDEC) is conducting market research and technology comparisons of potential candidate technologies. Several EWPSs have been deployed to Afghanistan in support of Urgent Needs Statements, requiring level IV and V PM engagement due to the specialized skills required and undermanning of PM in theater. The CASCOM concept of employment has the EWPS resident at echelons above brigade, and will require PM surveillance not currently programmed. The USAPHC is working with CASCOM and TARDEC to ensure PM oversight is considered throughout the entire development process.

Adapting Preventive Medicine Oversight

The USAPHC, as the level V PM support activity, is charged with providing technical assistance and consultation to levels I to IV, as well as developing and maintaining doctrine to minimize health risks on the battlefield. The sanitary control and surveillance procedures for legacy-based equipment evolved from solid scientific and engineering principles developed over years of research, and various wartime efforts. However, realizing that theater-specific conditions may dictate unforeseen requirements, *Technical Bulletin MED 577*[1] is general in nature and encourages the development of local supplements to address specific situations or those not covered in sufficient detail. For example, the Multi-National Corps [Iraq] standard operating procedure[11] addresses PM involvement in contract oversight and reduces shower point inspections and tank super-chlorination frequencies.

Water sustainability and the demand of the current battlefield to produce potable water outside major basecamps is requiring level V PM to review how water purification equipment is developed and evaluated, and how potable water will be certified. Traditionally, the US military has relied on robust water treatment equipment to counter other areas of the multibarrier approach that may lack sophistication or be subject to threats in a battlefield environment. However, individual and small unit water purification equipment often lack the technically-sophisticated contaminant barriers of military-fielded ROWPUs, and therefore, intrinsically pose higher levels of health risk. Additionally, users of commercial equipment are not trained by the military in operating, monitoring, or troubleshooting the equipment. The employment of this water purification equipment may lack, or have seriously degraded, 3 or more of the 5 aspects of the multibarrier approach. Because materiel development is slow, the PM community is tasked with developing ad hoc operating procedures while balancing the immediate need from the battlefield to fill this gap with the mandate to minimize health risks to the Warfighter.

The requirements for new materiel are not expected to diminish and are by far the more common subjects of field consultations received by USAPHC rather than bulk water systems. To respond, USAPHC is working with various research, development, testing and evaluation (RDT&E) organizations and combat developers to create evaluation criteria based on sound principles for reducing health risk. For example, the employment of a small unit water purifier as a means of producing drinking water on the battlefield is not doctrinally-approved as it lacks operation by Quartermaster and oversight by PM to certify water potability. Increased health risks result from the absence of source water quality characterization, less robust treatment technology, and lack of formal military test and evaluation. These limitations may be countered somewhat by the short term consumption of product water from these devices by Warfighters, however, this may not always be the case. While this identified materiel gap is being developed into a formal program, USAPHC is working with representatives from various military services to create interim solutions. Key to these solutions is the recommendation to evaluate device capabilities to reduce acute microbial threats via testing to NSF P248[10] and further evaluation against short term potability standards identified in *Technical Bulletin MED 577*.[1] However, evaluating treatment equipment in a laboratory setting, or even through the Army Test and Evaluation Command, then neglecting the monitor responsibility in the field hardly instills the same confidence engendered by the thorough, time-proven treatment and monitoring techniques of bulk water supplies. This exemplifies the current situation in the field. Individuals and military units require alternative water supplies to bulk and commercially-bottled water. The PM community has realized the materiel gap and

responded by initiating device evaluation procedures and interim deployment strategies. However the PM community has not yet identified doctrinally-mandated solutions for the oversight of unit-level water production when trained operators and PM personnel are not available.

SUMMARY AND CONCLUSION

Army transformation to a brigade-centric force has created a distributed battlefield, challenging the surveillance and logistical supply of field water. The daily requirement of up to 15 gal of potable water per person per day from bulk water supplies has been achievable for many years using currently fielded ROWPUs. However, the need to reduce the transport of water and move towards a sustainable force has created a gap in materiel capable of producing safe water at the individual and unit level. While materiel development is slow, the PM community, tasked with doctrine development and battlefield oversight of field water, is beginning to address the requirements of field water on the changed battlefield. In addition to materiel gaps, the transformed battlefield has created a lack of trained personnel for water production and oversight. Without trained operators and PM oversight, to what level of health risk are consumers of this water exposing themselves? Currently PM is unable to answer this question but is working diligently with the RDT&E community to develop materiel solutions, and with the medical community to provide interim guidance to reduce the potential health risks to using such equipment.

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Improving Detection of Extended-Spectrum Beta-Lactamase-Producing Bacteria in a Deployed Setting

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ABSTRACT

Introduction: Organisms that produce extended-spectrum beta-lactamase (ESBL) are significant causes of infection among deployed service members. These specific organisms have increased resistance to several antibiotics, limiting the choice of therapy for the provider. Currently, the deployed microbiology lab uses, by default, the Siemens NBPC30 panel to identify and measure antibiotic susceptibility of gram-negative organisms. However, when an ESBL is suspected, additional confirmatory testing is performed, during which time the health care provider is forced to use broad spectrum antibiotics to protect the patient from infection. In this study, we evaluated the NBPC30 and NBC41 panels for their ability to rapidly and accurately detect ESBL-producing organisms.

Methods: Identification and antimicrobial susceptibility testing of 79 strains of Enterobacteriaceae isolated from patients treated at Ibn Sina tertiary hospital (Baghdad) were performed using the NBPC30 and NBC41 panels. These results were confirmed using a Kirby-Bauer disk diffusion reference method described by the Clinical Laboratory Standards Institute. Sensitivities and specificities of the panels were determined in relation to this reference method.

Results: Sensitivity and specificity of the NBC41 were 96.7% and 89%, while they were 86.7% and 72% for the NBPC30 panel. False positive and false negative rates were higher for the NBPC30 panel.

Conclusion: Our data shows that the NBC41 panel is superior to the NBPC30 panel in rapidly identifying ESBL-producing organisms. Use of the NBPC41 panel decreases the turnaround time by 24 hours, allowing the provider to more accurately apply appropriate antibiotic therapy. Additionally, the NBPC41 panel provides more useful antibiotic susceptibility results compared to the NBPC30. We recommend use of this panel as a primary identification and susceptibility panel for gram-negative organisms.

INTRODUCTION

Extended-spectrum beta-lactamase (ESBL) production in bacterial isolates is becoming a worldwide problem. ESBL-producing organisms have been associated with limited therapeutic treatment options due to their broad spectrum resistance to ureidopenicillin, third-generation cephalosporins, and aztreonam.[1,2] Furthermore, these organisms can have a severe impact in wound, burn and bloodstream infections, often resulting in adverse outcomes.[3-6] In the United States, 75% of medical centers report the occurrence of EBSL producers, and there has been a relative increase in isolation of ESBL-producing *Escherichia coli (E. coli)* around the world.[7,8] Furthermore, overseas travel, particularly to India, Africa, and the Middle East, has also been identified as a risk for ESBL producer acquisition.[7] This trend is worrisome with the continued worldwide deployments of US service members in support of Operations New Dawn and Enduring Freedom, and Operation Enduring Freedom–Horn of Africa. In these regions there is a predisposition to infection by ESBL-producing organisms among US service members due to their increased exposure to battle-trauma injuries.[9] According to the National Nosocomial Infection Surveillance System, 40% of the isolated ESBL producers in US medical centers were obtained from intensive care units.[10] This is of particular interest because the intensive care unit is the hospital section responsible for proving care to severely injured US service members.

The phenotypic characteristic of ESBLs is concomitant/simultaneous resistance to aztreonam, cefotaxime, ceftriaxone, and ceftazidime.[10] The Clinical Laboratory Standards Institute (http://www.clsi.org/) recommends a confirmatory test to identify ESBL-producing organ-

isms, which increases the time required to obtain results.[11,12] This delay causes the clinician to rely on empiric therapy, which may or may not be sufficient depending on the accuracy of the local antibiogram. Studies have shown that inadequate initial antimicrobial therapy is a significant predictor of mortality, underscoring the importance of accurate antimicrobial susceptibility reporting.[6,8] Thus, early identification of such organisms at the combat support hospital (CSH) level is critical to avoid inappropriate treatment prior to evacuation, which is especially important since many such injuries are initially treated empirically.[13]

Currently the microbiology augmentation set (N403) normally deployed with the CSH uses the Negative Breakpoint Combo Panel Type 30 (NBPC30) (Siemens Healthcare Diagnostics Inc, Deerfield, IL). This panel is able to analyze growth and susceptibility patterns of rapidly growing aerobic and facultative gram-negative bacteria with a turnaround time of 48 to 72 hours. Studies have shown its effectiveness in gram-negative organism identification and susceptibility.[14,15] Similarly, Siemens produces the Negative Breakpoint Combo Panel Type 41 (NBC41). This panel is similar in many respects to the NBPC30 panel and is also available as an alternative for gram-negative identification and susceptibility testing. Standard operating procedures for the panels are published in the field laboratory information program disk,[16] but the default in many in-theater standard operating procedures is use of the NBCP30 for gram-negative identification and susceptibility testing (ID/AST).

The objective of this study was to compare and evaluate the efficiency of the NBPC30 and the NBC41 in the identification of ESBLs against the gold standard method. We performed bacterial ID/AST of isolated Enterobacteriaeceae in our laboratory using both panels. The reference method was the Kirby-Bauer method using Clinical Laboratory Standards Institute guidelines. Sensitivities and specificities of each panel were also calculated.

Materials and Methods

Facilities and populations were previously described by Yun et al.[17] Patients were seen at the Ibn Sina hospital tertiary care facility in Baghdad, Iraq, which treated a wide variety of patient populations including US military personnel, US civilians, coalition forces, foreign national contract employees, Iraqi local nationals, and detainees. The hospital also provides a spectrum of surgical, intensive, emergent, and outpatient care. The colocated outpatient clinic provides specialty services such as dermatology and physical therapy. Blast injuries and gunshot wounds are the most common cases seen.[9]

Strains included in this study were isolated using the CSH's normal microbiology laboratory operating procedures. The types of strains isolated and the degree of resistance is described elsewhere.[18] Isolates were initially identified as gram-negative organisms from the family Enterobacteriaceae using the NBPC30 panel. Any isolated members of the Enterobactericeae were subsequently tested on the NBC41. Panels were read using the Microscan Autoscan 4 (Siemens Healthcare Diagnostics Inc, Deerfield, IL).

Results and Comment

Seventy-nine potential ESBL-producing organisms were included in this study, with the most isolated organism was *E. coli*, followed by *K. pneumoniae*. Other Enterobacteriaceae species such as *K. oxytoca*, and *Proteus mirabilis* (*P. mirabilis*) were also isolated. Common sources include respiratory, wound, urine, and blood, with wound and urine being the most prevalent. As the CSH mostly treats battle-related traumatic injuries, wound cultures were among the most prevalent culture tests requested (Table 1).

We found that the NBC41 panel had substantially better sensitivity and specificity when compared to the NBPC30 (Table 2). Furthermore, the NPC41 panel detected a lower rate of false positives (1%) when compared to the NBPC30 panel (6%). One strain tested on the NBC41 showed resistance to aztreonam, cefotaxime, ceftriaxone, and ceftazidime, but was not presumptively identified as an ESBL by the NBPC30 panel. Interestingly, there were a few instances where the isolates demonstrated susceptibility to one antibiotic on the NBPC30, often ceftazidime or ceftriaxone, but

Table 1. Breakdown of isolates (N=79) by species and specimen source.

Organism	Blood	Peritoneal Fluid	Respiratory	Skin	Stool	Wound	Urine	Total
Escherichia coli	1	0	6	2	6	14	13	42
Klebsiella pneumoniae	8	0	9	0	0	8	4	29
Klebsiella oxytoca	0	0	0	1	0	1	0	2
Proteus mirabilis	0	1	0	0	2	1	2	6
Total	9	1	15	3	8	24	19	79

indicated resistance to all four on the NBC41 panel (data not shown in Table 2). This phenomenon was similar to Steward et al's observations in which they found that the MicroScan panels were less likely to report ESBL producers as ceftriaxone and ceftazidime resistant.[19] Although we found that the NBPC30 panel showed decreased resistance to cefotaxime similar to Steward et al's findings, we did not find decreased ceftriaxone resistance in ESBL producers. This underscores the superiority of the NBC41 panel over the NBPC30 panel in correctly identifying ESBL-producing organisms.

When compared to previous studies, our data showed that the NBPC30's sensitivity and specificity were better than those previously reported by Wiegand et al.[15] They compared the performance of the VITEK (bioMérieux, Inc, Durham, NC), Phoenix (BD Diagnostic Systems, Sparks, MD), and the MicroScan, with the MicroScan's sensitivity at 84%. However, their studies did include 150 samples, twice the number tested in this study. Another study by Linscott et al evaluated the MicroScan ESBL plus ESBL confirmation panel. This panel has similar antibiotics to the NBC41 with 2 exceptions; addition of cefpodoxime and cefotetan, and use of minimum inhibitory concentration determination. They reported 100% sensitivity and 98% specificity in ESBL detection.[20] This panel is available for use in the N403 kit. A study comparing the performance of the NBC41 to the ESBL confirmation panel will allow a direct evaluation of the former's performance in ESBL detection. Furthermore, additional studies with more isolates are required to determine the positive and negative predictive values of the panels.

Our data showed the NBC41 to be superior in detecting ESBL producers when compared to the currently used NBPC30 panels. The NBC41 panels also showed better concordance with the Kirby-Bauer method and did not show discrepancies in identification. Furthermore, the panel also tests 10 more antibiotics compared to the NBPC30 panel. As previously described, the main difference is the high utilization of antibiotic breakpoints in the NBC41 panel. This provides the clinician with a qualitative measure of susceptibility, which may be sufficient in most cases. Furthermore, although the MicroScan ESBL and ESBL confirmation panel is available for order with the N403 kit, it suffers from the same problem of additional turnaround time as the NBPC30 panel. Although evaluated as a valuable tool for ESBL confirmation,[21] this panel cannot perform bacterial identification and ESBL confirmation simultaneously. In comparison, the NBC41 panel eliminates the need to use additional confirmatory panels, shortening ID/AST of ESBL-producing organisms to 48 hours. Our study shows that using the NBC41 can substantially decrease turnaround time in ID/AST, while providing a confirmed result of the status of an isolate as an ESBL-producing organism.

Table 2. Specificities, PPV, and NPV of MicroScan panels for the detection of ESBL production with disk diffusion as a reference method (isolates N=79).

Panel	Positive	Negative	False Positives	False Negatives	Sensitivity (%)	Specificity (%)
NBPC30	58	21	5	8	86.9	72
NBC41	60	19	1	2	96.7	89

In theater, the N403 microbiology augmentation kit currently includes a MicroScan Autoscan 4 for routine bacterial identification. This equipment set is fielded with dried panels for the identification of gram-positive and gram-negative organisms. Currently, many in-theater labs use the NBPC30 as the default panel for identification of gram-negative organisms. However, due to the nature of the infection types ESBL-producing organisms cause, we highly recommend using the NBC41 as the primary panel for identification of gram-negative organisms. This panel is a better choice to provide crucial susceptibility data to the health care provider with its capability to test more antibiotics. Our data shows that isolates can be reported as confirmed ESBLs with confidence using the NBC41 panel. Benefits of this change include reduced turnaround time for antibiotic susceptibilities and, as a consequence, effective antibiotic treatment management for the patient.

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The Development of the Army Public Health Enterprise for Full Spectrum Operations

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Introduction

This article envisions US Army Public Health (PH) Enterprise support (level I through level V) for full spectrum operations, and frames the roles and relationships among US Army Medical Department (AMEDD) capabilities required to support operational forces through all phases of Army Force Generation (AFORGEN). Implementation of the Army PH Enterprise concept will enhance the detection, identification, analysis, and prevention of health threats to Department of Defense (DoD) personnel during the full spectrum of operations, while increasing efficiency and capabilities. The intent is to logically describe a tiered and layered approach to the optimization of PH services and the efficient provision of effective information to commander, with the ultimate goal of protecting the Warfighter.

Transformation Initiatives

Over the last 8 years, the Army has undergone a major reorganization of its combat and support formations. It has transformed from a forward-stationed, Cold War-structured organization into an expeditionary United States-based force prepared to deploy and provide sustained landpower in support of likely joint operations. The battalion combat team-structured Army is no longer focused on a linear battlefield. Years of conflict have made it clear that the Army requires additional adaptation to effectively and efficiently provide the full range of PH services to the Warfighter during wide-area combat and security operations.

Recent changes and initiatives, shown in the Table, illustrate the need to address PH support to operational forces during deployments. The concept presented in this article describes the roles, missions, and relationships across the capabilities of AMEDD functional areas and resources to provide PH support to the Warfighter during full-spectrum operations.

Recent changes and initiatives within military public health doctrine and structure.

Joint military	Multiservice concepts of operations for health readiness and force health protection.
AMEDD	Establishment of the US Army Public Health Command.
Army	Institution of capability-based assessments of Warfighter protection and sustainment functions. Series of revisions of *TRADOC Pamphlet 525-66.*[1]

Essential Requirements for the Army Public Health Enterprise

Mission command should be a seamless "system of systems" for the command and control of tactical, operational, and strategic resources, including Army Health System assets at all levels of support. The health system should be interoperable across Army systems and have joint compatibility and connectivity. It must be capable of operating efficiently and effectively in austere environments. It must be able to enhance the effectiveness of operational forces in accordance with DoD directives and instructions.[2,3] To that end, the system should include advanced communications along with medical, veterinary, occupational, and environmental surveillance to provide real-time detection of PH hazards, including toxic industrial chemicals and materials, as well as chemical, biological, radiation, and nuclear (CBRN) hazards. The risk assessments from this intelligence will maximize preventive measures and controls by making current information for the diagnosis and treatment of patients available to providers, along with other critical healthcare support services in theater. Public health assets must be flexible enough to minimize redundancies, and robust enough to execute their missions. Synchronized doctrine that addresses the roles and responsibilities of PH assets throughout the AFORGEN cycle (described in the following section) will also be required. The development process of the health system should include stakeholders from the mission command and Warfighter protection and sustainment functions to provide comprehensive risk management information:

- Psychological, physiological, biochemical, and human performance optimization.
- Large-scale real-time analysis and modeling.
- Real-time medical, occupational, and environmental surveillance and monitoring.
- Advanced sensors (mechanical and chemical).
- Bioengineered protective systems and materials.
- Advanced medical and personal wellness training.

The success of the Army's medical force protection effort depends on the linkages established between elements of PH and the healthcare providers. Direct healthcare providers must be given a noninvasive interface with the comprehensive PH system. This includes passive and active systems to collect pertinent health event data. Operation of such a system will require training of healthcare providers on responsibilities, procedures, and equipment associated with their surveillance roles. Additionally, healthcare providers must be afforded the opportunity to exercise these roles daily so that the tasks become routine. The responsibility for the surveillance role must be embraced by medical leaders at every level. The collection of data from healthcare providers is only the first step in the creation of a meaningful and comprehensive PH environment. Direct healthcare providers must become priority customers who rely upon PH specialists in the daily functions of their clinical practices. This procedural change requires a dramatic shift in the level of interaction between direct healthcare providers and the PH community.

Public Health Support of Army Force Generation

The AFORGEN cycle consist of 3 phases, Training/Ready (predeployment), Available (deployment), and Reset (redeployment). It is a supply-based model and a demand-based process used by the Army to progressively build readiness over time, and includes every Active Army, Army Reserve, and Army National Guard unit. Army Force Generation enables a steady, predictable flow of trained and ready forces to succeed across the full spectrum of conflict.

As part of the continuity of support, early interventions start prior to deployments and redeployment to ensure the immediate and long-term health of Soldiers. They provide commanders and units the ability to withstand the increased physical and mental health hazards of operational environments, as well as the often unanticipated stress of returning to the garrison and home environments.

Train/Ready (Predeployment) Phase

Specifically during the AFORGEN Training/Ready and Reset phases, PH support will come from a number of Level V organizations. While the US Army Public Health Command (APHC) is responsible for PH across the Army Medical Command, the regional medical commands (RMCs) and medical treatment facilities (MTFs) are responsible for the establishment of policy and executing the PH tasks, or requesting support from higher commands. The critical event during this phase is the handoff of units from the peacetime mission commander to the wartime commander.

US Army Public Health Command Support

Public health responsibilities using support from the Army Institute of Public Health (AIPH) and Army Public Health Command Regions (PHCR) during this phase include:

- Providing recurring subject matter expert courses.
- Providing technical assistance visits to operational forces (MTF public health assets may be leveraged).
- Evaluating the latest field technology PH equipment and providing just-in-time training.
- Providing all-source predeployment OEH site assessment reports and the historical periodic environmental and occupational monitoring summary.
- Serving as evaluators for units at training centers testing for PH scenarios (scenarios jointly developed by AMEDD Center & School, AIPH, and PHCR subject matter experts).
- Providing food and vulnerability assessment training, health promotion, and wellness product distribution.
- Consolidating, evaluating, and reporting installation data on disease and injury surveillance.

Regional Medical Command and Medical Treatment Facility Support

Support required from RMC and MTF for public health responsibilities during this phase includes:

- Army wellness centers.
- Family readiness support.
- Soldier and military working animal support.
- Providing mental health support as needed.
- Providing technical assistance.
- Providing medical threat briefs.
- Food and water vulnerability assessments.
- Predeployment health assessments and documentation of each Soldier's health status to establish a deployment cycle baseline.
- Administering vaccines and chemoprophylaxis for the full range of medical threats.
- Periodic health assessment.
- Installation disease and injury surveillance.
- Integrating assigned PH specialists into additional responsibilities to maintain and enhance individual skills.

Available/Deployment Phase

During the Available phase, PH support will come from various operational Level I to Level IV PH assets. These resources will work in concert with Level V generating force PH assets during all AFORGEN phases to provide a seamless network of PH support. The Level V generating force assets include the APHC, RMCs, and MTFs. Also during this phase, Level V PH assets are provided by the APHC in the form of specialized teams, training, or equipment that can augment Level II through Level IV PH resources when required.

Level I

The foundation of PH support to company-level units is established at Level I. Command emphasis and individual Soldier responsibility are the foundations for the accomplishment of the PH mission at this level. The commander is responsible for the health and welfare of the unit, including the prevention of disease and nonbattle injury casualties. As the authority for actions that occur within the unit, the commander sets the standards for health and welfare, and ensures the establishment of field sanitation team practices and/or devices that promote unit or collective preventive medicine measures.

Deployed Soldiers must be protected against the full range of food and waterborne diseases, occupational and environmental health threats, toxic industrial chemicals and materials, and CBRN agents. Company PH teams (Combat Medics (MOS* 68W)), Animal Care Technicians (MOS 68T), Civil Affairs Medics (MOS 68WW4) and Special Forces Medical noncommissioned officers (MOS 18D) will provide organic support for their units to counter these threats. They identify and diagnose diseases of medical and veterinary importance, and take corrective action to mitigate these threats. Their main focus is preventing casualties, optimizing each Soldier's health/performance, and communicating threats to commanders. The key to success is tying the PH assets, which provide healthcare services, to prevention and surveillance activities as a normal part of their operations.

Future capabilities for the prevention of casualties at this level could include an increase in the level of Soldiers' health and performance to enhance survivability against battlefield health threats. Possible examples of such capabilities include:

- Advanced user-friendly remote sampling devices and sensors which rapidly detect chemical, biological, radiological and environmental hazards in real-time.
- Nutritional and pharmacological techniques to optimize both performance and the body's defense system to resist diseases and wound infection, sustain blood loss, and counter toxic or infectious agents.
- Automated medical surveillance system with enhanced communications to rapidly identify disease outbreaks and document hazard exposures.
- Advanced training and distance-learning modules with which company commanders can prepare additional PH teams to operate at the platoon level, allowing them to perform split-based operations.

Level II

Level II is the first level of organic PH support with medically trained specialists to implement and monitor PH services for the division, brigade combat team, special forces group, and civil affairs brigade. The support provided should integrate Level I support and expand PH services to include preventive medicine (Environmental Science and Engineering Officer (AOC† 72D) and Preventive Medicine Technician

*Military occupational specialty
†Area of concentration

(MOS 68S)), and behavioral health (Psychologist/ Social Worker (AOC 67D), Unit Ministry, and Physical Therapist (AOC 65B)). These services should operate in concert with battalion aid stations and the brigade support medical company to track and report disease and nonbattle injury trends.

Deployed Level II PH assets should have the ability to provide quantifiable, presumptive analysis results in support of a commander's decision process for measures to prevent injuries and protect Soldiers against PH threats. Basic arthropod, rodent, and pest management and surveillance; focal application of pesticides; and limited medical surveillance should also be available, along with the capability to identify and mitigate the threat of diseases of medical and veterinary importance.

Advanced sensing, sampling, and training will be required to enhance surveillance of medical, environmental, veterinary, and combat operational stress factors. Such enhanced surveillance would provide real-time sample and inspection results for timely command decisions, thus maximizing our ability to provide a clearer common operating picture for PH resources. Future changes at this level could include additional clinical PH assets (Preventive Medicine/Occupational Health Physician (AOC 60C/D) and PH Nurse (AOC 66B)) at the division level to perform disease surveillance and comprehensive risk assessments.

Tactical dispersion (distance, terrain) can render brigade combat teams virtually on their own for self-protection. A PH force multiplier within the brigade combat team could be realized by either:

- Additional training in food protection functions for the Preventive Medicine Technician (MOS 68S) to inspect and conditionally approve Class I provisions, or
- Combining the skills and responsibilities of MOS 68S and the Veterinary Food Inspection Specialist (MOS 68R) into a comprehensive specialty.

Level III

Level III PH assets provide area support and consultation to operational medical, sustainment, and protection (CBRN, engineer, military police) units to minimize the effects of acute and long-term medical threats. Such assets include 100% mobile detachments, and command and control assets which support an area of operations for those units that do not have organic PH capabilities. Level III should also provide surge capability for units experiencing increased risk from PH threats. Levels I and II support should be integrated and PH services expanded to include preventive medicine (preventive medicine/occupational health physician, environmental science and engineering, PH nurse, entomologist (AOC 72B), radiation protection, dietitian (AOC 65C), and audiologist (AOC 72C)), medical (physician, physician assistant, nurse, medic), dental, veterinary, and combat operational stress control. These services provide and receive technical consultation and operate under the command and control of the multifunctional medical battalion (MMB), medical brigade, or medical command. They work in concert with Level II clinics and the combat support hospital for disease and nonbattle injury, medical surveillance, diagnostic and clinical laboratory, and other PH support.

Deployed Level III PH assets should provide a holistic approach to drive mission command and clinical decisions. To that end, there should be the capability to provide timely, quantifiable, confirmatory field laboratory analysis to support the commander's decision process. Further, there should be resources capable of providing occupational and environmental health (OEH) site assessments; arthropod, rodent and pest management and surveillance; pesticide application; feral animal control; food protection and testing; advanced medical surveillance and epidemiological investigations; comprehensive risk assessments; and human performance optimization.

Currently, there is no capability to provide near real-time field confirmatory analysis of toxic industrial chemicals and materials and CBRN agents at this level. Such capability must be available to truly perform this level of support. Medical surveillance, epidemiological, and risk assessment specialists will also be required to interpret and analyze the data from those capabilities. The capability gaps could be addressed by adding specialists directly to the staffing models for preventive medicine detachments, or be provided by generating forces (Level V) support in the form of equipment, training, or personnel/teams. Alternatively, if medical surveillance, epidemiological, and risk assessments capabilities are not added to preventive medicine detachments, they should, at a minimum, be added to their command and control element (medical brigade level).

Level IV

At Level IV, the area medical laboratory supports the entire theater of operations with the most advanced technical capabilities. The laboratory provides validation analytical laboratory services and advanced risk assessment consultation to medical, CBRN, engineer, military police, and sustainment communities. The laboratory also provides technical support and oversight to Level II and Level III PH assets for sampling and analysis.

During deployment, the area medical laboratory should provide forward laboratory support for the analysis of samples from the entire range PH threats. It should provide advanced analytical, investigative, and consultative services to assist in the identification, evaluation, and mitigation of potential PH threats to deployed forces (local or regional populations at risk) within the theater. The sample analyses and the evaluation of disease and nonbattle injury risks should support the OEH site assessment, and provide near real-time data for comprehensive medical risk assessments for the establishment of theater health policies. The laboratory should collect, consolidate, and archive theater laboratory data, and prepare samples/specimens for shipment to reference laboratories in the United States for definitive analysis.

Future capabilities at Level IV should include a theater epidemiologist, as well as increased unit modularity and flexibility to better support the entire scope of PH responsibilities.

Level V

This level of PH support is provided by the APHC and Army Medical Command units. Home station operations centers and MTFs, such as medical activities and medical centers at sustaining bases in the United States, will provide technical support for PH issues and support to the operating force throughout the deployment. The APHC (including subordinate activities) provides definitive laboratory analysis, serves as the technical center for expertise and consultative reach-back support, and is the ultimate repository of all medical surveillance data collected within the theater.[4] These efforts provide commanders and decision-makers with pertinent deployment OEH surveillance information necessary to detect, assess, and counter threats and hazards as part of the Comprehensive Health Surveillance Program.[2]

Reset (Redeployment) Phase

US Army Public Health Command Support

Public health requirements using Army Institute of Public Health and Army Public Health Command Region support during this phase include:

- Provide specific subject matter expertise to MTF assets.
- Prepare responses to requests for information, historical summaries, and periodic environmental and occupational monitoring summaries.
- Analyze archived data for after-action reports and lessons-learned.
- Army Institute of Public Health consolidates and evaluates installation data, and reports disease and injury surveillance.

Regional Medical Command and Medical Treatment Facility Support

Public health requirements for RMC and MTF support during this phase includes:

- Soldier reassimilation into the Family unit.
- Comprehensive assessment and documentation of each Soldier's health status upon redeployment.
- Mental health support as needed.
- Industrial hygiene/occupational health surveys and inspections of facilities (depots, ammo plants, maintenance facilities, etc).
- Environmental health support to sanitary food audits.
- Incident response (behavioral, environmental, clinical, occupational).
- Food and water vulnerability assessments.
- Installation disease and injury surveillance.
- Integrating operational force PH specialists into generating force work to maintain and enhance individual skills.

Conclusion

The development of the future AMEDD Public Health Enterprise must be coupled with improvement of our military public health efforts. We must place greater emphasis on preventive medicine at all levels, seeking the long-term and short-term benefits of such efforts.

Public health surveillance must be more synchronized within the Department of Defense and other US Government agencies with information networks spanning human and animal health and the environment. We must provide timely, accurate, and actionable data to our deployed commanders to quickly identify and mitigate any significant health risks. We must have effective ways to change risky behaviors and reduce injuries. Most importantly, we must enhance partnerships and collaborative efforts among public health experts in all of the uniformed services, as well as those in outside agencies. Assets must become more agile, modular, flexible, rapidly deployable, and technologically advanced as public health reshapes its role in all aspects of health protection. Finally, we must develop and publish public health doctrine in accordance with organization, training, materiel, leadership, personnel, facilities, operational doctrine, and policy domains to ensure synchronization within the AFORGEN cycle. A holistic public health approach is only possible when all subspecialties understand the core competencies, roles, missions, and capabilities of their partners, and work together to achieve common goals.

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Is Deployment Associated with An Increased Risk of Respiratory Outcomes? What Do We Know? What Do We Think?

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BACKGROUND

A recent article in the *Air Force Times*[1] presented an analysis of publicly available military personnel health data compiled by the staff of the paper's parent company, Military Times, for the years 2001 through 2009. The data used was that reported in the *Medical Surveillance Monthly Report* published by the Armed Forces Health Surveillance Center (http://afhsc.army.mil/home), and the total number of service members on active duty on September 30 of each of the 9 years. Among other things, the article reported that the rate of chronic obstructive pulmonary disease (COPD) in the military rose by 122% from 2001 to 2009, and included comments from various respiratory disease experts on the analysis.

The article did include the caveat that the health data reflected treatments of service members at military medical facilities at permanent bases, not data from either of the combat theaters. Two of the experts featured in the article were in agreement that "true significance of the data cannot be know without separating deployed and nondeployed service members."[1] However, the article also presents a number of potentially associated factors: "increased use of smoking tobacco…," "dust and sand, smoke from burn pits, diesel fumes, chemical from factories, a sulfur mine fire, a nuclear plant near Baghdad and intentional sabotage through chemicals by Saddam Hussein's army."[1] The implication is that the increased visits for COPD were deployment-related.

In actuality, the discussion in the body of the article compared data from 2 years, 2001 (before the start of the current combat operations), and 2009. This is a comparison of rates per population at 2 discrete points in time, rather than a trend analysis over the intervening period. It is possible that another year chosen for comparison would have resulted in a lower rate, although the data presented in the article's table does suggest an upward trend. The data used for analysis counted individuals treated, which means that it did not distinguish between new (incident) and existing (prevalent) conditions. Further, an individual who returned from deployment with concerns about a health condition such as COPD would be more likely to be referred for an evaluation visit at the time of their postdeployment assessment, particularly if they had exposure concerns.

The article implied that their staff analysis had identified a problem which was not apparent to the military. Indeed, COPD was not the only condition to be identified as having "rising rates" as the list included many conditions affecting different organ systems. However, the question raised is a legitimate one: does deployment, or multiple deployments, lead to an increased risk for respiratory conditions? This article evaluates the available data on this topic.

RESPIRATORY CONDITIONS WHILE DEPLOYED TO THE CURRENT THEATRE OF OPERATIONS

There is some evidence of an increase in respiratory symptoms such as cough and dyspnea during deployment. Reporting on the health effects of the Kuwait oil fires of 1991 among US troops, a survey found an increase in self-reported symptoms of upper respiratory tract irritation, shortness of breath, and cough associated with proximity to the Kuwaiti oil fires. The effects were generally short-lived and resolved after leaving Kuwait.[2] Anecdotally, service members note a variety of symptoms, such as irritation from dust and cough, while deployed to Southwest Asia, but medical providers will note that many individuals generally do not seek care for self-limited conditions. In a review of Joint Medical Workstation*

*The Joint Medical Workstation is a web-based medical command and control application. It provides medical information and unit status and readiness to medical leadership from the unit level to the joint task force, combatant commanders, and to service components. Information available at: http://dhims.health.mil/products/theater/jmews.aspx.

medical visits reported from selected sites during one quarter of 2006, the top 5 respiratory in-theater encounters, on a percentage basis, were for acute upper respiratory infections, acute nasopharyngitis (common cold), acute bronchitis, asthma, and chronic sinusitis.[3] In a survey of 15,000 military personnel redeploying from Iraq and Afghanistan, 69.1% reported experiencing respiratory illnesses, of which 17% required medical care.[4] This supports the premise that visits to providers while deployed are often to evaluate acute conditions that might require antibiotics or other treatment (acute respiratory infections, colds), or worsening of chronic conditions (asthma, chronic sinusitis). Currently, most routine disease surveillance in theatre includes disease and nonbattle injury tracking, with the aim of (1) communicable disease outbreak detection, (2) sentinel event detection, and (3) other relevant areas of public health and preventive medicine, such as injury prevention and exposure monitoring of environmental and occupational sources.[5]

Respiratory Symptoms Reported After Deployment

Survey data from the Department of Defense Millennium Cohort Study (http://www.millenniumcohort.org/index.php) found that deployed personnel had a higher rate of newly reported respiratory symptoms on return than nondeployed personnel (14% vs 10%).[6] However, these individuals reported similar rates of diagnosis for conditions such as chronic bronchitis/emphysema (1% vs 1%) and asthma (1% vs 1%). This study did not involve health outcome records review, but asked participants if they had been given such a diagnosis by a physician. Some diagnoses such as chronic bronchitis and asthma may require multiple visits or persistence of the problem to be diagnosed, and so it is conceivable that individuals with symptoms, if they persist, might ultimately receive a specific diagnosis, even if they had not at the time of the survey. A study comparing the predeployment and postdeployment outpatient encounters of deployers observed an overall decrease in postdeployment encounters for respiratory conditions. This was driven by decreased postdeployment encounters for respiratory infections as compared to prior to deployment.[3] Another study by the Naval Health Research Center evaluated the hospitalization experience of individuals who had deployed.[7] This study compared the pre- and postdeployment hospitalization experience of first-time deployers, and to that of nondeployed personnel. Overall, the deployed group showed a 40% increase in postdeployment hospitalization (statistically significant overall), with the highest rates associated with injury, poisoning, mental disorders, and musculoskeletal disorders. Looking specifically at respiratory disorders, the predeployment rate of 2.63 per 1000 person-years increased to 3.74 per 1000 person-years postdeployment. However, when compared to nondeployed personnel, the rate of hospitalizations was not elevated. Generally speaking, individuals who do not deploy may be ineligible due to medical conditions or other reasons ("healthy warrior effect"). Three conditions represented 44% of all respiratory conditions: ICD-9 518, other diseases of the lung (17.5%); ICD-9 493, asthma; and ICD-9 453, pneumonia, organism unspecified. This represents about one increased diagnosis per 1000 person-years of follow-up—which is not a very large increase—but given that the majority of hospitalizations were for a nonspecific diagnosis, it is difficult to interpret.

Specific Conditions Potentially Associated With or Exacerbated by Deployment

Asthma

The current guidelines for accession of new military personnel are service specific, but, in general, an established diagnosis of asthma after childhood has been an exclusion criterion. For the Department of the Army, the allergy and pulmonary consultants "recommend waivers for individuals with a history of asthma after age 13 if they have been asymptomatic without medication for over 3 years. The individual should have normal spirometry. A history of high-level sports without medication use is reassuring. Waivers may be considered for individuals with a history of well-controlled, exercise-induced, or mild intermittent asthma."[8] The extreme climate conditions in Southwest Asia along with high particulate matter exposures due to environmental dust exposure could potentially contribute to poor asthma control with increased exacerbations.[9] Studies in the United States examining the relationship between particulate matter and hospitalization for asthma demonstrate that asthmatics are more susceptible to high particulate levels.[10] However, it has been reported that those who joined the service with a waiver for a history of childhood asthma and are currently asymptomatic are no more likely to leave the military before the end of their enlistment than those without a waiver.[11] Roop et al[12] surveyed redeploying Army personnel and found that

5% of Soldiers deployed to Southwest Asia reported a previous diagnosis of asthma. Both asthmatics and nonasthmatics reported significantly increased respiratory symptoms during deployment compared to symptoms preceding deployment. It has been reported that high levels of particulate matter may be associated with new-onset asthma.[10] Szema et al[13] performed a review of over 6000 Veteran's Administration beneficiaries and reported increased rates of new-onset asthma in US military personnel who had deployed between 2004 and 2007 as compared to those who did not (6.6% vs 4.3%). The study used recorded ICD-9 codes, and it is not clear if the diagnoses were made based on reversible obstruction demonstrated on pulmonary function testing or history or presence of wheezing on examination.[12] It has been reported that some individuals joining military service conceal a history of asthma, and it is also known that individuals may enter with undiagnosed asthma. Concealment of the diagnosis at the time of entrance to military service was reported for 52.5% of all asthma related discharges.[11] However, some asthmatics do not complete basic training. Nish and Schwietz[14] evaluated 192 Air Force recruits for symptoms of exertional dyspnea and found that 45% of these patients had a previous diagnosis of asthma. The majority of these patients had mild or exercise-induced disease, but had clinically significant symptoms to be referred for a formal evaluation.[14] Exertional dyspnea may be the first manifestation of asthma. However, when this presents in the postdeployment period, the difficulty in performing physical training may be attributed to lack of conditioning, since some individuals may not conduct personal physical training while deployed for a number of reasons. Indeed, a study by Sharp et al[15] evaluated the change in physical fitness with deployment and noted that a 9-month deployment resulted in negative effects on aerobic performance, upper body anaerobic power, and body mass.[15] Individuals who started at a higher level of fitness had the most difficulty in maintaining it, even though 90% of people in the study reported facilities to maintain fitness were available at their deployment site. However, overall, at about 6 months postdeployment, physical training scores were the same as 4 months predeployment.

Because service members are required to pass a physical training test, it would appear that this is a type of screening test of pulmonary function. Individuals who are unable to pass their physical readiness tests may be referred for medical evaluation. Morris et al[16] noted that dyspnea on exertion was a common cause of referral to a pulmonary clinic at a large military medical facility. Many of the individuals had been given a diagnosis of exercise-induced asthma without demonstrating reversible obstruction on pulmonary function testing. They evaluated 105 individuals with this symptom, compared with 69 controls, with a series of tests to include chest x-ray, full pulmonary function testing, methacholine challenge, arterial blood gases, cardiopulmonary testing, and a variety of laboratory tests. They identified exercise-induced asthma in 35%, with an additional 12% diagnosed with asthma, 5% with nonreversible obstruction, vocal chord dysfunction in 10%, and 24% with no specific diagnosis identified.

Acute Eosinophilic Pneumonia

Early in the current conflict, it was observed that there were a small number of individuals who developed a severe respiratory condition requiring ventilator support. Eighteen cases of acute eosinophilic pneumonia occurred from March 2003 to March 2004 among 183,000 military personnel deployed in or near Iraq. There were 2 deaths from this cohort which were first reported in the medical literature in 2004 by Shorr et al.[17] Acute eosinophilic pneumonia is an unusual disease of unknown etiology characterized by acute illness (more than 2 weeks of symptoms), respiratory failure, bilateral pulmonary infiltrates, hypoxia, and predominant eosinophilia on bronchoalveolar lavage. Extensive evaluation failed to demonstrate an infectious etiology or association with known causes, and no geographic clustering was evident. Most individuals reported exposure to fine airborne dust, and all used tobacco, with 78% reporting that they had started smoking recently. New-onset smoking was considered a risk factor in these patients. This clustering of conditions was identified because it was unusual, and resulted in a relatively severe acute condition. However, it is not a new condition, and 2 cases were reported in 1999 from the National Training Center (Fort Irwin, CA), a similar dusty environment, and it also occurs in civilian populations in the United States.[18]

Constrictive Bronchiolitis

Constrictive bronchiolitis is a lung disease characterized by fixed airways obstruction and fibrosis of the distal airways or bronchioles, with extrinsic narrowing or obliteration of the bronchiolar lumen. It is most commonly seen in young individuals following organ transplant, but is also associated with some drugs, con-

nective tissue disorders, infection, and some environmental and occupational inhalation exposures, classically following exposure to nitrogen and sulfur dioxides. Recently, it has been associated with exposure to diacetyl in the popcorn flavoring industry. It is generally not considered reversible, and may cause permanent respiratory impairment. Constrictive bronchiolitis usually presents with shortness of breath on exertion and nonproductive cough. Spirometry will typically show airflow obstruction that is not reversible with bronchodilators. High resolution computed tomography scanning of the chest often shows air trapping on expiration and a pattern known as mosaic attenuation.[19] Following a sulfur fire that occurred in Iraq in 2003, Soldiers returning to Fort Campbell, KY, were offered pulmonary function testing. Some of these were ultimately referred to a pulmonologist who summarized 80 referrals from Fort Campbell seen between 2005 and 2009.[20] He noted that all had exertional dyspnea, cough, and decreased ability to perform the 2 mile run. Of the 80, 46 had an open lung biopsy. Thirty-five were diagnosed with constrictive bronchiolitis, and 26 of these had a history of exposure to the sulfur fire. However, many of these Soldiers had minimal finding on diagnostic tests, and this condition has not "clustered" at other locations or military treatment facilities. The diagnosis is made at open-lung biopsy, which is an invasive procedure, and thus not frequently performed. An epidemiological study of over 6000 individuals who were deployed within 50 km of the fire during this episode did not demonstrate increased rates of respiratory conditions as compared to 2 comparison groups, but the analysis was limited by an inability to identify specific exposure levels in individuals.[21]

POTENTIAL EXPOSURES ASSOCIATED WITH DEPLOYMENT

Particulate Matter

High levels of ambient particulate matter were identified as a potential impact to respiratory health early in the current conflicts. Preventive medicine personnel deployed to the US Central Command (CENTCOM) areas of operations conducted sampling which typically demonstrated particulate matter (PM) levels above those considered healthy by the National Ambient Air Quality Standards.[22] In 2005, the Assistant Secretary of Defense for Health Affairs chartered a Joint Particulate Matter Work Group to investigate and identify the potential health risks presented by PM. This group noted that there was limited data to answer fundamental questions, so two of the recommendations were to conduct enhanced particulate matter surveillance and to conduct epidemiological studies of potential adverse health effects of exposures to PM in Middle East areas of operation. Accordingly, extensive particulate matter sampling (EPMS) was conducted every sixth day at 15 locations throughout Southwest Asia, including 6 sites in Iraq and 2 in Afghanistan. Data were collected for 12 months from 2006 into 2007.[23] The Army asked the National Research Council (NRC) to review the EPMS report. The NRC was asked to consider the potential acute and chronic health implications, the epidemiological and health surveillance data collected in conjunction with this sampling, and to make recommendations for reducing or characterizing the health risk.[24(p81)]

In its report, the NRC noted:

> In the United States, sources of coarse particles (2.5 μm to 10 μm in diameter) include resuspension of soil from roads and streets; disturbance of soil and dust by agricultural, mining, and construction operations; and ocean spray. Sources of fine particles include emissions generated by motor vehicle combustion, smelters, and steel mills. In the Middle East, major sources of particles may differ from those in the United States and other industrialized regions, where fossil fuel combustion and vehicle emissions are primary sources of PM.[24(p3)]

The NRC pointed out that, in the Middle East, resuspension of dust and soil from the desert floor is a major contributory factor, along with combustion sources (vehicle exhaust) and industry.

In the conclusions and recommendations, the report states:

> Although interpretation of the epidemiological and health-surveillance studies was encumbered by uncertainties regarding the actual exposures, the small number of study subjects, and the limited amount of exposure data, the EPMSP results clearly document that military personnel deployed in the Middle East...are exposed to high concentrations of PM and that the particle composition varies considerably over time and space.[24(p72)]

The NRC also included a number of recommendations offered to improve the ability to discern an association between PM levels and health outcome—in particular, more frequent (daily) sampling.

Smoke from Burning Trash

Due to concerns raised that exposure to smoke produced by burn pit operations used to dispose of solid waste in CENTCOM areas of operations might be associated with acute and long-term health effects, the Armed Forces Health Surveillance Center and the Naval Health Research Center were tasked in 2009 to conduct expedient epidemiological studies using readily available data.[25-27] These studies were designed to assess whether a wide range of health outcomes (respiratory and cardiovascular conditions, chronic multisystem illness, lupus erythemetosus, rheumatoid arthritis, and birth outcomes for infants whose parents had been deployed) were potentially associated with deployment to a location where burn pit operations were known to have occurred.[28(pi)] However, the discussion here is limited to the assessment of respiratory outcomes. Specific individual exposure levels to smoke/combustion components was not available, and so the study design compared a never-deployed, continental US (CONUS) based cohort of service members against those service members in:

1. selected deployment locations where large, active burn pits were in operation;
2. CENTCOM locations without burn pit operations; and
3. the Republic of Korea (where particulate matter levels, a possible confounder for respiratory conditions, are also elevated).

The study report states:

> For all outcomes measured upon redeployment, Service members from the USCENTCOM locations and the Korea cohort had either similar or significantly lower incidence rates compared with the CONUS-based cohort, with the exception of "signs, symptoms. ill-defined conditions" among the Arifjan cohort (a location with no burn pit). Comparisons of medical encounters in theater between the USCENTCOM camps did show a higher proportion of medical encounters to be respiratory-related at Balad (a location with a burn pit) compared to the three other camps, possibly indicating increased acute respiratory effects of being at Balad, however…these effects did not persist upon redeployment. Additionally, the Balad cohort was more likely to self-report exposure to smoke from burning trash or feces, and Air Force personnel from Balad [Army personnel not mentioned] were more likely to self-report persistent health problems when compared to Air Force personnel stationed at Arifjan.[28(p3)]

Among the report conclusions:

> The epidemiological approach used in these studies found no evidence that Service members at burn pit locations are at an increased risk for most of the health outcomes examined.[28(p4)]

However, the report acknowledged the limitation posed by the inability to identify individual level exposures.

Difficulties in Assessing Health Outcomes Due to Deployment Environmental Exposures

While health outcome data analyzed to date has not demonstrated consistently elevated risks of respiratory disease in association with deployment, it is recognized that evaluating such associations poses difficulties. The first difficulty arises from the inability to control for the most significant risk factor for respiratory disease, cigarette smoking. While smoking may increase during deployment, and some individuals start smoking while deployed, health outcome data as such does not identify the smoking status of individuals. Ideally, increases in health outcomes would be evaluated controlling for smoking status. Second, while some studies evaluate health outcomes based on a history of deployment by comparing predeployment rates with postdeployment rates, or by comparing those who have deployed versus those have not, some studies do not. Even when done, the most typical measure of exposure used is deployment. "Deployment" is not a specific unique exposure, but rather represents time spent in a complex environment where numerous potential inhalational exposures are possible, including particulate matter of varying level and size, vehicle exhaust, riding in convoys, burning trash, local industry, etc. While a study can be conducted choosing one base camp location as a proxy for an exposure as compared to another thought to be without that exposure, in truth, a base camp is a complex environment comprised of complex microenvironments based on the activities occurring at locations throughout a camp. No study to date has utilized a standard exposure questionnaire to attempt to identify which of the previously mentioned or other potential exposures might be significant for an individual. Further, the situation becomes more complex when an individual has deployed multiple times to multiple locations. Such exposures may be common, but the development of respiratory conditions appears to be uncommon, therefore, if such exposures do impart an increased risk, individual risk

factors may be important. Factors such as genetic susceptibility, predisposition to certain conditions, known or undocumented presence of conditions such as asthma or atopy, history of an acute respiratory illness while deployed, or acute inflammation secondary to new-onset smoking while deployed may be relevant, and are generally unknown. Analysis of health outcomes in potentially susceptible subgroups might be informative, if such groups are identified.

ONGOING EFFORTS TO EVALUATE THE POTENTIAL ASSOCIATION BETWEEN DEPLOYMENT AND RESPIRATORY CONDITIONS

To further address such concerns, a working group convened in February 2010 at the National Jewish Medical Center, Denver, CO. Physicians and scientists, including pulmonologists, occupational and preventive medicine specialists, industrial hygienists, and exposure scientists from several academic medical centers, the Department of Defense, and the Department of Veterans Affairs discussed potential risk factors for pulmonary disease and the potential utility of screening for pulmonary disease, and proposed standardized evaluation of respiratory disease. The outcomes from this conference are scheduled to be published in 2011. Additionally, a new Pulmonary Health Task Area was proposed by the Military Operational Medicine Research Program of the US Army Medical Research and Materiel Command (MRMC), with the support of the MRMC commander.

In June 2010, the Military Operational Medicine Research Program brought together a diverse group of experts to examine current medical evidence and gaps, and to formulate a multidisciplinary research plan to address the issue of deployment-related respiratory disease. The working group included representatives of all 4 military services, Veterans Affairs, and academic experts in pulmonary medicine, toxicology, pulmonary pathology, occupational and preventive medicine, computer science, and epidemiology. The Pulmonary Health Task Area Working Group proposed priorities for research for the new task in 4 specific focus areas—clinical research, animal models of toxicity, biomarkers, and exposure assessment/epidemiology—and identified 4 major data gaps: prevalence and severity of deployment-related disease, methods for diagnosis and screening, intervention and treatment, and toxicity and pathogenicity of particulate matter from Southwest Asia.

CONCLUSION

The assessment of the relationship of complex deployed environments and respiratory health is difficult, but progressing. While respiratory health outcomes do not appear to pose a major burden of postdeployment illness, the majority of potential exposure concerns in the deployed setting are inhalation hazards. The Department of Defense should continue to support the evaluation of the association between these potential hazards and the respiratory health of our service members.

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Health Effects Associated With Geographical Area of Residence During the 1991 Gulf War: A Comparative Health Study of Iraqi Soldiers and Civilians

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ABSTRACT

Context: Although Iraqis sustained the gravest exposure conditions during the 1991 Gulf War (GW), little is known about the possible relationship between environmental exposures during the GW and long-term health in Iraqis.

Objective: To study the relationship between distance from Kuwait during the GW and somatic health among Iraqi Soldiers vs civilians.

Methods: A survey questionnaire was distributed to a sample of 742 GW veterans and 413 civilians in Iraq. The odds ratios were calculated for somatic disorders as a function of distance from Kuwait during the GW, as well as a self-reported environmental exposure index.

Results: Soldiers reported a significantly higher prevalence of somatic disorders as compared to civilians. Soldiers closest to Kuwait reported significantly more somatic disorders as compared to Soldiers deployed further away from Kuwait.

Conclusion: Iraqi GW veterans are at an increased risk of numerous somatic disorders. Soldiers are at an increased risk compared to civilians, suggesting that war-associated exposures are of etiologic relevance.

INTRODUCTION

The 1991 Gulf War (GW), also known as Operation Desert Shield/Desert Storm, occurred between August 1, 1990 and June 1, 1991. The war involved Iraqi Soldiers and Allied forces from nearly 50 countries. When the Allied Soldiers returned to their home countries, large numbers of them reported a series of somatic and mental health disorders. The most common complaints were headaches, respiratory symptoms, skin disorders, fatigue, depression, symptoms of posttraumatic stress disorder (PTSD), forgetfulness, etc.[1-17] There have been a series of studies concerning health-related disorders associated with the Gulf War. However, the rates of these disorders vary markedly between studies, with a low of less than 2% to a high of 20%. The Gulf War syndrome has been used as a collective term for these symptoms, although it is not known whether such a specific constellation of symptoms actually exists or if they are part of a more general group of environmental illnesses.[14-18] Similar symptoms have been reported by Soldiers deployed to other recent conflicts, including the 2003 invasion of Iraq, albeit more limited in the numbers affected.[19-24] Epidemiological studies provide evidence for an increased prevalence of nonspecific medical symptoms, and common mental disorders among GW veterans as compared to nondeployed Soldiers, or Soldiers deployed to other conflicts.[6,11,25,26] Somatic disorders, on the other hand, do not seem to be overrepresented in GW veterans versus comparison populations.[27]

A number of factors have been evaluated as to their potential etiologic role in precipitating the GW syndrome, including sand flies, molds, infectious agents, vaccines, medical prophylaxis (for example, pyridostigmine bromide), pesticides, depleted uranium, oil-fire smoke, biological and chemical warfare agents (including sarin and cyclosarin), and

psychological stress.[6,28-30] However, no generally accepted theory has been developed to explain these symptoms.

An important limitation in prior epidemiological studies is the risk for nondifferential and differential misclassifications of exposure, as well as lack of sufficient and reliable data to allow a complete assessment of exposures of interest. Without the ability to properly monitor potential exposures from, for example, plumes from destruction of stockpiles of chemical munitions, health risk assessments become difficult. Another important limitation of studies to date is that they most typically concern veterans from non-Gulf countries, including the United States, United Kingdom, Denmark, Australia, France, and Canada. When Allied Soldiers are compared with nondeployed Soldiers, there is a range of factors that differ between the groups, apart from the Gulf War experience and environmental exposures per se. For example, most Allied forces were not accustomed to the Gulf War region's geographic, ethnic, and cultural characteristics, nor to the desert climate. Comparing Allied Soldiers new to the Iraq/Kuwait environment to controls or nondeployed Soldiers makes it difficult to evaluate other exposures of etiologic interest. Furthermore, GW veterans are more commonly single, less educated, and/or with a lower socioeconomic status and exhibit a higher participation rate in surveys as compared to nondeployed comparison groups.[31,32] A major limitation is the fact that most previous studies have been conducted on Soldiers who have left the Gulf War Region and have been in their native country for some time.

Studies comparing Iraqi Soldiers (both deployed and not deployed to Kuwait) during the GW with Iraqi civilians would attenuate differences between the groups' prior experiences (for example, they are used to the desert environment and local culture), and enhance the ability to identify possible GW-related exposures of relevance. By including civilians who were living in the same geographical areas to which Soldiers were deployed, apart from Kuwait per se, we were able to substantially reduce the number of potential Soldier-specific exposures of interest, assuming Soldiers were more exposed than civilians to such agents. Iraqi Soldiers were also the group most at risk for exposure to war-related factors due to limited protective equipment and intensive assault from the Allied forces. To the best of our knowledge, Iraqi Soldiers did not receive the wide array of preventive biological and pharmacological treatments provided to the Allied forces.

There have been prior studies of the mental and somatic well-being of Iraqi Gulf War veteran refugees living in the United States.[33-35] In general, these studies report poor mental health and high prevalence of PTSD, depression, and anxiety among them.

The aims of this study, conducted 10 years after the GW, are to determine if self-reported medical conditions varied by distance from Kuwait, and if self-reported medical conditions varied between Iraqi Soldiers deployed during the Gulf War and civilians after controlling for age, years of military service, and education. The 2 main hypotheses tested were:

- Soldiers report more symptoms than civilians, controlling for distance from the Kuwait war zone.
- Soldiers deployed further away from the Kuwait war front suffered less from physical symptoms as compared to Soldiers deployed in Kuwait.

Participants and Setting

The study sample selected consisted of a convenience sample of men who were Soldiers, or civilians, between the ages of 18-45 years and resided in the Iraq provinces of Basrah or Messanat the time of the 1991 Gulf War. They had to live within 300 km of the Kuwait border to be eligible for the study. Participants were enrolled during 2002. Three surgical residents from Basrah University were trained by one of the coauthors to administer a questionnaire to participants and their acquaintances (Soldiers and civilians) found in waiting rooms at 3 local medical clinics and government outpatient clinics. Individuals who accompanied patients attending the 3 outpatient clinics in the Basrah and Messan Provinces in Iraq were eligible to participate in the study. Thus, in order to minimize selection bias, we only interviewed persons accompanying patients to the health clinics. The 3 clinics were run by the Iraq Ministry of Health and were available to all Iraqis, further limiting the possibility to differential recruitment biases. Potential participants were approached by the medical residents and asked about their interest in participating in a study evaluating long-term health effects from the Gulf War. Participation was voluntary and respondents were able to withdraw from the study at any time.

Once verbal consent was obtained, the medical residents proceeded to ask each question and read their respective response choices in Arabic and recorded the participants' responses.

A structured interviewer-administered questionnaire was based on the survey developed and used in several studies of large numbers of US Gulf War Veterans.[36,37] This questionnaire was initially designed and validated at the University of Iowa, the Iowa Department of Health, and the Centers for Disease Control and Prevention, and was used with permission. The original questionnaire was translated into Arabic and back-translated into English to ensure the validity of the phrasing of the questions. In this study, we excluded a total of 24 questions from the original English version since 12 questions were not applicable, and an additional 12 questions were deemed culturally too sensitive.

Briefly, the questionnaire contained questions concerning socioeconomics, smoking history, age, height, and weight. Body mass index (kg/m^2) was calculated and participants were classified into 3 categories: underweight, <18.5; normal weight, ≥ 18.5 to <25; overweight to obese, ≥ 25. Obese participants were included in the overweight category because there were very few obese participants. The participants' residential or deployed distance from Kuwait was queried. Distance from Kuwait was classified into 3 zones: $zone_1$ consisted of Soldiers in Kuwait, 1 to 100 km; $zone_2$, participants (Soldiers and civilians) 101 to 200 km from Kuwait; and $zone_3$, participants (Soldiers and participants) between 201 to 300 km from Kuwait. Out of a total of 1200 respondents, 45 respondents were removed from the analysis because they had resided between 300 km to 860 km from Kuwait. We collected self-reported years of military experience, military status (deployed/nondeployed, Soldier/civilian) and primary job at time of the survey in 2002 and prior to 1990. Fifteen primary employment classifications were available. They were collapsed into the following categories: students, unskilled workers, Soldiers, skilled workers (farmers, self-claimed skilled workers, and clerks), and professional workers (teachers, doctors, self-claimed professionals, and those in the health profession).

The survey also included detailed questions regarding possible exposures to a range of environmental contaminants in water, food, ground, and the air, including burning oil wells. The participants were asked to respond to whether they had had any of a number of specific medical conditions during the last year. If they responded affirmatively to any of the medical conditions, they were asked whether the conditions had debuted before, during or after the Gulf War. Respondents were asked about symptoms experienced in the month before the interview. They were asked to rate to what degree they were affected by specific symptoms. Scores ranged from 1 (symptom not experienced) to 5 (extremely affected). Participants were asked if, during the last year, they had had any of 35 physical health symptoms, including fatigue, fever, inflammation, neurological symptoms, seizures and convulsion, headaches, cardiovascular symptoms, gastrointestinal symptoms, dermatological signs and symptoms, and musculoskeletal symptoms.

With regard to medical diseases/disorders, participants were presented a list of 57 specified conditions and asked if they had one or more during the last year. If so, follow-up questions related to whether the disorders had debuted before, during, or after the GW. All but 6 specific medical conditions were collapsed into broader medical history categories by body system (Table 1). These categories included hypertension, cardiovascular disease (coronary heart disease and tachycardia), headaches (recurrent headaches and migraines), respiratory disease (bronchitis, pneumonia, tuberculosis, and other lung condition), asthma, ear/nose/throat diseases (chronic sinusitis and ear infection), ulcer disease, gastrointestinal disease (gastritis, enteritis, colitis, hepatitis, cirrhosis, frequent diarrhea), diabetes, genitourinary disease (recurrent bladder infections, renal disease, and any disease of the genital organs), hematology disease (aplastic anemia, leukemia, lymphoma, and any other cancer), rheumatologic disease (arthritis, rheumatism, fibromyalgia, or fibrositis), musculoskeletal disease (lumbago and any disease of the muscles or tendons), chronic fatigue syndrome, allergy (rhinitis and any allergy), skin disorders (skin cancer, tumors, cysts, eczema, psoriasis, dermatitis, and any disease of the hair or scalp including hair loss). A category referred to as "other medical conditions" was created for medical conditions with very low reported prevalence. Other medical conditions included neurological diseases (repeated seizures, convulsions or blackouts, neuralgia or neuritis), endocrine diseases (thyroid and other endocrine disorders), infectious diseases (malaria,

leishmaniasis, chronic mononucleosis, and hepatitis), chronic candidiasis, amnesia, and sleep apnea.

All aspects of this study were approved by the Human Investigative Committees at Basrah University and Wayne State University as a collaborative research investigation. Arnetz et al[38] provide further details of study design.

Statistical Analyses

The proportions of Soldiers and civilians (no civilians in $zone_1$, the epicenter of the war) in each zone were calculated. Means and standard deviations for continuous variables are reported. Chi-square (χ^2) tests were used to determine differences between groups for categorical variables, and *P* values are reported. Yates's correction for χ^2 tests was used as indicated by the data. We calculated unadjusted odds ratios (ORs) and 95% confidence intervals (CIs) to determine the univariate associations between military status and self-reported medical conditions. We then reported the adjusted ORs for these associations controlling for age, smoking status, and years of education based on unconditional logistic regression modeling. Age and years of education were included as continuous variables. We also examined associations between distance from Kuwait and self-reported medical conditions. Specifically, we compared $zone_1$ to $zone_3$ and $zone_2$ to $zone_3$ where $zone_3$ served as the reference group. All reported *P* values are 2-tailed, and *P* values $\leq .05$ were considered statistically significant. All analyses were performed using SAS version 9.1.2 (SAS Institute, Cary, NC).

Table 1. Reported medical history by military status: unadjusted and adjusted associations between somatic disorders and military status.

Somatic Disorders	Soldiers n_1=742 CD: Count by Disorder CD (%n_1)	Civilians n_2=413 CD (%n_2)	*P**	Unadjusted Odds Ratio (95% CI)	Adjusted† Odds Ratio (95% CI)
Hypertension	77 (11.3)	28 (6.9)	.018	1.72 (1.09-2.70)[a]	1.22 (0.74-2.02)[b]
Cardiac disorder	90 (13.1)	32 (7.8)	.007	1.78 (1.17-2.72)[c]	1.73 (1.08-2.77)[a]
Headaches	215 (30.0)	83 (20.2)	.003	1.70 (1.27-2.26)[d]	1.43 (1.04-2.00)[a]
Respiratory disorder	106 (15.1)	39 (9.6)	.008	1.68 (1.14-2.48)[c]	1.94 (1.22-3.09)[c]
Asthma	31 (4.6)	21 (5.2)	.666	0.88 (0.50-1.56)[b]	0.77 (0.42-1.42)[b]
Ear/nose/throat disorder	91 (13.3)	44 (10.8)	.223	1.27 (0.87-1.86)[b]	1.22 (0.80-1.86)[b]
Ulcer	42 (6.2)	17 (4.2)	.156	1.52 (0.85-2.70)[b]	1.42 (0.75-2.66)[b]
Gastrointestinal disorder	253 (36.0)	113 (27.8)	.005	1.46 (1.12-1.91)[d]	1.60 (1.17-2.18)[c]
Diabetes	24 (3.6)	11 (2.8)	.443	1.33 (0.64-2.74)[b]	1.26 (0.55-2.86)[b]
Genitourinary disorder	131 (18.5)	40 (9.8)	<.001	2.09 (1.44-3.05)[e]	1.82 (1.18-2.80)[c]
Hematology disorder	09 (1.3)	11 (2.7)	.105	0.49 (0.20-1.18)[b]	0.68 (0.23-2.01)[b]
Rheumatology disorder	87 (12.8)	37 (9.1)	.063	1.47 (0.98-2.20)[b]	1.06 (0.68-1.64)[b]
Musculoskeletal disorder	195 (27.3)	86 (21.0)	.019	1.41 (1.06-1.89)[a]	1.28 (0.92-1.78)[b]
Chronic fatigue	56 (8.1)	11 (2.7)	.001	3.19 (1.65-6.17)[d]	6.99 (2.49-19.66)[d]
Allergies	253 (36.6)	131 (32.0)	.117	1.23 (0.95-1.59)[b]	1.42 (1.06-1.91)[a]
Skin disorders	181 (26.6)	72 (17.7)	.001	1.69 (1.24-2.29)[d]	1.66 (1.16-2.36)[c]
Miscellaneous disorders	46 (6.5)	20 (4.9)	.267	1.36 (0.79-2.33)[b]	1.15 (0.63-2.09)[b]

Percentages are based on non-missing data.
Odds ratio represents the magnitude of association between medical condition and military status with civilians.
*Represents the p-value for χ^2 tests for each medical condition by military status.
†Adjusted for age, smoking status, and years of education.
a: *P*<.05
b: No significant difference
c: *P*<.01
d: *P*<.001
e: *P*<.0001

Results

Of 1200 participants asked to participate in the survey, 1155 accepted for an overall response rate of 96.3%. Sixty-four percent (n=742) of the participants had been deployed as Soldiers during the 1990-1991 GW. Among the Soldiers, 168 (22.6%) had been deployed to $zone_1$, the Kuwait war zone; 253 (34.1%) to $zone_2$; and 321 (43.4%) to $zone_3$, the reference zone. Among the 413 civilians, 147 (35.6% of all civilians) had resided in $zone_2$ and 266 (64.4%) in $zone_3$ during the war.

Table 2 depicts demographics by military status. Soldiers were significantly older, and had fewer years of formal schooling as compared to civilians. They also reported higher income, less underweight but worse self-rated health. It was more typical that civilians had been students prior to the 1990 GW. There were no significant differences in smoking history between Soldiers and civilians.

Table 1 depicts unadjusted and adjusted (age, smoking status, and years of education) odds ratios for 17 defined somatic disorders. Based on unadjusted odds ratios, the 2 study groups (Soldiers vs non-Soldiers) differed significantly on 9 of the somatic disorders, including a higher risk of hypertension, cardiac disease, headaches, respiratory disease, gastrointestinal, genitourinary, musculoskeletal, chronic fatigue, and skin disorders among Soldiers as compared to civilians. However, after adjusting for age, smoking status, and years of education, the odds ratios remained statistically elevated for 8 out of the original 9, including hypertension, cardiac disease, headaches, respiratory disease, gastrointestinal disorders, diabetes, chronic fatigue, allergy, and skin disorders. Following the adjustment, Soldiers also exhibited a significantly higher risk of suffering from allergies as compared to civilians. In the second phase of the analysis, we were interested in studying whether there was a dose-response relationship between zones (distance from the Kuwait war zone) and the specific somatic disorders studied, regardless of military status. Table 3 shows that the odds ratios were significantly elevated for 9 of the 17 somatic disorders in $zone_1$ as compared to $zone_3$, the reference zone. With regard to $zone_2$ vs $zone_3$, 10 somatic disorders exhibited significantly elevated odds ratios. The odds ratios for respiratory disease, rheumatologic disease, chronic fatigue syndrome, allergies, and skin disorders were elevated both in $zone_1$ and $zone_2$ as compared to the reference zone. Using $zone_3$ as the reference category, we looked at the possible increased risks of suffering from somatic disorders among Soldiers only exposed to the most intense war zone, ie, $zone_1$. The risks were increased for 9 of the 10 somatic disorders studied (Table 4).

Table 2. Demographic data by military status.

	Civilians n_1=413	Soldiers n_2=742	All Participants N=1155
	Mean (SD)		
Age, years*	28.7 (5.6)	32.1 (8.0)	31.0 (7.5)
Military service, years*	10.7 (5.6)	14.1 (8.0)	13.0 (7.5)
Body mass index	20.7 (2.4)	20.9 (2.7)	20.8 (2.6)
	CC: Count by Category		
	CC (%n_1)	CC (%n_2)	CC (%N)
Education status*			
8th grade or less	73 (18.3)	212 (28.6)	285 (25.3)
8th grade or more, no high school	150 (37.5)	218 (30.1)	368 (32.7)
Completed high school	91 (22.8)	161 (22.2)	252 (22.4)
Some college (incomplete)	20 (5.0)	28 (3.9)	48 (4.3)
Bachelors degree/higher	66 (16.5)	106 (14.6)	172 (15.3)
Smoking Status			
Never smoked	205 (50.1)	344 (47.3)	549 (48.3)
Former smoker	62 (15.2)	115 (15.8)	177 (15.6)
Current smoker	142 (34.7)	268 (36.9)	410 (36.1)
Income*			
Less than $20,000	373 (94.7)	606 (84.3)	979 (88.0)
$20,000 to < $50,000	6 (1.5)	66 (9.2)	72 (6.5)
$50,000 or more	15 (3.8)	47 (6.5)	62 (5.6)
Primary job prior to 1990*			
Student	195 (49.7)	239 (34.8)	434 (40.2)
Unskilled worker	21 (5.4)	63 (9.2)	84 (7.8)
Skilled worker	34 (8.7)	112 (16.3)	146 (13.5)
Soldier	66 (16.8)	112 (16.3)	178 (16.5)
Professional	38 (9.7)	57 (8.3)	95 (8.8)
Other	38 (9.7)	104 (15.1)	142 (13.2)
Primary job at time of survey*			
Student	25 (7.7)	23 (4.7)	48 (5.9)
Unskilled worker	25 (7.7)	75 (15.4)	100 (12.3)
Skilled worker	74 (22.8)	206 (42.3)	280 (34.5)
Soldier	8 (2.5)	32 (6.6)	40 (4.9)
Professional	192 (59.3)	151 (31.0)	343 (42.3)
Body mass index classification*			
< 18.5: underweight	101 (24.5)	145 (19.5)	246 (21.3)
≥ 18.5 to < 25: normal	301 (72.9)	586 (79.0)	887 (76.8)
≥ 25: overweight to obese	11 (2.7)	11 (1.5)	22 (1.9)
Self-rated health status at time of survey*			
Excellent	16 (3.9)	32 (4.3)	48 (4.2)
Very good	100 (24.5)	131 (17.7)	231 (20.1)
Good	258 (63.2)	465 (62.8)	723 (63.0)
Fair	27 (6.6)	98 (13.2)	125 (10.9)
Poor	7 (1.7)	14 (1.9)	21 (1.8)

Percentages are based on non-missing data.
* *P* (range between < .05 and < .001) represents the *P* value for overall χ^2 tests.

DISCUSSION

During the last 16 years, there have been a large number of studies of medical symptoms and diseases among veterans of the 1991 Gulf War.[1-13] More recently, studies conducted among GW veterans 10 years after the completion of the active first Gulf War are starting to appear.[27] Compared to other recent conflicts (for example, the 2003 wars in Iraq and Afghanistan), the GW appears to have resulted in a higher prevalence of medical symptoms with longer durations.[19]

Studies to date have mostly dealt with members of the Allied forces. Epidemiological studies typically compare Soldiers that have been deployed to the Gulf in 1991 to nondeployed Soldiers, or Soldiers deployed elsewhere. However, these studies are characterized by a number of important limitations. Typically, Soldiers deployed are younger, less educated, of lower socioeconomic status and military rank, and more often single.[18,31] Medical charts, including total dosage of vaccines and medical prophylaxis received, are not always known. Details about exposure during the war are commonly inferred from the location of the Soldier's battalion rather than based on person-specific data. Modeling of exposure to oil-well smoke, for example, is also complex. Exposure assessments based on self-reported data and modeled exposure do not necessarily coincide.[31] More seriously, however, Allied Soldiers deployed to Iraq experienced a number of potentially stressful exposures, apart from GW-specific factors, including being away from familiar territory, the desert climate, sand flies, and an environment with different microbial composition from their natural habitat. A major limitation is also the fact that most studies of Allied forces occurred some time after the Soldiers have returned to their native countries. We are thus unable to pinpoint more specifically at what process purported war-related symptoms debut. There is also no compensation scheme available to Iraqi Soldiers as compared to US and UK Soldiers. All of these factors might be of importance in identifying reasons for the increased rates of medical symptoms in GW veterans, and these exposures differ systematically and nonrandomly between GW veterans and nondeployed referents. In terms of exposure, Iraqi Soldiers and civilians, by most accounts, were exposed to higher doses of war-related environmental factors, and for a considerably longer period of time. Thus, there are numerous reasons why there is a need for long-term follow-up health studies of Iraqis, regardless of whether they were deployed during the Gulf War or not.

Table 3. Reported medical history by zone and odds ratios (95% CI) for zones 1 vs 3 and zones 2 vs 3.

Somatic Disorders	All Zones N=1155	Zone 1 n_1=168	Zone 2 n_2=400	Zone 3 n_3=587	*P**	P_{Trend}†	Zones 1 vs 3‡	Zones 2 vs 3§
	CD: Count by Disorder						Odds Ratio (95% CI)	
	CD (%N)	CD (%n_1)	CD (%n_2)	CD (%n_3)				
Hypertension	105 (9.7)	18 (14.9)	25 (6.7)	62 (10.6)	.017	.871	1.48 (0.84-2.60)[a]	1.66 (1.02-2.69)[b]
Cardiac disorder	122 (11.2)	20 (16.5)	22 (5.7)	80 (13.6)	<.001	.258	1.26 (0.74-2.14)[a]	2.61 (1.60-4.26)[c]
Headaches	298 (26.4)	1 (54.7)	71 (18.1)	146 (24.9)	<.001	<.001	3.65 (2.51-5.31)[c]	1.50 (1.09-2.06)[b]
Respiratory disorder	145 (13.1)	42 (31.3)	44 (11.3)	59 (10.1)	<.001	<.001	4.09 (2.60-6.43)[c]	0.88 (0.60-1.32)[a]
Asthma	52 (4.8)	11 (9.8)	7 (1.8)	34 (5.8)	<.001	.975	1.77 (0.87-3.61)[a]	3.29 (1.44-7.51)[d]
Ear/nose/throat disorder	135 (12.4)	130 (95.6)	27 (7.0)	85 (14.9)	<.001	.597	1.43 (0.86-2.38)[a]	2.25 (1.43-3.53)[e]
Ulcer	59 (5.4)	13 (11.4)	17 (4.4)	29 (4.9)	.012	.054	2.48 (1.25-4.93)[e]	1.12 (0.61-2.07)[a]
Gastrointestinal disorder	366 (32.9)	58 (42.9)	103 (26.6)	205 (34.9)	.008	.852	1.40 (0.96-20.05)[a]	1.48 (1.12-1.97)[d]
Diabetes	35 (3.3)	7 (6.3)	6 (1.7)	22 (3.8)	.038	865	1.71 (0.71-4.11)[a]	2.31 (0.93-5.76)[a]
Genitourinary disorder	171 (15.3)	50 (35.5)	51 (13.0)	70 (11.9)	<.001	<.001	4.06 (2.65-6.21)[c]	0.91 (0.62-1.33)[a]
Hematology disorder	20 (1.9)	4 (3.6)	44 (37.6)	9 (1.5)	.402	.203	2.40 (0.73-7.94)[a]	0.84 (0.31-2.28)[a]
Rheumatology disorder	124 (11.4)	27 (23.7)	14 (3.7)	83 (14.1)	<.001	.789	1.88 (1.15-3.08)[b]	4.34 (2.43-7.77)[c]
Musculoskeletal disorder	281 (25.0)	78 (53.4)	80 (20.4)	123 (21.0)	<.001	<.001	4.33 (2.96-6.33)[a]	1.03 (0.75-1.42)[a]
Chronic fatigue	67 (6.1)	38 (30.2)	27 (7.0)	2 (0.3)	<.001	<.001	126.3(29.9-532.8)[c]	0.05 (0.01-0.19)[c]
Allergies	384 (34.9)	61 (47.3)	107 (27.8)	216 (36.8)	<.001	.665	1.54 (1.05-2.26)[b]	1.51 (1.14-2.00)[d]
Skin disorders	253 (23.3)	44 (37.6)	67 (17.5)	142 (24.2)	<.001	.2285	1.89 (1.24-2.87)[d]	1.51 (1.09-2.08)[b]
Miscellaneous disorders	66 (5.9)	23 (17.0)	17 (4.4)	26 (4.4)	<.001	<.001	4.43 (2.44-8.05)[c]	1.02 (0.54-1.90)[a]

Percentages are based on non-missing data.
*Represents the *P* value for overall χ^2 test.
†P_{Trend} represents the *P* value for trend test.
‡OR represents the magnitude of association between medical condition and zone 1 where zone 3 is the reference zone.
§OR represents the magnitude of association between medical condition and zone 2 where zone 3 is the reference zone.
Note: Zone 1=In Kuwait; Zone 2=100-190 km from Kuwait; Zone 3=360 km from Kuwait.
a: No significant difference
b: *P*<.05
c: *P*<.0001
d: *P*<.01
e: *P*<.001

To the best of our knowledge, this is the first epidemiological study of the health of Iraqi Soldiers being part of the GW operations in 1991. Moreover, we have assessed Iraqi civilians using well-validated measures. We applied a theoretical dose-response exposure-effect model, based on the distance from Kuwait. The theoretical dose-response model is based on the a priori assumption that:

- Soldiers, as compared to civilians, controlling for distance from Kuwait, were exposed to higher doses and a more varied assortment of environmental factors, including biological and chemical warfare agents, oil fire smoke, and mental stressors.
- Soldiers closer to Kuwait should exhibit a higher cumulative harmful exposure dose as compared to Soldiers further away from Kuwait.

As reported in many studies of Allied forces, Soldiers included in our convenient sample, were less educated and had lower income.[18,24] However, in contrast to many studies of Allied forces, Soldiers in our sample were older.[18,31] There were no differences in smoking habits between deployed Soldiers and civilian controls. Prior to the 1991 GW, military service was obligatory for all Iraqi men. This fact is supported by the fact that Soldiers in this study had a mean military service period of 14.1 years as compared to 10.7 for civilians. Many of the Soldiers as well as the non-Soldiers had most likely been part of prior wars, predominantly the war between Iran and Iraq. Overall, we believe our convenient sample is representative for Iraqi Soldiers and civilians in the areas studied.

The odds ratios for a number of somatic disorders were elevated for Soldiers as compared to civilians, including cardiac disease, headaches, respiratory disease, chronic fatigue syndrome, allergies, and skin disorders. This held true even after adjusting for possible confounders such as age, smoking status, and years of education. A number of studies of Allied

Table 4. Reported medical history among study group and odds ratios (95% CI) for zones 1 vs 3 and zones 2 vs 3.

Somatic Disorders	All Zones N=742	Zone 1 n_1=168	Zone 2 n_2=253	Zone 3 n_3=321	*P**	Zones 1 vs 3†	Zones 2 vs 3‡
	CD: Count by Disorder					Odds Ratio (95% CI)	
	CD (%N)	CD (%n_1)	CD (%n_2)	CD (%n_3)			
Hypertension	77 (11.3)	18 (14.9)	19 (8.0)	40 (12.5)	.102	1.22 (0.67-2.23)[a]	1.65 (0.93-2.92)[a]
Cardiac disorder	90 (13.1)	20 (16.5)	16 (6.6)	54 (16.8)	.001	0.98 (0.56-1.72)[a]	2.87 (1.60-5.15)[b]
Headaches	215 (30.0)	81 (54.7)	46 (18.6)	88 (27.4)	.001	3.2 (2.13-4.80)[c]	1.65 (1.10-2.47)[d]
Respiratory disorder	106 (15.1)	42 (31.3)	25 (10.1)	39 (12.2)	.001	3.30 (2.02-5.42)[c]	1.23 (0.72-2.09)[a]
Asthma	31 (4.6)	11 (9.8)	4 (1.7)	16 (5.0)	.003	2.08 (0.93-4.62)[a]	3.12 (1.03-9.46)[d]
Ear/nose/throat disorder	91 (13.3)	23 (19.5)	19 (7.8)	49 (15.3)	.003	1.34 (0.78-2.32)[a]	2.13 (1.22-3.73)[e]
Ulcer	42 (6.2)	13 (11.4)	11 (4.5)	18 (5.6)	.036	2.17 (1.03-4.58)[d]	1.26 (0.58-2.70)[a]
Gastrointestinal disorder	253 (36.0)	58 (43.0)	70 (28.3)	125 (38.9)	.006	1.18 (0.79-1.78)[a]	1.61 (1.13-2.30)[e]
Diabetes	24 (3.6)	7 (6.3)	5 (2.2)	12 (3.7)	.167	1.72 (0.66-4.47)[a]	1.74 (0.60-5.01)[a]
Genitourinary disorder	131 (18.5)	50 (35.5)	35 (14.1)	46 (14.3)	.001	3.28 (2.06-5.23)[c]	1.02 (0.63-1.64)[a]
Hematology disorder	9 (1.3)	4 (3.6)	1 (0.4)	4 (1.3)	.051	2.96 (0.73-12.05)[a]	3.07(0.34-27.61)[a]
Rheumatology disorder	87 (12.8)	27 (23.7)	12 (4.9)	48 (15.0)	.001	1.77 (1.04-3.00)[d]	3.38 (1.76-6.53)[b]
Musculoskeletal disorder	195 (27.3)	78 (53.4)	55 (22.2)	62 (19.3)	.001	4.79 (3.13-7.35)[c]	0.84 (0.56-1.26)[a]
Chronic fatigue	56 (8.1)	38 (30.2)	18 (7.4)	0 (0.0)	.001	277 (16.6-4558.60)[c]	0.02 (0.001-0.32)[c]
Allergies	253 (36.6)	61 (47.3)	68 (28.2)	124 (38.6)	.001	1.42 (0.94-2.15)[a]	1.60 (1.12-2.29)[e]
Skin disorders	181 (26.6)	44 (37.6)	40 (16.5)	97 (30.2)	.001	1.39 (0.89-2.17)[a]	2.19 (1.45-3.31)[b]
Miscellaneous disorders	66 (5.9)	23 (17.0)	17 (4.4)	26 (4.4)	.001	5.29 (2.55-10.98)[c]	0.84 (0.36-1.93)[a]

Percentages are based on non-missing data.
*Represents the *P* value for overall χ^2 test.
† OR represents the magnitude of association between medical condition and zone 1 where zone 3 is the reference zone.
‡ OR represents the magnitude of association between medical condition and zone 2 where zone 3 is the reference zone.
Note: Zone 1 = In Kuwait; Zone 2 = 100-190 km from Kuwait; Zone 3 = 360 km from Kuwait.
a: No significant difference
b: *P*<.001
c: *P*<.0001
d: *P*<.05
e: *P*<.01

forces also report an increase in mental disorders, including depression and anxiety, and chronic fatigue syndrome.[6,11,19,23] Studies of Allied forces have also reported an increased prevalence of skin disorders[31] and respiratory symptoms, including bronchitis and asthma.[29] The increased risk for respiratory disease in this study of 1.94 (95% CI, 1.22-3.09) is similar to that reported by Iowa Persian Gulf Study Group.[36] Our study confirms prior findings of GW veterans that psychosomatic disorders, including headaches and fatigue, appear to be the most systematically increased somatic and psychosomatic disorders.[6,8,18,21,31]

With regard to our á priori hypothesis of a dose-response relationship between an increased odds ratios for somatic disorders and closeness to Kuwait, we confirmed the hypothesis for a total of 15 out of 16 conditions studied. Even after controlling for a person's distance from Kuwait during the GW, we confirmed an increased risk for over half of the somatic disorders studied. However, counter to our á priori hypothesis, the odds ratios were not uniformly increased for persons closest to Kuwait. Rather, both $zone_1$ and $zone_2$ appeared to be at increased risk for symptoms. Interestingly, however, headaches, chronic fatigue, allergies, and skin disorders were all more common in the 2 first zones as compared to $zone_3$. In the most refined analysis, we studied only Soldiers and medical conditions and symptoms as a function of distance from Kuwait. Restricting the analysis to Soldiers only, we still found a dose-response relationship for 14 of the 17 somatic disorders studied. Once again, the increased risks for specific somatic disorders seemed to be related to both $zone_1$ and $zone_2$.

In reality, most of the fighting occurred in the first 2 zones, that is, within 200 km of Kuwait. Environmental and war-specific exposures, including oil well smoke and aerial bombings, were also most frequent in this area.

In conclusion, this study of Iraqi GW veterans and civilians confirms many of the prior findings from Allied GW veterans. Moreover, Iraqi Soldiers exhibited significantly more somatic disorders than did civilians. Closeness to Kuwait was an independent risk factor for most somatic disorders. Since our sample population is used to the climate, culture, and microbial characteristics of Iraq, many of the confounders from prior epidemiological studies of Allied GW veterans can be eliminated as possible precipitators of GW-related symptoms and syndromes. Iraqi Soldiers were not administered any of the biological and pharmacological treatments, including anthrax vaccine, that most Allied Soldiers received. Nevertheless, they exhibited a higher rate of a range of somatic disorders, as compared to Iraqi civilians. This suggests there were other risk factors for these disorders than the medical countermeasures. We have reported a dose-response relationship between distance from Kuwait during the 1991 GW and a range of somatic disorders studied. This suggests that one or more war-associated factor or factors contributed to the findings. We are now in the process of planning further studies of the Iraqi cohort in order to better define prior environmental exposures and current somatic and mental well-being.

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Marine Corps Breacher Training Study: Auditory and Vestibular Findings

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ABSTRACT

This article presents an overview of a contemporary research protocol conducted at the Marine Corps Weapons Training Battalion, Quantico, VA. The study was a comprehensive collaborative research initiative that evaluated a variety of environmental, auditory, and vestibular factors among Marines enrolled in the Breacher Training Course. The length of each course is 2 weeks and involves multiple exposures to blast overpressure and physical shock from ingress strategies used during the training. Observational data were collected pretraining, during training, and posttraining between September and June 2007. There was no change in the way the Marines conducted their training, and all data were collected based on the actual training scenario. The primary objective of this research protocol was to determine if Marines in the Breacher Training Course were at risk of injury during standard training practices. The principal conclusions were that hearing loss was statistically and clinically significant whereas the vestibular findings were overall unremarkable.

BACKGROUND

In the tactical environment, initial breaching is an important specialty. If the breach into a potentially hostile location is not successful or the entry portal is not opened in a rapid fashion, enemy combatants will have time to react and military operatives and innocents may well be put in jeopardy. This paper is an overview of a contemporary research protocol conducted at the Marine Corps Weapons Training Battalion, Quantico, VA. This study was a comprehensive collaborative research initiative that evaluated a variety of environmental, auditory, and vestibular factors among Marines enrolled in the Breacher Training Course. The length of the course was 2 weeks and involved multiple exposures to blast overpressure and physical shock from ingress strategies used during the training. Observational data were collected pretraining, during training, and posttraining between September and June 2007. There was no change in the way the Marines conducted their training, and all data were collected based on the actual training scenario. Table 1 presents the series of evaluation methods. The primary objective of this research protocol was to determine if students in the breacher training were at risk of injury during standard training practices. In view of the specific area of the author's expertise, as well as in the interest of brevity, this article focuses solely on the auditory and vestibular affects of the breacher injury study.

AUDITORY EFFECTS

Introduction

Hearing is a critical Warrior sensor that increases their survivability and lethality. When hearing loss is present, the ability to conduct auditory tasks is greatly

Table 1. Categories Investigated and their Corresponding Variables

Areas of Investigation	Evaluation Factors
Pressure	2 free field or interior overpressure measurements 28 breacher overpressure measurements 2 gauges in the helmet, 2 gauges on the vest
Head Orientation	Yaw Pitch Roll
Air Sampling	Lead Copper
Auditory	Immittance Acoustic reflexes Thresholds Distortion product otoacoustic emissions
Vestibular	Dynamic visual acuity test Limits of stability Modified clinical test of sensory integration on balance

diminished. Good hearing is required to perform such tasks as localizing sound, gauging auditory distance, identifying a sound source, and understanding verbal orders and radio communications. This multidimensional sense provides an indispensable amount of information on the battlefield. Good hearing can mean the difference between life and death in combat, as well as in training.

Verbal communications, as well as hand and arm signals between dismounted Warriors, remain the primary means of communication on the battlefield. Although technological advances have improved battlefield communication systems, these electronic advances cannot overcome the fact that human hearing is required to complete communication. No matter how sophisticated the communication system, effective communication requires normal hearing.

Studies have shown that the likelihood of accomplishment of a unit's mission is directly proportional to the ability of the personnel in that unit to communicate effectively. If effective communication drops by 30%, the capability to control the unit to accomplish the task drops by 30% as well.[1] During combat, this problem is magnified by the chaotic environment, the complexity of the problems encountered, and the reaction time required. Warriors' hearing must be protected from damage caused by hazardous impact and sustained noise without compromising the ability to hear and communicate in these environments. Hearing loss is an invisible injury that is often viewed as having little or no impact on military operations. However, sound is frequently the first source of information a Warrior has before direct contact with the enemy. Unlike visual information, auditory cues come to us from all directions, through darkness, and over or through many obstacles. Aggressive action produces sound the enemy cannot hide or camouflage. The ability to hear and recognize combat-relevant sounds is a vital component to situational understanding and provides a tactical advantage. Noise-induced hearing loss is a tactical risk and threatens both individual and unit combat effectiveness. Hearing loss due to noise exposure usually occurs in the high frequencies. Since speech sounds that give meaning to words (for example, consonants such as ch, th, sh, f, and p) are high-frequency sounds as well as the sounds that provide the ability to determine the signature of weapons and vehicles. High-frequency hearing loss is particularly devastating to military operations. The ability to distinguish the sounds of different weapons, both friendly and enemy, is a combat-critical skill. If the sounds of weapons fire are coming from the next block of buildings, knowing whether it is enemy or friendly, small arms or automatic weapons, small caliber or large caliber, or whether it is a rocket propelled grenade or an antitank weapon determines a Warrior's reaction and is critical information available only with good hearing. Oftentimes, Warriors are exposed to an explosion such as an improvised explosive device or a mortar round and have no apparent injuries, but can sense their hearing has decreased and tinnitus is present. With no visible injuries, the Warriors return to their duties. This is where the term "invisible injury" is derived.

Hearing Threshold Analyses

Pure tone hearing thresholds, the lowest level of sounds that can be detected 50% of the time, were measured using a GSI 61 clinical grade audiometer (Grason-Stadler, Inc, Eden Prarie, MN) with E-A-RTone 3A insert earphones (Aearo Company, Indianapolis, IN). Paired data of hearing thresholds of 38 subjects (76 ears) were compared pretraining and posttraining. All subjects were wearing Department of Defense (DoD) approved hearing protection of their choice. All subjects were noise free for 14 hours before data collection and only threshold data from subjects with normal middle ear function were collected. Since the data were paired, no weighting for age or gender was used. The differences in hearing thresholds at 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, and 8 kHz were evaluated before training began and after training was completed.

The breacher training resulted in:

- A slight increase in hearing threshold at 500 Hz ($\bar{X}$=0.3289, SD=4.3463). This increase was not statistically significant: t_{75}=-0.66, P>.01, 2-tailed.
- An increase in hearing threshold at 1 kHz ($\bar{X}$=1.8421, SD=4.46035). This increase was statistically significant: t_{75}=-3.6, P<.01, 2-tailed.
- An increase in hearing threshold at 2 kHz ($\bar{X}$=1.8667, SD=4.33159). This increase was statistically significant: t_{75}=-3.732, P<.01, 2-tailed.
- An increase in hearing threshold at 3 kHz ($\bar{X}$=1.8421, SD=3.72756). This increase was statistically significant: t_{75}=-4.308, P<.01, 2-tailed.

- A slight increase in hearing threshold at 4 kHz ($\bar{X}$=1.0526, SD=4.34479). This increase was not statistically significant: t_{75}=-2.112, P>.01, 2-tailed.
- A slight increase in hearing threshold at 6 kHz ($\bar{X}$=1.3816, SD=5.45275). This increase was not statistically significant: t_{75}=-2.209, P>.01, 2-tailed.
- A slight increase in hearing threshold at 8 kHz ($\bar{X}$=8.553, SD=7.67629). This increase was not statistically significant: t_{75}=-0.971, P>.01, 2-tailed.

Even though there is statistically significant positive threshold shifts at 3 individual frequencies, the results only address a change in the means using very sensitive and robust analyses. Thus, it does not reflect significance with respect to the actual number of significant positive threshold shifts as defined by the DoD standard of an average shift of 10 dB in either ear at 2 kHz, 3 kHz, and 4 kHz. Therefore, another analysis must be performed using the same data set in a nonparametric delineation to if there is an increase in the number of significant threshold shifts between pretraining and posttraining.

Calculations to determine if there were any significant threshold shifts according to the DoD standard of an average shift of 10 dB in either ear at 2 kHz, 3 kHz, and 4 kHz were performed. The number of subjects (not individual ears as with the previous analysis) with a significant threshold shift and no threshold shifts were counted. A chi-square analysis was conducted on the categorical variables using SPSS version 11.0 (IBM SPSS, Chicago, IL).

The analysis showed a statistically significant increase in positive significant threshold shifts, $\chi^2(1, n=38) = 5.158$, P<.05. Ironically, the subjects also showed a statistically significant increase in negative significant threshold shifts, $\chi^2(1, n=38) = 6.737$, P<.05.

It may seem paradoxical that there were statistically significant positive threshold shifts at 1 kHz, 2 kHz, and 3 kHz in the previous analysis and there were nearly as many negative significant threshold shifts as there were positive significant threshold shifts posttraining. However, the method used to quantify whether a significant threshold shift had occurred is nonparametric and does not take into account the magnitude of any threshold shift, just whether a defined shift has occurred or not. The test for means actually takes into account the size of the threshold shifts. The negative threshold shifts that occurred were not remotely as large as the positive threshold shifts and in many cases were shifts in only one individual frequency. On the other hand, the positive significant threshold shifts were predominantly in more than one individual frequency and had much larger shifts. Figures 1 and 2 illustrate the thresholds by frequency in pretraining and posttraining with box plots.* This data set shows predominantly normal data both pretraining and posttraining with several of the students demonstrating extreme hearing threshold shifts. Therefore, the data and analyses support the conclusion that breacher training can result in permanent significant hearing loss, even with approved hearing protection. It also opens the discussion of why did some of the Marines get affected by the training and others did not. It is possible that the exposures were different among the trainees (ie, distance from blast, angle of incidence,

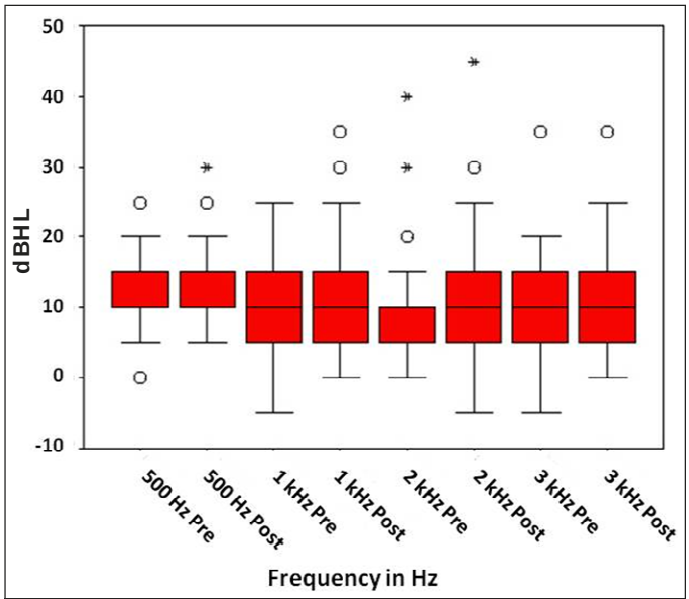

Figure 1. Median and quartiles of the data comparing hearing thresholds by frequencies between pretraining and posttraining. dbHL indicates decibels hearing level; Pre indicates pretraining measurements; Post, posttraining measurements.

Box plots provide a vertical view of the data in percentiles. The boundaries of the box indicate the 25th percentile and the 75th percentile. The length of the box represents the difference between the 25th and 75th percentiles. The horizontal line inside the box represents the median. The lines drawn from the ends of the box show the largest and smallest values that are not outliers. Outlier and extreme data points are labeled as "o" (outlier) and "" (extreme). The outliers are cases with the values between 1.5 and 3 box-lengths from the 75th percentile or 25th percentile. The extreme values are cases with the values more than 3 box-lengths from the 75th percentile or 25th percentile.

etc) or that there were different protective factors in the approved hearing protection. However, it also is possible that some are more genetically susceptible to losing hearing than others and the subject warrants further exploration.[2]

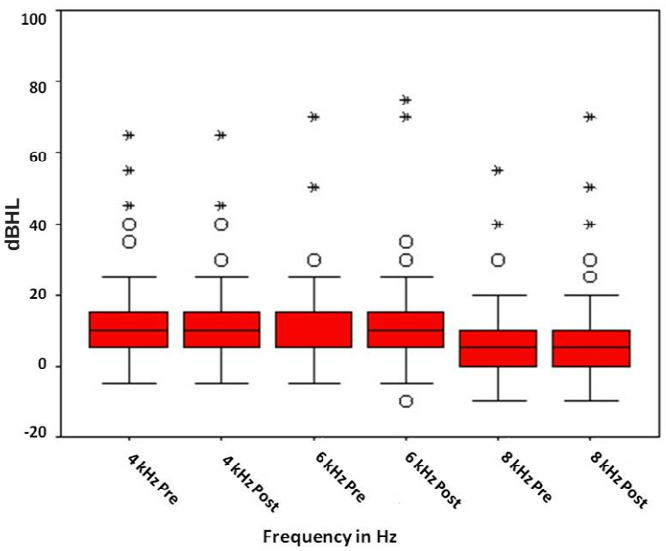

Figure 2. Median and quartiles of the data comparing hearing thresholds by frequencies between pretraining and posttraining. dbHL indicates decibels hearing level; Pre indicates pretraining measurements; Post, posttraining measurements.

Distortion Product Otoacoustic Emission Analyses

Otoacoustic emissions are an excellent objective measure of cochlear health and are generally present when hearing thresholds are under 30 dB hearing level at each corresponding frequency measured. Otoacoustic emissions are frequency specific sounds that are generated within the inner ear. Otoacoustic emissions decrease or disappear at corresponding frequency loci of the cochlea after the cochlea has been damaged (ie, hearing loss at 3 kHz will correspond to decreased or absent otoacoustic emissions at 3 kHz). Paired data of distortion product otoacoustic emissions of 26 subjects (52 ears) from the same group as the hearing thresholds were taken from were compared pretraining and posttraining. The number of subjects is smaller than the hearing threshold group because some participants did not complete the posttraining measurements. All subjects were noise free for 14 hours before data collection and only threshold data from subjects with normal middle ear function were collected. Since the data were paired, no weighting for age or gender was used. The difference in distortion product otoacoustic emissions were compared at 1828 Hz, 2016 Hz, 3047 Hz, and 4124 Hz before and after training was completed. The Bio-logic Scout Sport (Bio-Logic SAS, San Carlos, CA) was used to measure the distortion product otoacoustic emissions with the parameter settings listed in Table 2.

Table 2. Distortion Product Otoacoustic Emissions Results.*

Parameter	Setting
Frequency begin (Hz)	1800
Frequency end (Hz)	4300
F2/F1 ratio	1.22
Points per octave	30
L1 level dB	65
L2 level dB	45
Minimum DP amplitude (dB)	-5
Noise floor (dB)	-17
S/N ratio (dB)	8
Point time limit (seconds)	20
Sample size	1024
No. of tests	1
Minimum No. of samples	50

*F1 indicates Frequency 1; F2, Frequency 2; L1, the amplitude of F1; L2 the amplitude of F2; DP, distortion product; and S/N, signal to noise.

The breacher training resulted in:

- A slight increase in the distortion product otoacoustic emission at 1828 Hz ($\bar{X}$=0.5077, SD=9.20903). This increase was not statistically significant: t_{52}=0.398, P>.01, 2-tailed.
- A slight increase in the distortion product otoacoustic emission at 2016 Hz ($\bar{X}$=0.0692, SD=10.13394). This increase was not statistically significant: t_{52}=0.049, P>.01, 2-tailed.
- An increase in distortion product otoacoustic emission at 3047 Hz ($\bar{X}$=3.2712, SD=7.18548). This increase was statistically significant: t_{52}=3.283, P<.01, 2-tailed.
- A slight decrease in the distortion product otoacoustic emission at 4124 Hz ($\bar{X}$=-1.4615, SD=8.82423). This decrease was not statistically significant: t_{52}=-1.194, P>.01, 2-tailed.

Figure 3 shows box plots for the individual frequencies pretraining and posttraining. Since otoacoustic emissions decrease with declining cochlear health at the corresponding loci of the frequency response in the cochlea, it stands to reason that it may serve as an early indicator of possible hearing loss. The cochlea requires more energy than most parts of the body to function and therefore has a high metabolism.[3] Therefore, if anything goes wrong in the cochlea, it is more apparent in the measures of the outer hair cells which is the origin of the otoacoustic emission and is an extremely sensitive measure of cochlear function. Bohne and Clark estimate that hearing thresholds can reflect normal levels with up to 25% of the outer hair cells

in the cochlea being permanently damaged.[4] Early indication of potential cochlear damage would afford an audiologist the opportunity to take preventive precautions before hearing loss actually manifests itself. Therefore an analysis was conducted during mid training to determine if there was any significant change in the distortion product otoacoustic emissions, with particular attention being paid at 3 kHz, since it was the only significant change in the preanalysis and postanalysis.

The breacher training resulted in:

- A slight decrease in the distortion product otoacoustic emission at 1828 Hz ($\bar{X}$=-0.1442, SD=4.99248). This decrease was not statistically significant: t_{52}=-0.208, P>.01, 2-tailed.
- A slight increase in the distortion product otoacoustic emission at 2016 Hz ($\bar{X}$=0.1596, SD=6.44136). This increase was not statistically significant: t_{52}=-0.179, P>.01, 2-tailed.
- A slight increase in the distortion product otoacoustic emission at 3047 Hz ($\bar{X}$=1.0981, SD=7.40986). This increase was not statistically significant: t_{52}=1.069, P>.01, 2-tailed.
- A slight decrease in the distortion product otoacoustic emission at 4124 Hz ($\bar{X}$=-0.7038, SD=6.31472). This decrease was not statistically significant: t_{52}=-0.804, P>.01, 2-tailed.

While the distortion product otoacoustic emissions did not prove useful in this population for early identification of outer hair cell damage and hearing loss, the measures did match the permanent hearing threshold shifts at posttraining measurements. One explanation is that the hazardous noise was impulse in nature and could easily have induced instantaneous damage to the outer hair cells. This would account for the inability of the distortion product otoacoustic emissions measures to detect small amounts of outer hair cell damage as in the Bohne and Clark study.[2] Hazardous steady state noise exposure typically causes gradual degeneration of the cochlea and hazardous impulse noise can cause instantaneous damage.

AUDITORY DISCUSSION

Weiner and Ross[5] describe the resonant characteristics of the outer ear as boosting the sound pressure level of the frequencies between 2500 Hz and 3500 Hz. Donahue and Ohlin[6] describe the middle ear as frequency selective because the transfer functions of the middle ear allow the mid to high frequency sounds (approximately 1500 Hz through 4000 Hz) to pass through it with considerably less resistance than the low-frequency sounds. The result is that the low frequency sounds reach the cochlea at a lower intensity than when it entered the ear canal. Conversely, sounds at frequencies between 1 kHz and 3 kHz are transferred to the cochlea with significantly less resistance and greater intensity than when they entered the ear canal. Rudmose[7] and Ward[8] independently demonstrated that when high intensity pure tones reach the cochlea in the 1 kHz to 3 kHz frequency range, the resulting threshold shift occurs approximately a half to one whole octave above the pure tone exposure. As the waveform increases in amplitude on the basilar membrane due to an increase in sound intensity, the vibration becomes less localized and moves toward the basal portion of the cochlea.[5] Ylikoski and Ylikoski[9] state that this movement causes damage to loci of the cochlea that are different from the stimulus frequencies. For broadband noise with equal energy in all bandwidths, the maximum threshold shift occurs between 3 kHz and 6 kHz.[8]

Hazardous noise exposure causes 2 types of cochlear hearing loss: temporary and permanent. Temporary threshold shifts occur from metabolic fatigue and tend to recover within 48 hours, but is relative to the length

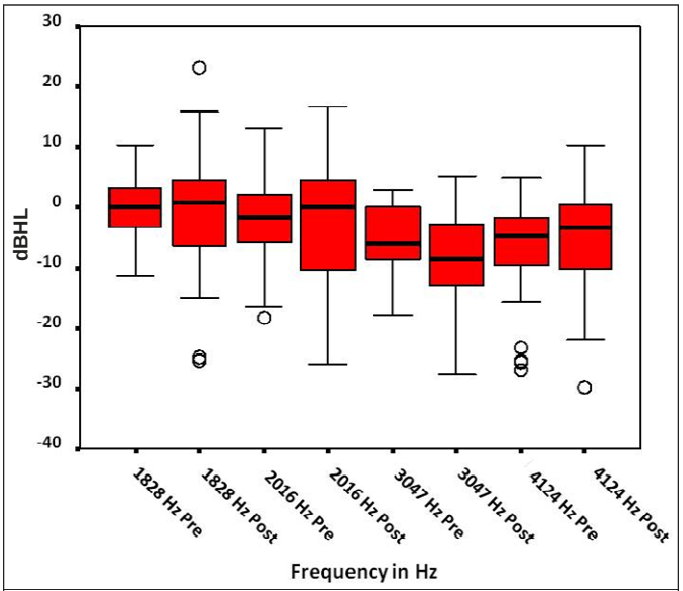

Figure 3. Median and quartiles of the data comparing hearing thresholds by frequencies between pretraining and posttraining. dbHL indicates decibels hearing level; Pre indicates pretraining measurements; Post, posttraining measurements.

and intensity of exposure. Restoration of hearing thresholds after a temporary threshold shift are due to the restoration of depleted metabolites and neurotransmitters, a decrease of edema in the hair cells, and healing of micro tears in the structure of the cochlea. Permanent threshold shifts are a result of the swelling and deforming of outer hair cells and alterations in endoplasmic reticulum.[10] The cochlear hair cells detect displacement of the basilar membrane and are the weakest link in the transduction of sound energy through the cochlea. The more intense a sound gets, greater the amplitude of displacement of the basilar membrane and therefore more shearing force on the hair cells. Bohne and Harding[11] found that the cochlea undergoes 2 histopathologic stages after an acoustic trauma: degeneration of the outer hair cells; and the continued degeneration of supporting cells, afferent nerve fibers, and additional hair cells. The second histopathologic stage has delayed onset with respect to identification of threshold shifts with routine monitoring. Simply put, hearing loss is progressive after an acoustic assault and therefore the actual rate of hearing loss among the participants in this study is greatly underestimated, especially when other exposures during training or multiple combat tours are taken into account. Hamernik[12] identified impulse noise, specifically blast waves with very short durations (0.5 millisecond) and high peak intensities, as capable of producing a mechanical impulse which can result in extremely high shear stresses and premature failure of elastic structures. He further described blast wave exposure as producing 2 fundamentally different lesion patterns: severe mechanical damage to the organ of Corti where large pieces of sensory and supporting cells were torn loose from the basilar membrane, and lesions that were more limited in extent and consisted primarily of missing or damaged sensory cells with the structural elements of the organ of Corti remaining essentially intact. This latter pattern of loss was frequently associated with damage to the tympanic membrane. The number of servicemen and servicewomen on disability because of hearing damage will increase no less than 15% under current combat conditions and disability policies.[13] Even if a Warrior's hearing thresholds are within a normal tolerance, the damage may have begun. Future hazardous noise exposure will append to previous damage and lead to future hearing loss that is not within acceptable limits for military standards. Once a service member's speech reception threshold in the best ear is greater than 30 dB hearing level (measured with or without a hearing aid), their ability must be evaluated for functionality and personal risk with respect to their jobs. For instance, if a helicopter pilot has a hearing loss and poor speech intelligibility; many lives are at risk if he or she cannot hear radio communication. Also, the pilot risks further hearing loss due to the hazardous noise of the helicopter. If the findings of the review board are negative, the service member is offered a medical discharge or a change to a job that does not involve hazardous noise exposure. Even if service members choose to change jobs rather than take a medical discharge, the organizational knowledge and technical experience goes with them.

Vestibular Affects

The vestibular system, combined with the visual and proprioceptive systems, contributes to spatial orientation. It is estimated that 80% of spatial orientation is based on visual cues, but when visual cues are no longer available or are diminished, the vestibular system's role is critically elevated. Situations while flying aircraft or driving an armored personnel carrier, such as whiteouts (snow) or brownouts (sand), may lead to greatly reduced visual cues. If the vestibular system of a pilot or driver is damaged, the chance of spatial disorientation occurring in low-vision environments may increase, resulting in a potentially catastrophic accident. It is also possible that this spatial disorientation could be a cause of danger for the ground troops in similar low visibility situations while weighted down with a basic combat load. If a relationship between hearing loss and vestibular damage can be identified, the results could lead to further studies on possible audio-vestibular screenings.

During the first year of the war in Iraq, there was an average of one medical evacuation a day for hearing loss with no other concurrent injury. Medical evacuations for hearing loss were sent to the audiology clinic at Landstuhl Regional Medical Center in Germany. McIlwain[14] found that 65% of the 564 patients seen at the audiology clinic during this time were there because of blast injuries. Sensorineural hearing loss from friendly forces weapons systems made up approximately 25% of the injuries. The remaining 10% were balance-related or conductive type hearing loss that was predominantly unrelated to hazardous noise exposure. As a result, a military audiologist position was temporarily placed in Baghdad in 2004 to evaluate acoustic trauma patients.

This provided an efficient way to determine a Soldier's hearing ability without the need of a lengthy and expensive medical evacuation for a non–life-threatening injury.[14] Unfortunately the average number of monthly audiology evaluations reached 175 in 2007.[15] If Warriors are experiencing hearing loss, they may also be experiencing asymptomatic vestibular damage.

Limits of Stability Assessment

The Limits of Stability test quantifies the maximum distance a person can intentionally displace their center of gravity by leaning their body in a given direction without losing balance, stepping, or reaching for assistance. These movements are referred to as dynamic balance. The measured parameters are reaction time, center of gravity movement velocity, directional control, end point excursion, and maximum excursion. For each of 8 trials, the subject maintains the center of gravity standing on a balance platform that measures movement. The subject tracks his or her movement on a computer screen that displays movement with a cursor. On command, the subject must move the center of gravity as quickly and accurately as possible towards a second target located on the screen, and then holds that position as close to the target as possible. The subject is allowed up to 8 seconds to complete the trial. The reaction time is the time in seconds between the command to move and the subject's first movement. Movement velocity is the average speed of the center of gravity movement in degrees per second. Endpoint excursion is the distance of the first movement toward the designated target, expressed as a percentage of maximum limits of stability distance. The endpoint is considered the point at which the initial movement toward the target ceases. Maximum excursion is the maximum distance achieved during the trial. Directional control is a comparison of the amount of movement in the intended direction to the amount of extraneous movement. The ability of a subject to voluntarily move the center of gravity to positions within the limits of stability is fundamental to mobility tasks such as reaching for objects, transitioning from a seated to standing position, and walking. Reaction time delays are commonly associated with difficulties in cognitive processing, motor diseases, and traumatic brain injury. Reduced movement velocities are indicative of high-level central nervous system deficits such as Parkinson's disease, age-related disorders, and traumatic brain injury. Inability to reach targets in a single movements and poor directional control are indicators of motor-control abnormalities.

This test was conducted using a NeuroCom Basic Balance Master (NeuroCom, Clackamas, Oregon). In this assessment, the researcher entered each subject's height into the computer to determine foot placement on the platform. For each of the comprehensive outputs, a 3 (group) by 3 (time) analysis of variance was conducted. In this study, the limits of stability assessment was completed twice, in succession, during the pre- and postevaluations, and a single assessment of the 8 body weight shifts were performed at the interim evaluations due to time constraints. Data from the first trial of the pre- and postevaluations and the single trial from the interim evaluation are used in the following analyses, the results of which are presented in Table 3.

Table 3. Analysis of Limits of Stability

Comprehensive Output	Effect	df	F	*P*	η^2	Power
Reaction time	Time	2, 70	0.39	0.68	0.01	0.11
	Group	2, 34	0.64	0.53	0.04	0.15
	Interaction	2, 70	0.86	0.49	0.05	0.26
Movement velocity	Time	2, 70	1.25	0.29	0.03	0.26
	Group	2, 34	0.38	0.38	0.02	0.26
	Interaction	2, 70	2.48	0.10	0.12	0.47
Endpoint excursion	Time	7, 70	6.77	<0.01	0.16	0.91
	Group	2, 34	0.56	0.69	0.03	0.18
	Interaction	2, 70	2.42	0.10	0.12	0.46
Maximum excursion	Time	2, 70	7.19	<0.00	0.17	0.92
	Group	2, 34	1.89	0.12	0.10	0.54
	Interaction	2, 70	4.29	0.02	0.20	0.71
Directional control	Time	2, 70	4.42	<0.01	0.11	0.74
	Group	2, 34	1.63	0.18	0.09	0.48
	Interaction	2, 70	0.31	0.73	0.02	0.10

While there were 3 statistically significant outcomes, the results were overall clinically unremarkable. Six subjects showed abnormal responses to limits of stability assessment. Three of these subjects scored outside normal limits for reaction time in both interim and postevaluations, as compared to preevaluation. Two subjects were outside the normal range for endpoint maximum excursion at preevaluation, and one for endpoint maximum excursion at postevaluation. Abnormal limits of stability testing are indicative of a possible functional balance deficit. Specifically, slower reaction time may indicate a

central processing problem in which a person may be able to recognize a target, but have difficulty quickly moving toward the target. Deficiencies in directional control may indicate a person has difficulty maintaining their balance once they reach the target. A deficit in endpoint maximum excursion indicates that a subject had difficulty transferring his center of gravity toward the outer edge of the individual base of support, affecting gait and stance.

The modified Clinical Test of Sensory Intergration on Balance provides an objective measure of postural control and was measured with the Neurocom Basic Balance Master system. When performing this evaluation, the subjects stood with feet positioned on a set of reference marks on the force plate platform. The lateral malleolus of each foot was positioned relative to an indicator line and the outside edge of each foot was aligned perpendicular to the anterior-posterior center line. This foot position was used for 2 tests: firm surface with eyes open (to evaluate the visual contribution to balance), and firm surface with eyes closed (an evaluation of the vestibular balance component). A 4- inch thick foam pad with similar markings as the force plate platform was then placed on the force plate platform and the feet were positioned similarly. Two tests were performed with the foam pad: foam surface with eyes open (to evaluate the cognitive component of balance), and foam surface with eyes closed (an evaluation of the proprioceptive aspect of balance). The subject was instructed to stand quietly with his arms at his side for approximately 30 seconds (3 trials for 10 seconds each) for each of the 4 conditions. Sway in degrees per second were measured for each trial. All subjects completed the 4 tests for the pre- and postevaluations. An interim evaluation was completed for the subjects of the September cohort, but only the foam surface eyes-open and foam surface eyes-closed conditions were conducted at interim evaluation for the June cohort. The June cohort did not participate in the interim evaluation firm surface eyes-open and firm surface eyes-closed tests due to time constraints.

For the comprehensive score, a 3 (group) by 3 (time) analysis of variance showed significant results for the interaction effect $F_{2,70}=2.69$, $P=.04$, $\eta^2=0.13$, Power=0.72, main effect for group $F_{2,35}=4.46$, $P=.02$, $\eta^2=0.20$, Power=0.73, and main effect for time $F_{2,70}=23.95$, $P<.01$, $\eta^2=0.41$, Power=1.00. Follow-up analyses showed that the groups were equivalent at the pre-assessments $F_{2,35}=1.81$, $P=.18$ and were significantly different at the interim $F_{2,35}=4.64$, $P=.02$ and at postevaluations $F_{2,35}=3.53$, $P=.04$ with instructors and controls showing significantly poorer performance than the students at the interim and post-evaluations. This finding indicates that the breacher instructors did not experience performance decrements any greater than that associated with the control group.

To investigate the influence of breacher training on static balance, a series of *t* tests were performed to evaluate all subjects exposed to the breacher training environment (instructors and students) between pre- and postevaluations.

- There was no change in firm surface eyes-open condition between pre- and posttraining ($\bar{X}=0.00$, SD=0.01). There was no statistical significance $t_{31}=0.27$, $P>.01$, 2-tailed.
- There was a slight increase in the firm surface eyes-closed condition between pre- and post-training ($\bar{X}=0.01$, SD=0.07). There was no statistical significance $t_{31}=-0.23$, $P>.01$, 2-tailed.
- There was a slight decrease in the foam eyes-open condition between pre- and post-training ($\bar{X}=-0.03$, SD=-0.02). There was no statistical significance $t_{31}=2.5$, $P>.02$, 2-tailed.
- There was a decrease in the foam eyes-closed condition between pre- and post-training ($\bar{X}=-0.33$, SD=0.04). This decrease was statistically significant $t_{31}=4.25$, $P<.01$, 2-tailed.
- There was a decrease in the comprehensive condition between pre- and post-training ($\bar{X}=-0.10$, SD=0.02). This decrease was statistically significant $t_{31}=3.36$, $P<.01$, 2-tailed.

While there were 2 statistically significant variables in this assessment, overall the findings were clinically unremarkable.

Dynamic Visual Acuity Test

The dynamic visual acuity test is an assessment of the ability of a person to accurately identify an object that changes in size and orientation during head movement at predetermined velocities in degrees per second. It measures impairment and quantifies the impact of vestibular ocular reflex system injury or pathology on

a subject's ability to maintain visual acuity while moving. In normal individuals, losses in visual acuity are minimized during head movements because the vestibular ocular reflex system maintains the direction of gaze on an external target by moving the eyes in the opposite direction of the head movement. When the vestibular ocular reflex system is injured, visual acuity degrades during head movements. The output of this evaluation is the acuity of vision while moving the head. The results are expressed in LogMAR units. LogMAR is a scale that is expressed as the logarithm of the minimum angle of resolution. This test requires rhythmic head movements in left to right and down to up planes. Once the head completes 3 consecutive cycles of movements, an optotype in the shape of the capital letter "E" is immediately presented to the subject on a computer monitor. The optotype is presented for 40 milliseconds. The size and orientation of the optotype is manipulated from trial to trial by the Neurocom software which is determined by each individual's static visual acuity. The subject responds by saying the orientation of the optotype and the researcher documents the response.

To assess time and group effects for movement plane, a 2 (head movement) by 2 (time) by 3 (group) analysis of variance (ANOVA) was performed for left and right; pre- and postevaluations; between the instructors, students, and controls. Table 4 presents the ANOVA results conducted for the horizontal plane. Two effects emerged significant. The head movement group was significant, with instructors and students showing significantly less performance degradation from pre- to postevaluation than the controls for both the left and right movement direction. A time effect was significant between pre- to postevaluation performances of the control group.

To assess time and group effects for the vertical movement plane, a 2 (head movement) by 2 (time) by 3 (group) ANOVA was performed for down and up; pre- and postevaluations; between the instructors, students, and controls. Table 5 displays the results of the ANOVA performed for vertical movement. The main effect for head movement emerged significant, dynamic visual acuity was significantly better in the up movement than the down movement direction.

While there were some statistically significant findings in this test, the overall results for perception time, gaze stabilization, and dynamic visual acuity testing was clinically remarkable.

VESTIBULAR DISCUSSION

The vestibular system may also be damaged by hazardous noise due to its close proximity and similarity in cell structure to the cochlea.[16] Warriors are exposed to explosions, such as improvised explosive devices, mortars, or car bombs. They are also exposed to many steady-state noises such as aircraft, track vehicles, or large electrical generators. These noise sources may cause asymptomatic damage to their vestibular system. Shupak et al[17] did find that symmetric noise-induced hearing loss is correlated with symmetric peripheral vestibular system damage. These results were corroborated by M. E. Hill, AuD, and D. S. McIlwain, AuD (unpublished data, 2006). It is possible to be unaware of a vestibular deficit in conjunction with acoustic trauma because of the complex relationship between the central nervous system of the brain and the 3 primary sensory modalities critical to equilibrium—vestibular, visual, and proprioceptive systems. If an insult to the vestibular system occurs, the central nervous system

Table 4. Analysis of Variance of the Dynamic Visual Acuity Test in the Horizontal Plane

Effect	F	*P*	η^2	Power
Head movement	3.39	0.07	0.09	0.43
Head movement group	4.69	0.02	0.22	0.75
Time	5.30	0.03	0.14	0.61
Time group	0.86	0.43	0.05	0.19
Head movement time	0.43	0.52	0.01	0.10
Head movement time group	0.22	0.80	0.01	0.74
Group	0.03	0.97	0.00	0.05

Table 5. Analysis of Variance of the Dynamic Visual Acuity Test in the Vertical Plane

Effect	F	*P*	η^2	Power
Head movement	6.47	0.02	0.16	0.69
Head movement group	2.12	0.14	0.11	0.40
Time	0.77	0.39	0.02	0.14
Time group	0.25	0.78	0.01	0.09
Head movement time	1.91	0.18	0.05	0.27
Head movement time group	1.43	0.25	0.08	0.28
Group	0.16	0.85	0.01	0.07

relies heavily on information from vision and proprioception to make up for the lack of neural firing from the balance center to compensate. The central nervous system adapts to the different levels of neural input it receives. During this adaptation time, the individual often experiences a slight feeling of imbalance, dizziness, or even vertigo, especially in the absence of vision. Symptomatic feelings of imbalance, dizziness, and vertigo typically subside. If studies such as the one presented in this article can aid in determination of how much hazardous noise effects the peripheral vestibular system, the development of screening tools may be of great importance.

CONCLUSION

In an instant, a Warrior can become "walking wounded." These types of injuries can affect the lives of our service members and their families. It also places them at risk for further injury as well as put others at risk due to decreased job performance. Research such as this are important to understanding the invisible injuries our Warriors are experiencing, such as hearing loss and mild traumatic brain injury, and is even more tantamount in developing prevention strategies and treatments.

Hearing loss was statistically and clinically significant in this study, whereas the vestibular findings were overall unremarkable. Therefore, hearing conservation practices should be reviewed by a military audiologist to determine a proper solution to prevent hearing loss in this course. It must be noted that the pressure measurements, head orientation, and air sampling are not discussed in this article, but did show some potentially serious exposures that may cause health affects over time and are addressed in other publications. It must also be noted that long term affects of this type of training were not the object of this research protocol. As with many research initiatives involving new scientific territories, some of our research questions were answered and many new ones were discovered. Therefore, a new breacher injury research protocol has been developed based on lessons learned and is currently in progress.

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The 2-week Breacher Training Course at the USMC Weapons Training Battalion, Quantico, VA, involves multiple exposures to blast overpressure and physical shock from explosive charges used as part of the ingress strategies taught during training. Photos courtesy of the authors.

Effectiveness of Pedometer Use in Motivating Active Duty and Other Military Healthcare Beneficiaries to Walk More

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ABSTRACT

Although implementing a regular exercise program may initially seem overwhelming to individuals attempting weight loss, increasing walking with a focus on steps-per-day may be a more realistic means for encouraging physical activity. This study evaluated the effectiveness of pedometer use for motivating an increase in physical activity among overweight/obese military beneficiaries. Participants (N=106) were randomly assigned to either the "Usual Lifestyle" (no change in activity advised) or "Pedometer" group (education and encouraged to obtain 10,000 steps per day), and both groups were assessed for changes in physical activity, anthropometric measures, and clinic measures over time. Results (n=89) demonstrated improvements in physical activity and all measured indices across both groups. There was a statistically significant increase in steps per day by time ($P < .001$), however, no statistically significant difference between treatment groups over time ($P = .167$). Approximately 49.4% of participants achieved the 10,000 steps per day goal at follow-up. All secondary measured indices, except blood pressure, demonstrated a significant change overall from baseline to posttest: weight ($P < .001$), BMI ($P < .001$), percent body fat ($P = .001$) and heart rate ($P = .005$). Findings indicate that all participants made lifestyle changes, possibly as a result of frequent investigator-participant interaction, however, more likely due to the pedometer serving as a tangible tool to constantly remind the wearer to get up and walk more, regardless if a step count is tracked.

INTRODUCTION

In its 2008 survey, the Department of Defense Military Health System found that, similar to the general American population, 62% of active duty personnel were overweight.[1] Not surprisingly, the overweight problem facing military healthcare is not limited to active duty personnel. In January 2005, the TRICARE Management Activity reported the results of a survey that revealed that 41% of adult beneficiaries were overweight, and 22% were obese.[2] This population has a significantly different lifestyle than the majority of the US population. Service members may be stationed virtually anywhere to meet the needs of the military, move more frequently than their civilian counterpart and are often located far from family support networks. The high deployment rate also adds to the stress of the military family lifestyle and often leaves families alone in unfamiliar places. Such a lifestyle may be emotionally and physically stressing and could account for some of the difficulty associated with maintaining a healthy weight within the Department of Defense (DoD) population.

Even though the majority of active duty military members are required to participate in physical training at least 2 to 3 times weekly, their jobs and lifestyles may not be physically active enough to meet the minimum physical activity recommendations of 30 minutes of moderate activity on most days of the week.[3,4] A regular physical training program is often left up to the motivation of the individual, especially in medical facilities due to irregular duty hours often experienced by healthcare Soldiers and professionals, eliminating the opportunity for organized physical activity. High-stress and busy lifestyles challenge one's ability for increased regimented physical activity and weight loss. Spouses of military members may also find themselves too busy putting the needs of their families ahead of their own to successfully maintain a regular workout routine, despite free access to installation fitness facilities.

The DoD offers weight loss classes to beneficiaries (family members and retirees), yet the obesity rate continues to climb, suggesting that these classes may not be sufficient to promote healthy lifestyle changes or weight loss. Many beneficiaries do not take full

advantage of services offered due to a variety of barriers or lack of readiness for lifestyle modification. There are several concepts important to successful behavior modification: self-monitoring, goal setting, stimulus control, problem solving, cognitive restructuring, relapse prevention, and education on nutrition and physical activity.[5,6] The Theory of Planned Behavior suggests that a behavior (physical activity, for example) is determined by one's motivation to perform the behavior and is supported by one's perception of control over the behavior.[7] With this perception of control, an individual's self-efficacy for implementing a particular behavior change is enhanced. Many of these concepts can be applied to promote self-efficacy for increasing physical activity. Programs that focus on a concept of "lifestyle change" by embracing the importance of small, focused lifestyle modifications, such as taking the stairs, parking farther away when completing errands, or walking during breaks or lunch times, appear to be more successful in promoting long-term adherence compared with regimented exercise, such as treadmill exercise at a fitness center.[8]

Although walking is not the most efficient way to burn calories for weight loss, it may be the most effective method for initiating lifestyle changes associated with weight loss and weight maintenance. Studies covering diverse populations have shown a direct correlation between an increase in daily walking and improvements in self-efficacy, glucose tolerance, resting heart rate (HR), waist circumference (WC), body fat percentage (BF%), blood pressure (BP), and body weight (WT).[9,14] According to the American Dietetic Association, weight loss of 5% to 10% or a transition in WC from a level of elevated risk (≥108 cm for men and ≥88 cm for women) to one of decreased risk is sufficient to induce clinical health benefits, such as decreased BP, insulin resistance, and heart disease risk.[15]

Figure 1. The Yamax Digi-Walker SW200 pedometer. Photo courtesy of Yamasa Tokei Keiki Co, Ltd.

The Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ASCM) recommend 30 minutes of moderate-intensity physical activity most days in order to limit adverse health outcomes; however, this is often not sufficient to promote weight loss or weight maintenance, which typically requires 60 to 90 minutes of activity per day.[16,17] By achieving 10,000 steps per day (s/d), individuals are likely getting over 60 minutes of activity, given that 30 minutes equates to approximately 3,100-4,000 steps, depending on stride length.[18,19] On average, walking 10,000 s/d burns approximately 300-400 cal, depending on the size of the walker and intensity of the walking conditions.[20] The estimated amount of time (90 minutes minimum) achieved by walking 10,000 s/d is triple the amount of time (30 minutes) recommended by the US Surgeon General, CDC, and ASCM to promote health benefits, although those steps may not be taken at the intensity necessary for cardiovascular benefits.[17,18] The amount of time required to achieve a 10,000 s/d goal will likely require individuals to dedicate time outside of their daily activities to walking; however, the gradual progression to this goal may make maintenance of such a lifestyle change more manageable.

Although research has found that self-monitoring by tracking the number of steps taken throughout the day is effective, it requires a practical tool, such as a pedometer. Pedometers are battery-operated devices designed to measure walking motion. Accuracy of step counting is dependent on the pedometer brand and type. In studies comparing pedometers versus manually counted steps, the Yamax Digi-Walker SW200 (Yamasa Tokei Keiki Co, Ltd, Tokyo) (Figure 1) proved to be the most accurate for all body types.[19,21-23] These devices also assist with promoting user self-awareness and self-efficacy, thereby encouraging increased daily steps. Previous studies show the most successful pedometer users were those who combined daily pedometer use with goal-setting, progress-logging, and/or counseling.[10,11,18]

A study by Richardson et al[24] demonstrated success in increasing participant step counts by implementing an internet-mediated, pedometer-based walking program. This online program generated motivational messages, step goals, and graphs to show participant progress. Participants in the lifestyle group found the internet program especially effective, with 100% reporting program satisfaction and recommendation to friends. This study demonstrated the potential for immediate-feedback devices, such as pedometers and internet programs, to assist participants in increasing self-efficacy and weight loss. The internet and email are

convenient methods to reach out to program participants and assist with self-monitoring, goal-setting, contingency planning, cognitive restructuring, and problem-solving.[25]

To date, most military weight loss programs are classroom or regimented exercise-oriented programs, with no pedometer studies yet conducted. The purpose of the present study was to evaluate the effectiveness of pedometer use with an interactive website in increasing physical activity, decreasing WC, and maximizing continued adherence within the population of military healthcare providers and their families. The authors hypothesized that use of pedometers and an interactive website would motivate participants to significantly increase daily steps, promoting improvements in health indices, including WC, WT, BMI, BP, and HR.

Participants and Methods

Study Setting

The study was conducted at Brooke Army Medical Center (BAMC) in San Antonio, Texas, in accordance with the ethical standards of the Institution Review Board and with the Helsinki Declaration of 1975, as revised in 2000. Written informed consent was obtained from all participants.

Participants

The participants met the following inclusion criteria: (a) unrestricted walking, (b) overweight or obese with a Body Mass Index (BMI) of 25 or more, (c) at least 18 years of age, (d) active duty military, military family members, or retirees, (e) able to regularly access internet, and (f) planning to remain in the area for the duration of the study. Participants were excluded if a walking limitation or physical profile was reported by a physician, or if as a Soldier was assigned to the Army Weight Control Program within 4 weeks of study initiation. The weight control program may necessitate a dramatic change in physical activity, contradicting control group assignment instructions of no activity change, which should stabilize within 4 weeks of weight control program involvement.

Design and Recruitment

This 12-week study was a 2-armed trial with a randomized, controlled, repeated measures design. Two months prior to the start of the study, participants were recruited through flyers and facility-wide emails at BAMC. Interested individuals attended one of several information sessions to receive a thorough explanation of the study, including the purpose, measurements taken, expected time commitment, and potential risks or discomforts associated with participation. Following the information session, interested and eligible individuals signed an informed consent document, provided the investigators with contact information, and signed up for a return date to complete baseline measurements. The study was initiated in the first week of January 2008.

Random Assignment to Groups

Following the baseline measurement session, all participants were randomly assigned to either the Usual Lifestyle (UL) (control) group or the Pedometer (PED) (intervention) group. Randomization was performed using a computer-generated random-numbers list in Microsoft Excel 2003 (Microsoft Corp, Redmond, WA). Assignments were sequentially numbered, placed in sealed, opaque envelopes, and given to participants following baseline data collection.

Intervention Versus Control Group

Participants in the PED group were assigned a pedometer to wear daily and instructed to log their daily steps into the "New Lifestyles" interactive website (http://www.everystepcounts.com), whereas each member of the UL group was only provided a sealed pedometer to wear during the data collection weeks. The pedometers were physically sealed from view and opened only by an investigator at the end of the data collection week. The PED participants were encouraged to create weekly step goals, increasing by 500-1,000 steps per week, until reaching the ultimate walking goal of 10,000 s/d. The New Lifestyle website converted tracked steps into estimated distance traveled on a virtual journey across a section of the United States and provided visual and intermediate targets to increase motivation. The PED participants chose a code name as their only form of identification on the New Lifestyles website to communicate with one another on the website's message board and provide encouragement and advice. Each of the 5 investigators was assigned 15 PED participants to provide consistent encouragement, positive feedback, and strategies for improvement through the interactive website message board until the end of study (week 12). Between end of study and the 5-month follow-up, however, investigators stopped interaction with partici-

pants through the website, thus leaving the PED group to independently maintain or improve lifestyle habits. Participants in the UL group did not have access to the website, nor did they receive pedometers to wear daily, except when sealed during the 3 data collection weeks. Rather, the UL group was asked to maintain and not increase their physical activity levels throughout the course of the study. To encourage continued participation, participants of both groups were given "Step This Weigh" t-shirts at posttest and were able to keep their pedometers. All participants were given one-year access to the website after the follow-up session.

Data Collection

Outcomes were assessed for all participants at baseline, midstudy (6 weeks), posttest (12 weeks), and at a 5-month follow-up point. Step count and WC were primary outcome measures. Step count is defined as the average daily steps logged on the pedometer. All participants were instructed to wear sealed pedometers daily for a minimum of 3 weekdays and one weekend day at baseline, midstudy, posttest, and follow-up. Participants returned to the research site the following week with their sealed pedometers, at which time the pedometer was unsealed by an investigator and the average daily steps were recorded. Pedometers were collected from participants in the UL group following each data collection period; PED participants kept their unsealed pedometer and continued tracking daily steps. Waist circumference is defined as the centimeters around the waist measured at the umbilicus to the nearest 0.25 cm, taken in duplicate, and averaged. Waist circumference was taken at the navel rather than at the top of the iliac crest because pilot testing demonstrated a greater potential for inaccuracy when measuring the iliac crest area on obese individuals. By using the navel, the investigators ensured consistent placement of the measuring tape at each session and decreased instances of interinvestigator measurement variability.

Secondary outcome measures included WT, BMI, BF%, BP, HR, exercise level, and demographic information. Body weight was measured in kilograms in duplicate and averaged. Height, measured in centimeters, was taken in duplicate and averaged. Body mass index was calculated using kilograms divided by square meters. Body fat percentage was calculated according to *Army Regulation 600-9*,[26] which uses the following formulae (body measurements in inches):

- Female: $(163.205 \times \text{Log}(\text{waist+hip-neck})) - (97.684 \times \text{Log}(\text{height})) - 78.387$
- Male: $(86.010 \times \text{Log}(\text{waist-neck})) - (70.041 \times \text{Log}(\text{height})) + 36.76$

Blood pressure was measured with an electronic aneroid sphygmomanometer (mm Hg) in duplicate and averaged. Resting heart rate was measured at the radial nerve with an electronic sphygmomanometer (beats per minute) in duplicate and averaged.

Self-reported physical activity data was collected using the validated International Physical Activity Questionnaire (IPAQ).[27] The survey is divided into 5 sections to assess the time participants spent sitting and doing activities related to work, transportation, household cleaning, and leisure. From this data, participant activity levels were determined in terms of metabolic equivalent (MET) hours per week and categorized into low, moderate, and high levels of physical activity. More specifically, the IPAQ analysis describes a moderate activity level as a minimum of at least 10 MET-hours over the course of 5 or more days per week. A high activity level is achieved with at least 50 MET-hours over the course of 7 days per week. The IPAQ is validated and captures both sedentary behaviors and physical activity at variable levels, to include low-intensity activities such as walking.

Demographic characteristics, assessed at baseline, consisted of age, gender, ethnicity, education level, employment status, household income level, marital status, and tobacco and alcohol use habits.

The data collection sessions at baseline, midstudy, and posttest included 30 minutes of nutritional guidance for all participants as a benefit to participation. The intent was to minimize the dietary biases that also affect health outcome measures through a variety of dietary habits by providing both groups the same generic nutrition guidance. A consistent message was presented to limit extreme or mythical dieting practices often experienced in weight management efforts. The baseline session covered the Food Guide Pyramid[28] and portion sizes. The food groups were highlighted using a variety of food models in the proper serving size. A generic template for meal plan guidance was provided to estimate the daily energy needs and identify the numbers of servings from each food group to meet the estimated energy needs. The midstudy session covered the topics of label reading

and healthy shopping. Participants were taught how to read a food label to make healthier shopping choices, and were given tips on alternative healthy cooking practices. The posttest session discussed healthy dining-out and techniques to overcome mindless eating habits. The emphasis was on understanding the concept of following physiological cues of hunger and fullness instead of emotional, environmental, and social cues to trigger eating when biologically not needed. The participants were also given handouts on better fast food choices when dining-out.

Statistical Analysis

SPSS Sample Power 2.0 (SPSS Inc, Chicago, IL) was used to perform the power analysis. Four subjects per group were necessary to depict an increase in steps from 4,000 to 8,000 with 80% power and an alpha set at 0.05; however, 30 subjects per group were necessary to detect a 0.74 SD effect size in WC change. The intent was to recruit 120 subjects to account for a 50% attrition rate.

SPSS 16.0 was used to analyze the data set. Continuous data (s/d, WC, WT, BMI, BF%, BP, and HR) were examined using a 2-factor analysis of variance (ANOVA) of treatment and time with repeated measures on time (baseline, midstudy, and posttest). Significant results were analyzed further with a post hoc analysis, using a Bonferoni correction for multiple comparisons. Descriptive data and baseline measurements were checked for normalcy using the Shapiro-Wilkins test. Regular independent *t* tests were used to compare means of normally distributed data, while the Mann-Whitney *U* test was used for variables of abnormal distribution. The continuity correction, as part of a contingency test, was used to correlate 2 dichotomous variables. Pearson's correlation was used when correlating 2 or more continuous variables.

RESULTS

Participant Characteristics

One hundred six participants completed baseline data collection. Baseline demographics and measurements are presented in Tables 1 and 2, respectively. Groups were not statistically different on sociodemographic and baseline measurements, except systolic BP.

Over the course of the 12-week intervention period, 17 participants withdrew for a variety of reasons. Figure 2 depicts the timeline and details of participant attrition. Analysis conducted on demographic characteristics of study completers versus noncompleters indicated no significant differences between groups in any category, except ethnicity ($P = .040$), in which case completers were slightly more likely to have identified themselves as Caucasian. At the end of the study, the attrition rate was balanced across treatment groups (30.1% of PED group; 27.7% of UL group).

Participant Outcomes

Primary. There was a statistically significant increase in s/d by time ($P < .001$), however, no statistically significant difference between treatment groups over time ($P = .167$). Post hoc analysis confirmed a significant change in steps from baseline to midstudy ($P < .001$) and baseline to posttest ($P < .001$). A nonparametric boxplot, graphing average daily steps

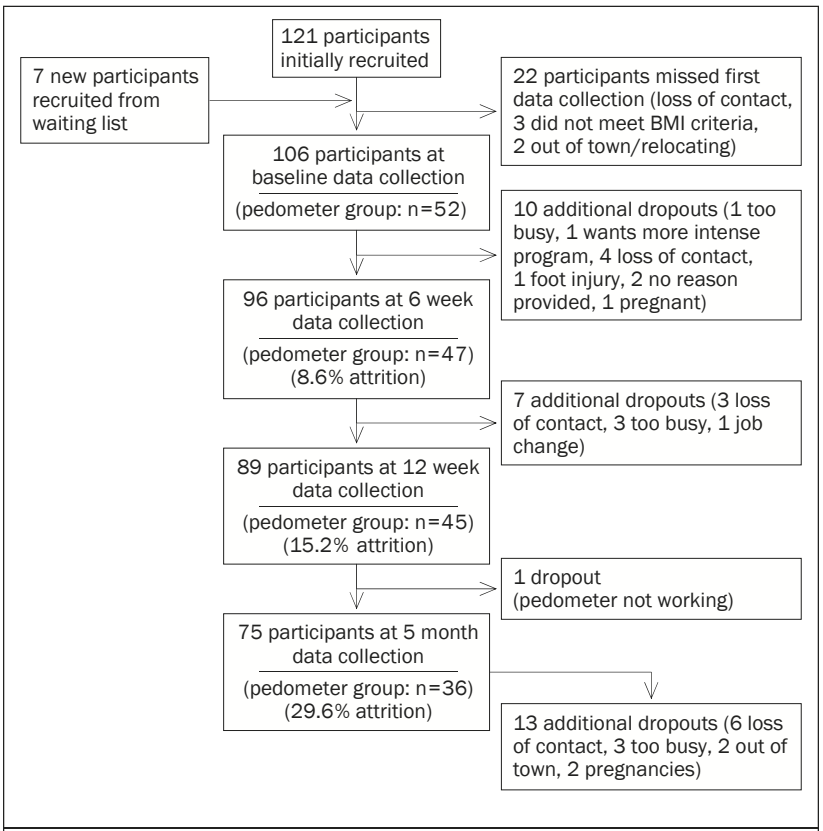

Figure 2. Participant attrition.

Table 1: Baseline demographic information for both treatment groups. The data reveals no statistically significant difference between treatment groups.

	Overall N=89	PED Group n_1=45 (50.6% N)	UL Group n_2=44 (49.4% N)
Age, mean (SD), years	50 (9.3)	50 (10.1)	50 (8.4)
Demographic Category [variable]			
Gender			
Female [F]	F=71 (79.8% N)	39 (54.9% F)	32 (45.1% F)
Male [M]	M=18 (20.2% N)	6 (33.3% M)	12 (66.7% M)
Military or Civilian			
Enlisted [E]	E=5 (5.6% N)	2 (40% E)	3 (60% E)
Officer [O]	O=11 (12.4% N)	6 (54.5% O)	5 (45.5% O)
Civilian [C]	C=73 (82% N)	37 (50.7% C)	36 (49.3% C)
Income Bracket, Annual			
<$25,000 [$B_1$]	B_1=3 (3.4% N)	2 (66.7% B_1)	1 (33.3% B_1)
$25,001-50,000 [$B_2$]	B_2=17 (19.1% N)	12 (70.6% B_2)	5 (29.4% B_2)
$50,001-75,000 [$B_3$]	B_3=20 (22.5% N)	7 (35.0% B_3)	13 (65.5% B_3)
$75,001-100,000 [$B_4$]	B_4=26 (29.2% N)	11 (42.3% B_4)	15 (57.7% B_4)
>$100,000 [$B_5$]	B_5=23 (25.8% N)	13 (56.5% B_5)	10 (43.5% B_5)
Education Level			
High School [HS]	HS=10 (11.2% N)	6 (60% HS)	4 (40% HS)
Some College Courses [SC]	SC=24 (27% N)	13 (54.2% SC)	11 (45.8% SC)
Associate's Degree [AD]	AD=16 (18% N)	8 (50% AD)	8 (50% AD)
Bachelor's Degree [BD]	BD=19 (21.3% N)	10 (52.6% BD)	9 (47.4% BD)
Graduate Degree [GD]	GD=20 (22.5% N)	8 (40% GD)	12 (60% GD)
Employment Status			
Unemployed [UE]	UE=4 (4.5% N)	3 (75% UE)	1 (25% UE)
Part-time [PT]	PT=3 (3.4% N)	2 (66.7% PT)	1 (33.3% PT)
Full-time [FT]	FT=77 (86.5% N)	37 (48.1% FT)	40 (51.9% FT)
Retired [R]	R=5 (5.6% N)	3 (60% R)	2 (40% R)
Occupational Level			
Professional [P]	P=42 (47.2% N)	22 (52.4% P)	20 (47.6% P)
Clerical [CL]	CL=19 (21.3% N)	11 (57.9% CL)	8 (42.1% CL)
Technical [T]	T=17 (19.1% N)	6 (35.3% T)	11 (64.7% T)
Staff [ST]	ST=4 (4.5% N)	2 (50% ST)	2 (50% ST)
Other (retired/ unemployed) [RU]	RU=7 (7.9% N)	4 (57.1% RU)	3 (42.9% RU)
Marital Status			
Single [SNG]	SNG=2 (2.2% N)	1 (50% SNG)	1 (50% SNG)
Married [MRD]	MRD=72 (80.9% N)	33 (45.8% MRD)	39 (54.2% MRD)
Separated [SEP]	SEP=10 (11.2% N)	7 (70% SEP)	3 (30% SEP)
Widowed [W]	W=5 (5.6% N)	4 (80% W)	1 (20% W)
Ethnicity			
Caucasian [CAU]	CAU=42 (47.2% N)	20 (47.6% CAU)	22 (52.4% CAU)
African American [AA]	AA=21 (23.6% N)	11 (52.4% AA)	10 (47.6% AA)
Hispanic [H]	H=16 (18% N)	10 (62.5% H)	6 (37.5% H)
Other (Asian, Indian, mixed Heritage) [OTH]	OTH=10 (11.2% N)	4 (40% OTH)	6 (60% OTH)

for both groups at baseline and posttest, depicted 5 (PED, n=2; UL, n=3) out of 89 data points as outliers with a distance from the median greater than 1.5 times the interquartile range. After exclusion of these 5 outliers, a 2-factor ANOVA with repeated measures on time (baseline and posttest), depicted a significant difference in average daily steps between treatment groups and time (P=.005). Although overall steps increased significantly (P=.004), the average steps decreased slightly in the PED group between the posttest and follow-up sessions (10,200±760 at posttest to 9,775±722 at follow-up). This pattern is visible in Figure 3, however, the regression was not significant (P=.486). Despite this insignificant regression, 49.4% of participants achieved the 10,000 s/d goal at follow-up.

There was a statistically significant decrease in WC by time (P=.027); however, no statistically significant difference between treatment groups over time (P=.460). Post hoc analysis confirmed a significant difference in WC only between baseline and posttest (P=.043). Although the mean decrease in WC was only 1.8 cm from baseline to follow-up, approximately 16% of participants achieved a clinically relevant decrease in WC, defined as the transition from a high risk WC measurement to one of lower risk (male, <102 cm; female, <88 cm).

Secondary. All secondary measured indices, except systolic and diastolic BP (P=.278 and P=.362 respectively), demonstrated a significant change overall from baseline to posttest: WT (P<.001), BMI (P<.001), BF% (P=.001), and HR (P=.005). However, there was no significant difference between treatment groups over time for any of these indices: WT (P=.180), BMI (P=.202), BF% (P=.736), and HR (P=.455). Figure 4

displays a graphical representation of each of these variables over time. Although the mean decrease in WT was only 1.2 kg from baseline to follow-up, approximately 16.0% of participants achieved a weight loss of clinical relevance, defined as a 5% weight loss.

The IPAQ physical activity survey found an overall increase in reported activity (MET-hours per week) over time (baseline to posttest); however, the change was insignificant ($P = .077$), with no difference between groups noted. The IPAQ survey did, however, indicate a significant decrease in the amount of time participants from both groups spent sitting per day (from an average of 6.7 hours per day to 5.9 hours per day; $P = .005$).

Table 2: Baseline measures for both treatment groups.

	Mean (SD)			
	Overall	PED Group	UL Group	*P*
Weight, kg	87.6 (16.3)	87.1 (16.1)	88.0 (16.7)	.827
BMI, kg/m^2	32.5 (5.4)	32.3 (4.6)	32.6 (6.2)	.915
Waist circumference, cm	102.6 (11.8)	102.6 (11.3)	102.6 (12.4)	.980
Body fat, %	42.0 (9.0)	43.3 (7.5)	40.6 (10.1)	.152
Systolic blood pressure, mm Hg	120 (13.4)	123 (13.6)	117 (12.5)	.035*
Diastolic blood pressure, mm Hg	77 (8.7)	78 (8.9)	76 (8.5)	.602
Resting Heart Rate, beats per minute	76 (11.3)	76 (10.9)	76 (11.8)	.977
Average steps per day	7404 (3275)	7357 (2980)	7452 (3586)	.850
Average MET-hours per week	93.9 (76.2)	88.3 (75.5)	99.7 (77.3)	.384
Average hours sitting per day	6.8 (2.8)	6.5(2.5)	6.9 (3.1)	.570

*Significant to the $P<.05$ level.

COMMENT

The results of this study depict an average increase of 3,000 s/d and a decrease in WT, WC, BMI, BF%, and HR across both groups; however, none of these changes were significantly different between the PED and UL groups. Removal of the 5 control group outliers yielded a significant difference between groups; however, by the time data was analyzed, the authors were unable to confirm if these outliers were related to unusual circumstances (such as running a marathon), a faulty pedometer, participant underreporting the number of days the pedometer was worn, or a data entry error.

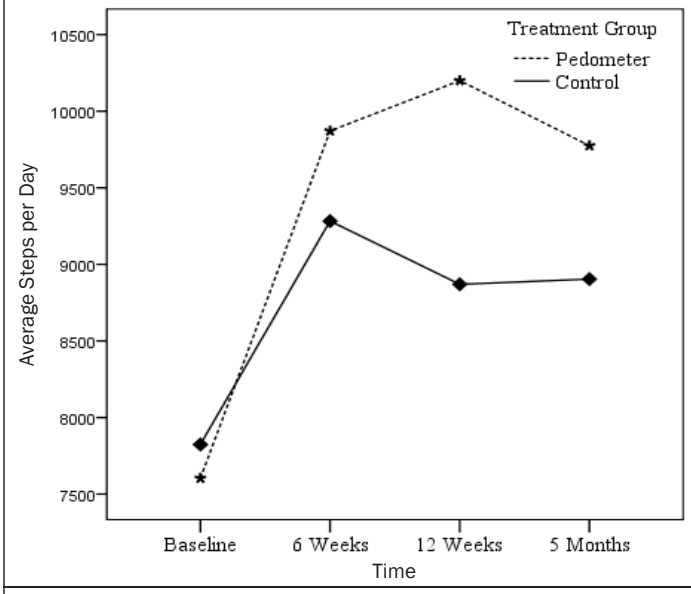

Figure 3. Comparison of average steps per day between groups over time. Note: Repeated Measures ANOVA used.

Regardless, at study initiation, step count data indicated that the usual lifestyles of many of the participants were more active than anticipated. Based on previous research, the alleged sedentary study population averaged 4,000 s/d at baseline and significantly increased to 8,000 s/d[18]; however, in the current study, participants averaged more than 7,000 s/d at baseline. One plausible explanation for this elevated baseline step count was the location of recruitment and data collection. The large medical center in which the study took place required most hospital workers to do a great deal of walking in their everyday duties. Moreover, at this particular hospital, the walk to and from the parking lot alone is approximately 1,500 steps. With a higher than anticipated baseline step average, it was less realistic to expect the PED group to double or dramatically increase their steps. This notion demonstrates that pedometers may have greater potential to elicit results in a sedentary population. For this reason, future researchers may consider establishing more stringent exclusion criteria at baseline in order to target a sedentary population (eg, participants must average 4,000 or less s/d).

It was impossible for investigators to prevent the UL group from taking measures to increase their physical activity (for example, purchasing pedometers or starting an exercise program),

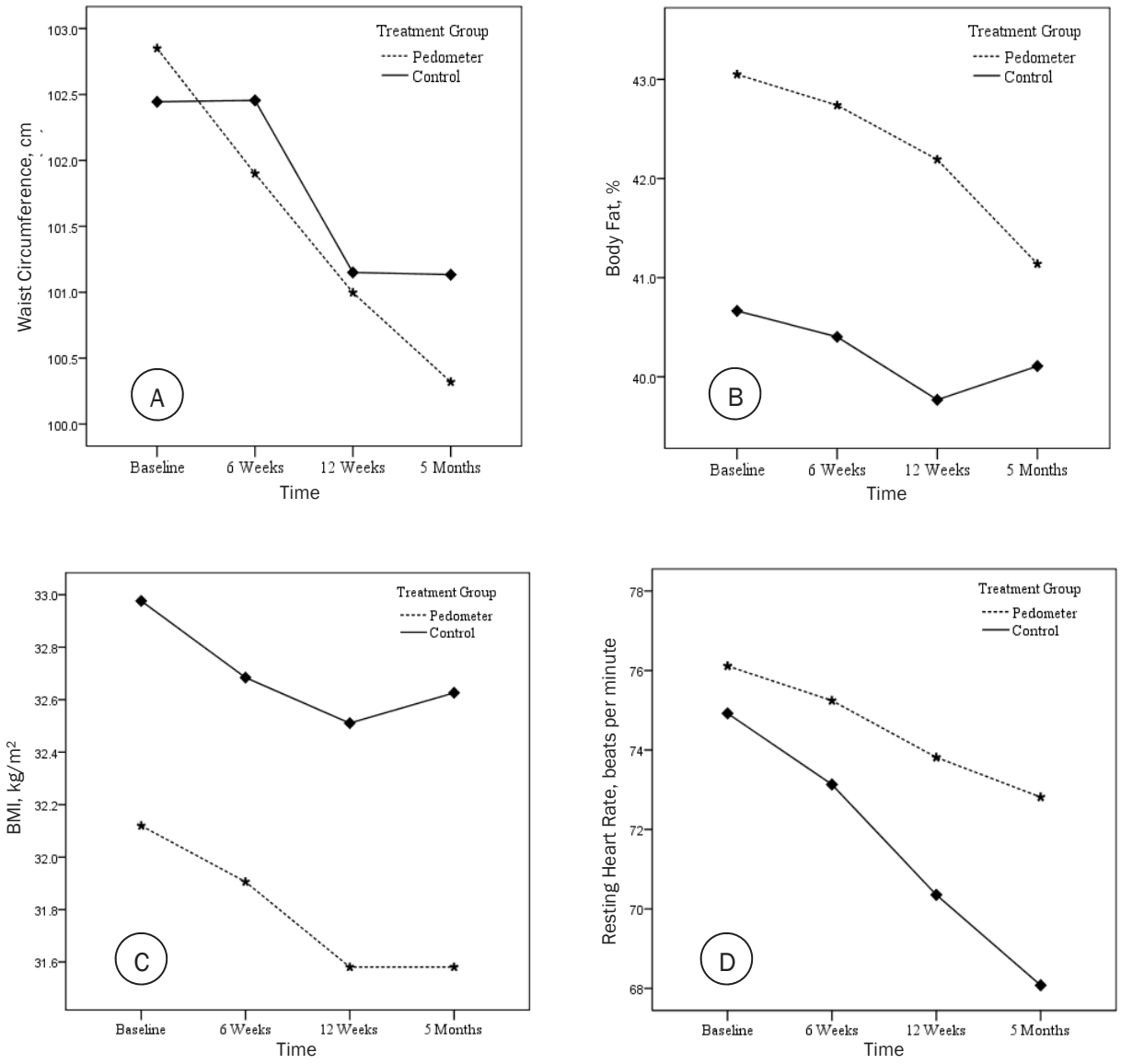

Figure 4. Comparisons of measured indices of groups over time. Panel A: Change in waist circumference. Panel B: Change in body fat percentage. Panel C: Change in body mass index. Panel D: Change in resting heart rate.
Note: Repeated Measures ANOVA used.

despite instruction to not change their physical activity. In conjunction, an unforeseen obstacle was the inability to minimize group interaction. The cohesive hospital environment and proximity of acquaintances and coworkers in the study may have contributed to step and body measurement changes across both treatment groups. Specifically, actions the PED group took to increase steps potentially had a direct effect on members of the UL group, as walking partnerships formed among treatment groups per anecdotal reports from subjects. As discussed as part of the Theory of Planned Behavior model, social influence, motivation to perform, and confidence in one's ability to perform a particular behavior may have a profound effect on behavior change.[29]

Furthermore, investigators attribute a large part of the heightened awareness and success within both groups to primarily 2 factors: frequent participant-investigator interactions and the use of pedometers as tangible devices to increase awareness of sedentary behavior for both groups. These concepts are demonstrated in the study by Shimon and Petlichkoff,[30] which assessed 3 pedometer adolescent groups over a 4-week period: (1) self-regulatory group; daily monitor and recording of s/d with a 10-minute researcher interaction on goal-

setting strategies, (2) open group; daily monitor and recording of s/d without researcher interaction, (3) control group; use of a sealed pedometer without the ability to monitor progress. They found that both self-regulatory and open groups significantly increased steps per day and attributed the progress to increased self-awareness and self-referent motivation.

In the present study, participants of both groups attended measurement sessions and wore sealed pedometers for all data collection periods. These frequent evaluations by study investigators may have provoked a Hawthorne effect, characterized by an intervention process offering all participants sufficient reinforcement and motivation to make lifestyle changes. This notion is strengthened by similar results of a study conducted by Gleeson-Kreig,[31] in which the control group increased activity as much as the intervention group. Likewise, the authors attributed the positive results in both groups to the benefits of personal interaction with a physical activity professional. Similarly, Zoellner et al[32] found that a pedometer walking program resulted in increased step counts and diary compliance among participants when their investigator "coach" was also compliant and provided adequate social support.

Current study investigators suspect the pedometer, the second factor, also served as an effective tool even when sealed, because participant awareness of its presence and function likely encouraged extra efforts to increase steps, despite the inability to view the step value. This appears to be reinforced when users know their step progress will be monitored by others (ie, study investigators). Essentially, the pedometer itself appears to be a motivator due to its ability to serve as a physical reminder for users to get up and walk.

The ultimate goal of the study was to increase participant daily walking, which was statistically apparent within both groups. The concept that pedometers may be effective more as a result of their tangible presence than the actual step count value to provide immediate feedback captures the difficulty associated with conducting controlled pedometer research. A control group represents a portion of the sample uninfluenced by study intervention. Therefore, it may be unrealistic to develop legitimate randomized-controlled trials of this design, given that investigators are virtually unable to mitigate the motivating effects of the pedometer's presence.

The results also demonstrated that an increase in steps was not directly correlated with decreases in WT, WC, BMI, or BF%. The intensity of the walking pace likely played a significant role in anthropometric changes and health benefits, as others studies have suggested,[33,34] in which greater benefit was found when participants walked 7,000 to 8,000 steps at an intensity of 3 METs rather than 10,000 steps at a lower intensity. Pal et al[35] conducted a study using the IPAQ survey and found only a significant difference in perceived MET hours from walking in the pedometer group compared to the control group, but found no difference in the perception of moderate, vigorous, or total MET hours. Because current study investigators were unable to assess walking intensity (not a function available on the Yamax SW200), it is plausible that participants achieving a smaller step goal at a higher intensity may have seen more benefit than those walking 10,000 steps or more at a low intensity. Also, previous pedometer studies highlighting weight loss and WC improvements often included a nutrition intervention component to enhance the effects of increased physical activity.[10,14] In the present study, both groups were educated about general healthy eating guidelines and not used as a specific intervention to assist with weight loss to prevent any bias between groups.

The limited duration of the present study prevented investigators from fully evaluating participant success in making lifestyle changes manageable for the long-term. The interactive website offered limited benefit despite its use as a self-monitoring tool, due to its inadequate space for communication (limited to 10 lines of text before disappearing). Based on current research, there have been inconsistent findings regarding the effectiveness of internet-based interventions. For instance, Steele et al[36] found that their internet-delivered physical activity intervention was as effective as their face to face intervention, whereas Harvey et al[37] found that web-based data collection was not as successful as expected, and Carr et al[38] found that their web-based program was not effective for long-term physical activity adherence (75% returned to baseline s/d at 8-month follow-up). Furthermore, in the current study, some participants opted not to use the internet tools, and regression in the present study at the 5-month follow-up was minimal. A study by Walders-Abramson et al[39] offers insight into a more effective web-based system which allows participants to electronically download daily

step counts onto the computer with the use of the Omron HJ-112 (Omron Healthcare, Kyoto, Japan) pedometer, thus maximizing internet tool usage and minimizing reliance on self-report data. This reliance potentially served as a major limitation in the present study, as investigators based step count data on participant self-report of number of days of sealed pedometer use. Many pedometer and accelerometer manufactures now offer advanced models with the capability of downloading data through the internet.

Overall, pedometer use with step count tracking via an interactive website was not effective at increasing step counts or improving health outcomes in a military hospital setting, when compared to a control group without access to the interactive website. Future studies should establish more stringent guidelines to minimize participant group interaction effects and more accurately assess the motivating factor behind wearing a pedometer. These procedures may include assessing people at different stages of change to determine when pedometer use is most effective and if wearing a pedometer aids in transition through the stages. Additionally, pedometer studies should attempt to use larger sample sizes, more precise control measures, and longer duration. As demonstrated in the literature, the use of accelerometers to measure activity intensity in place of pedometers may be more effective when evaluating overall health benefits of increased physical activity. Accelerometer studies completed solely within a military population may help evaluate the physical activity intensity of overweight or obese service members in order to identify viable fitness options for military weight loss programs.

IMPLICATIONS FOR PRACTICE

Despite military efforts to promote weight management, a significant number of DoD beneficiaries remain overweight; therefore, it may be necessary to approach alternative methods to better accommodate the typical DoD beneficiary lifestyle. Pedometers have demonstrated effectiveness in promoting behavior change by offering individuals small, gradual measures in physical activity. The Theory of Planned Behavior model addresses this concept with its recognition that an individual's confidence in his/her ability to perform a particular behavior relies heavily on outcome measurements and past experiences with the particular behavior.[29] The results of this study indicate that success associated with pedometer usage is independent on the ability to track one's progress. The pedometer was effective in increasing daily step counts by serving as a tangible tool and a constant reminder for participants to get up and walk. Practitioners may be able to use these findings to provide clients with pedometer recommendations in conjunction with regular follow-up visits, characterized by health assessments, goal-setting, and self-monitoring, to elicit increases in physical activity and resulting health benefits.

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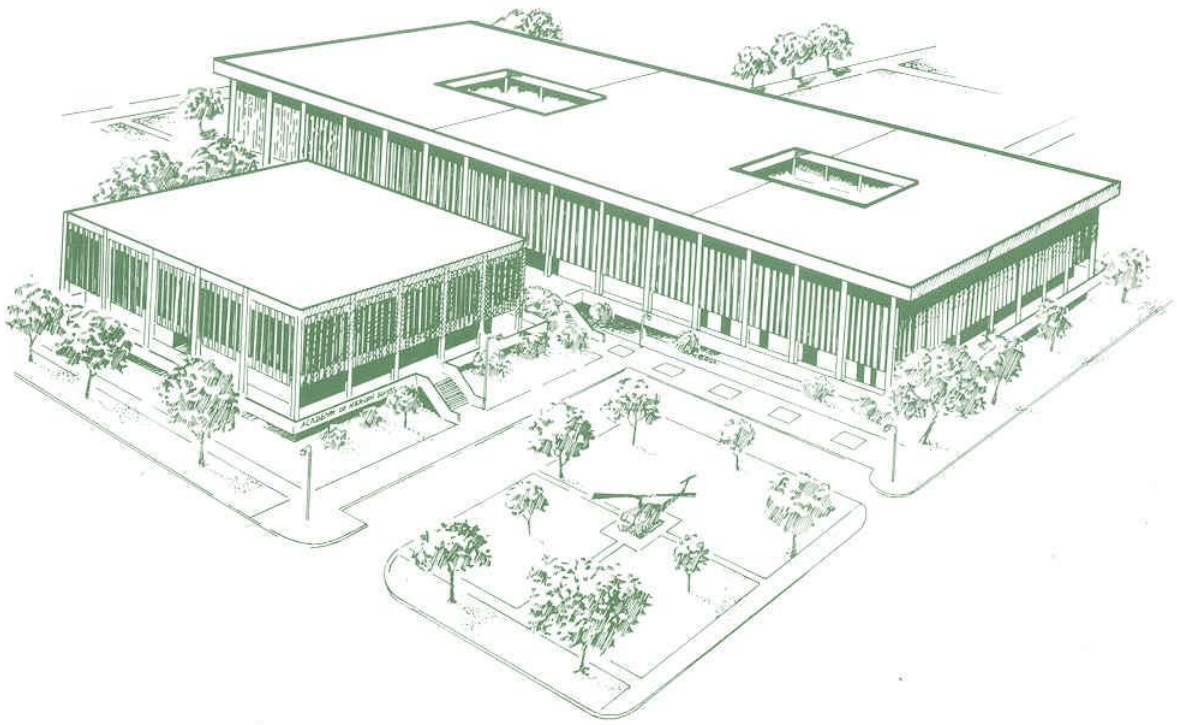

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