Feasibility of Obtaining Intraosseous and Intravenous Access Using Night Vision Goggle Focusing Adaptors

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ABSTRACT

Background: The optimal tactical lighting for performing medical procedures under low-light conditions is unclear. **Methods:** United States Navy medical personnel (N = 23) performed intravenous (IV) and intraosseous (IO) procedures on mannequins using a tactical headlamp, night vision goggles (NVGs), and night vision goggles with focusing adaptors (NVG+A) utilizing a randomized within-subjects design. Procedure success, time to completion, and user preferences were analyzed using analysis of variance (ANOVA) and nonparametric statistics at $p < .05$. **Results:** IV success rates were significantly greater for the headlamp (74%) than for NVG (35%; $p < .03$) and somewhat greater than for NVG+A (52%; $p = .18$). IO success rates were high under each lighting condition (96% to 100%). Time to completion was significantly faster using headlamp (IV, 106 ± 28 s; IO, 47 ± 11 s) than NVG (IV, 168 ± 80 s; IO, 56 ± 17 s) or NVG-A (IV, 157 ± 52 s; IO, 59 ± 27 s; each $p < .01$). Post-testing confidence on a 1-to-5 scale was somewhat higher for NVG+A (IV, 2.9 ± 0.2; IO, 4.2 ± 0.2) than for NVG (IV, 2.6 ± 0.2; IO, 4.0 ± 0.2). Participants cited concerns with NVG+A depth perception and with adjusting the adaptors, and that the adaptors were not integrated into the NVG. **Conclusion:** While this mannequin study was limited by laboratory conditions and by the lack of practice opportunities, we found some small advantages of focusing adaptors over NVG alone but not over headlamp for IV and IO access in low-light conditions.

KEYWORDS: *low light; military medicine; Special Operations; intravenous access; intraosseous access; night vision goggles; focusing adaptors*

Introduction

Military operations are frequently performed at night to provide a tactical advantage. Close-in medical procedures, such as IV and IO access, are challenging in low-light conditions. Because hemorrhage remains the leading cause of death on the battlefield, IV and IO access are crucial to the resuscitation of casualties.[1–8]

Tactical lighting, such as headlamps, is widely used by medical personnel to deliver care in low-light operational environments. Tactical headlamps have advantages, including a wide field of lighting, hands-free operation, and normal visual focusing. However, tactical lighting has limited utility when light discipline is paramount.

NVGs were developed to preserve distance vision in low-light conditions while maintaining light concealment. However, NVGs were not designed for close-in medical procedures such as IV and IO access. To perform close-in tasks, the objective lenses of the NVGs need to be refocused, resulting in loss of distance focus, which can be detrimental in a kinetic environment. Empirical studies have demonstrated that medical procedures are feasible using NVGs but that these procedures have a lower rate of success and take longer to complete compared with conventional procedures.[9–14]

Focusing adaptors that attach to NVGs have recently been developed to allow for near-field focus down to 18 inches while maintaining distance focus out to infinity. However, these adaptors decrease the amount of light coming through the NVGs, potentially reducing efficacy. To our knowledge, no studies published to date were specifically designed to evaluate NVG+A compared with NVGs alone or tactical headlamps on the success rate or time to completion of any medical procedure.

To fill this important gap, we conducted a prospective, randomized, within-subjects experiment using mannequins to contrast NVG, NVG+A, and green-light tactical headlamp lighting on IV and IO access success rates and times to completion. Our null hypotheses were that there would be no statistically significant differences between lighting conditions in

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success rates or times to completion. Further, we hypothesized that there would be no statistically significant differences between lighting conditions in perceived difficulty for IV and IO placement, user confidence, or user preference.

Methods

Setting

This study was conducted at the Naval Medical Center San Diego (NMCSD). This study complied with the ethical guidelines of the AMA and NMCSD, including Institutional Research Board approval. Written informed consent was acquired from each participant prior to data collection. All materials were provided by the participants, supplied by the NMCSD Bioskills Simulation Center, or purchased by the authors.

Participants

The participants were 23 United States Navy medical personnel who met the inclusion criteria indicating previous Tactical Combat Casualty Care (TCCC) training, although exact courses were not collected, and being familiar with the use of NVGs. Tests of power using G*Power software indicated a minimum of 18 participants would be needed to achieve 80% power.[15] To ensure adequate power, we included 23 participants.

Most (18/23; 78%) participants were US Special Operations (SO) medics, with 17% (4/23) Special Amphibious Reconnaissance Corpsmen (SARCs), and 4% (1/23) Field Medical Service Technicians (FMSTs). Participants averaged 8.5 (±1.2) years of military service. None of the participants was colorblind, and 9% (2/23) reported wearing contact lenses. Participants ranged from familiar to expert with headlamps (mean [M] = 4.7 ± 0.1 on 1-to-5 scale ranging from no familiarity to expert) and with NVGs (M = 4.4 ± 0.1). Most (18/23; 78%) had no familiarity with the focusing adaptors (M = 1.6 ± 0.3). All participants reported using headlamps and NVGs in operational environments, while 3 of 23 (13%) reported prior use of NVG+A in operational environments.

Materials

Tactical Headlamp

The Storm Headlamp (Black Diamond) is lightweight (110 g with four AAA batteries), measures 2.54 × 5.08 × 2.54 cm, and has a maximum output of 350 lumens. White, red, green, and blue hues are available, but only green light was used in our study, based on prior research demonstrating green as the optimal hue for medical procedures of the hues available with this headlamp, and to match the green phosphor color of the NVGs described below.[16–18]

Night Vision Goggles

AN/PVS-31 dual-tube green phosphor NVGs weigh 595 g and measure 11.55 × 7.62 × 6.6 cm. These NVGs were provided by the study participants and were attached to participants' helmets by the participants themselves.

Adaptors

Tarsier Eclipse (Matbock) focusing adaptors weigh 453 g, measure 5 × 5 × 2.5 cm, and were provided by the study team. The rubber housing slides onto the objective lens of the AN/PVS-31 NVGs and retains its position by friction. The adaptors are focused by rotating the outside housing to increase or decrease the aperture of the iris. The aperture was set by each individual participant. Per the manufacturer's recommendations, participants were instructed first to ensure that the NVGs were focused two-thirds of the way to infinity, then attach the Tarsier Eclipse to NVG tube, close the Tarsier Eclipse aperture to the smallest opening, and slowly open the Tarsier Eclipse to allow the appropriate amount of light needed, as determined by the participant.

Intravenous Access Mannequins

Multi-Venous IV Training Arms (Laerdal Medical) with overlying modified IV Suture Sleeves (Strategic Operations) that employ dyed red water as simulated blood were used. IV access also required nitrile gloves, elastic tourniquet, alcohol pad, 18-gauge IV needle with catheter, MicroClave Clear neutral connector (ICU Medical), window transparent film dressing (6 × 7cm), 10mL syringe, and gauze sponge (5.1 × 5.1 cm).

Intraosseous Access Mannequins

SimMan 3G (Laerdal Medical) simulation legs were used for tibial IO access. IO access also required the ChloraPrep Frepp (Becton, Dickinson) 1.5mL applicator (2% chlorhexidine gluconate/70% isopropyl alcohol), nitrile gloves, EZ-IO Power Driver, EZ-IO 25-mm 15-gauge needle set, and EZ-Connect Extension Set (Teflex).

Procedures

Room Preparation

A simulation laboratory was adapted for low-light conditions by covering all possible light sources, so that ambient light was reduced to <0.3 lux, as confirmed by a lux meter. Two IV simulation arm stations and two IO simulation leg stations were arranged in the room, separated by physical barriers.

Informed Consent

In a lighted room adjacent to the simulation lab, participants signed a consent form that provided an overview of the study and detailed participant rights to privacy, confidentiality, and withdrawal from the study at any time or to refuse to answer any survey questions. Prior to signing the consent form, an ombudsman was available to address all participant questions and concerns. Following informed consent, participants completed the pretest survey.

Training and Instructions

After providing informed consent and completing the pretesting survey, participants entered the darkened simulation laboratory room. Following the 10-minute dark-adaptation period, participants familiarized themselves with the equipment by green chem light illumination and were provided instructions on the procedural steps listed here:

IV Procedure Steps

1. Identify venous access point.
2. Apply tourniquet.
3. Clean access site with alcohol wipe.
4. Insert IV catheter.
5. Connect MicroClave Clear neutral connector.
6. Apply window transparent film dressing.
7. Attach 10mL syringe to the MicroClave Clear neutral connector.

IO Procedure Steps

1. Identify tibial IO insertion site.
2. Clean insertion site with ChloraPrep.

3. Attach IO needle to the EZ-IO Power Driver.
4. Insert IO needle.
5. Remove stylet.
6. Secure EZ-Connect Extension Set to the IO tubing.

The experiment did not begin until participants indicated that they were comfortable with these steps.

Data Collection

All participants were required to wear nitrile gloves during the procedures and were not allowed to open any packaging before the start time. However, participants could arrange the materials on an adjacent table as they preferred. One proctor was present at each procedural station. Each round of testing included three or four participants.

Two key data points were collected per procedure. Time to completion was recorded as the time between when the proctor started the stopwatch and when the participant indicated that they were done. Successful placement of the IV and IO needles was judged and recorded by the proctor as 1 = success, 0 = failure. Successful IV placement was confirmed by return of fluid into the syringe attached to the IV. Successful IO placement was confirmed by removal of the simulated skin and direct visualization of the IO needle in the simulated tibial IO access site. Any complications or protocol violations were recorded by the proctor. There were two protocol violations: one participant lost a piece of equipment, necessitating a pause, and one participant accidentally used red light instead of green. Neither of these data points (access success or time to completion) were included in the analysis.

After completing both IV and IO procedures under each of the three lighting conditions, normal room lighting was restored, and participants completed the posttest exit survey, which included perceived difficulty of the procedures per lighting condition, confidence, and preferences on which combinations of lighting and procedure they would use in operational environments. Participants were also given space to provide qualitative feedback on the materials, device design, and applicability of the study to their operational role.

Primary Outcomes

Our primary outcomes were success rate and time to completion. Time to completion was measured in seconds. Additionally, user ratings and confidence were assessed on 1-to-5 scales. Preferences were assessed using six-alternative forced choices. Open-ended questions were scored using grounded theory methodology, so that our conclusions would be based on user responses and not on any potential experimenter bias. Grounded theory scoring begins with identifying useful components of individual responses (open coding), which are assembled into categories (axial coding), then refined (selective coding) to develop major themes.[19,20]

Study Design and Statistical Analysis

For this prospective, within-subjects experimental design, each participant was randomly assigned to a sequence of lighting conditions using a mirrored Latin square, with IV and IO procedures randomized within each lighting condition for each participant.

Scaled variables (time to completion and ratings) were analyzed via repeated-measures ANOVA with localizing pairwise comparisons, each confirmed with nonparametric statistics. Effect sizes are expressed as the differences between means in units of standard deviation (Cohen's *d*).[21,22] Effect sizes are categorized as small (d <0.20), medium (d = 0.20 to 0.80), and large ($d \geq .80$).[21]

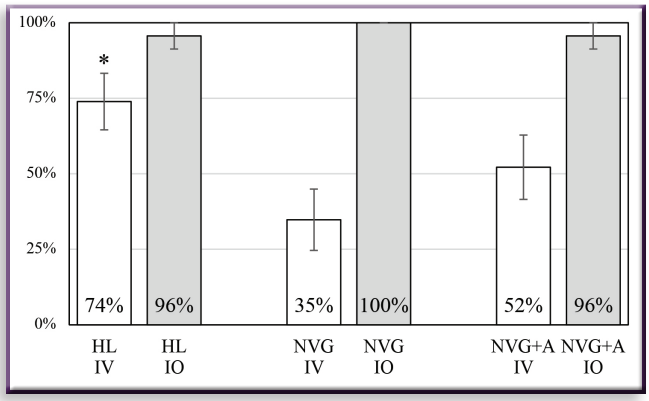
Success data were analyzed using Cochran's Q and localizing McNemar's tests. Differences were considered to be statistically significant at the $p < .05$ threshold. All analyses were conducted in SPSS software (version 23; IBM).

Results

Procedure Success

Figure 1 shows that success rates for IV access under headlamp (HL) conditions were significantly greater (17/23; 74% ± 9%) than those for NVG (8/23; 35% ± 10%) ($p < .03$) but not NVG+A (12/23; 52% ± 11%) ($p = .18$). IV NVG and NVG+A success rates were not significantly different ($p = .34$), even though the success rate for NVG+A was roughly 1.5 times that of NVG. IO success rates were statistically similar between the three lighting conditions (HL: 22/23; 96% ± 4%; NVG: 23/23; 100%; NVG+A: 22/23; 96 ± 4%) ($p = .61$).

FIGURE 1 *Procedure success rate by lighting condition for intravenous and intraosseous procedures.*



*$p < .03$ vs NVG IV.
HL, tactical headlamp; IV, intravenous; IO, intraosseous; NVG, night vision goggle; NVG+A, night vision goggle with focusing adaptor.

Time to Completion

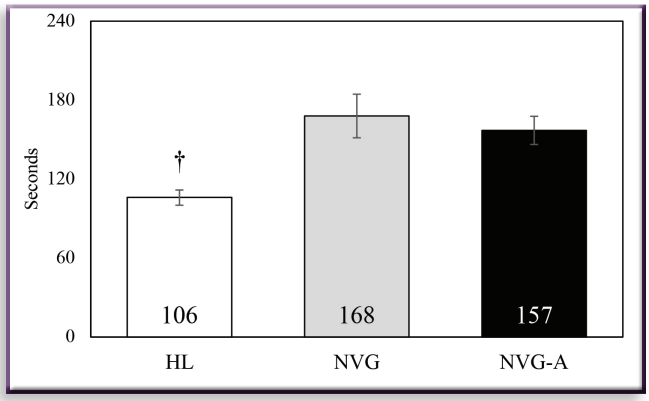
Time to IV procedure completion was significantly faster using the headlamp (106 ± 28 s) than the NVG (168 ± 80 s) or NVG+A (157 ± 52 s) (each $p < .001$). NVG and NVG+A were statistically similar in time to IV procedure completion ($p = .98$). The effect sizes were large, with headlamp IV completion 1 full minute faster than NVG completion ($d = 1.00$) and 51 seconds faster than that of NVG+A ($d = 0.82$) (Figure 2).

Similarly, IO procedure completion was significantly faster using the headlamp (47 ± 11 s) than using NVG (57 ± 17 s) and NVG+A (59 ± 27 s) (each $p < .01$). NVG and NVG+A were statistically similar in time to IO completion ($p = .62$). The effect sizes for IO access were medium in magnitude, with the headlamp averaging 10 seconds faster than NVG ($d = .52$) and 12 seconds faster than NVG+A ($d = .60$) (Figure 3).

Difficulty

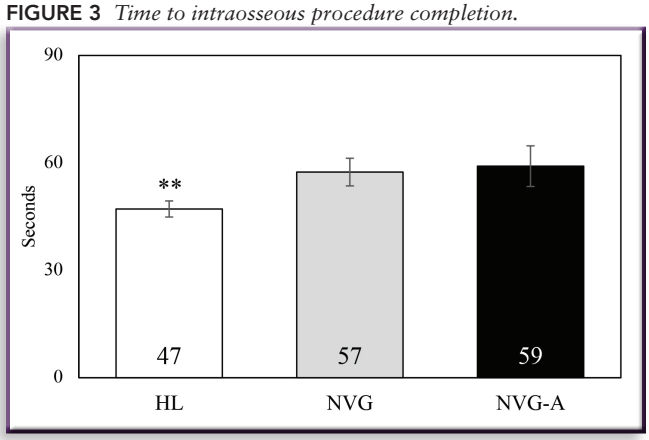
On the posttesting survey, participants were asked to rate the difficulty in placing IO needles and IV catheters using each of the lighting conditions on a 1-to-5 scale (1 = no difficulty,

FIGURE 2 *Time to intravenous procedure completion.*



†$p < .001$ vs NVG, NVG+A.
HL, tactical headlamp; NVG, night vision goggle; NVG+A, night vision goggle with focusing adaptor; NVG-A.

FIGURE 3 *Time to intraosseous procedure completion.*



**$p < .01$ vs NVG, NVG+A.
HL, tactical headlamp; NVG, night vision goggle; NVG+A, night vision goggle with focusing adaptor; NVG-A.

5 = very difficult). Figure 4 shows that the headlamp was rated significantly less difficult than the NVG and NVG+A for both IV (each $p < .001$) and IO procedures (each $p < .01$).

Confidence

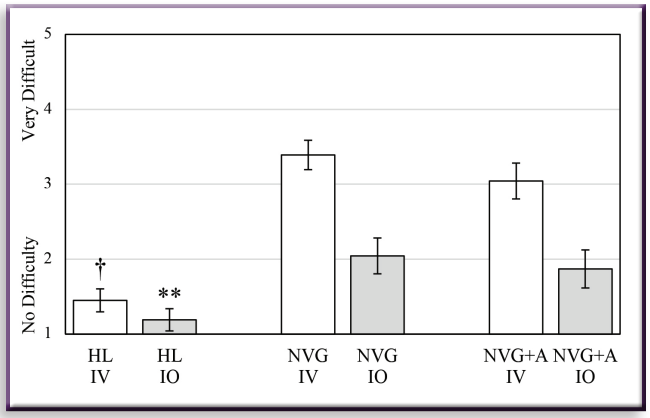
Participants were asked to rate their confidence in starting IV and IO needles under each lighting condition. Table 1 shows that pretesting confidence for both IV and IO procedures was significantly higher with the headlamp than with NVG or NVG+A (each $p < .001$). Pretesting NVG confidence was significantly higher than that for NVG+A for IV and IO access (each $p < .01$). NVG and NVG+A posttesting confidence did not significantly differ between IV or IO procedures.

Table 1 also shows that pre–post changes in confidence were mixed. Confidence using NVG+A significantly increased for IV and IO procedures. Confidence using the headlamp significantly increased for IO procedures but not for IV procedures. Confidence using NVG did not significantly change for IV or IO procedures and actually trended lower for IV.

Exploratory Analyses

To guard against the possibility that the substantive finding from hypothesis testing was artificially driven by potentially confounding variables, comprehensive exploratory analyses were conducted to determine whether participant-centric

FIGURE 4 *Perceived difficulty in procedure application.*



†$p < .001$ vs NVG, NVG+A.
**$p < .01$ vs NVG, NVG+A.
HL, headlamp; IV, intravenous; IO, intraosseous; NVG, night vision goggle; NVG+A, night vision goggle with focusing adaptor.

demographic, experience, confidence, or training variables were significantly correlated with study outcomes, significantly interacted with lighting conditions in factorial ANOVA, or altered the hypothesis-driven outcomes when included as covariates in analysis of covariance (ANCOVA).

These exploratory analyses included years in the military, contact lens use, familiarity with the lighting equipment, use of NVG or NVG+A in operational environments for IV or IO placement, presurvey and postsurvey confidence in use of the lighting equipment for IV or for IO placement, and training (US SO, SARCs, FMSTs).

None of the study participant-centric demographic, experience, confidence, or training variables were significantly correlated with study outcomes, with two exceptions. First, a participant's number of years in the military was significantly associated with greater IV success in the NVG+A lighting condition ($p < .02$). Second, US SO participants were significantly faster than SARC participants in IO access in completion times under NVG (50 ± 3 s vs 81 ± 9 s; $p < .001$) and NVG+A (51 ± 4 s vs 93 ± 29 s; $p < .01$) lighting conditions. However, neither years in the military nor training (US SO versus SARC, excluding the one FMST participant) significantly interacted with lighting conditions in IV or IO success rates or application times in factorial ANOVA. Further, including years in the military and training as covariates in ANCOVA analyses failed to alter the substantive findings from hypothesis testing in application success or in application times for IV or IO procedures. That is, the substantive findings displayed in Figures 1, 2, and 3 were robust to comprehensive exploratory analyses to account for potentially confounding demographic, experience, confidence, and training variables.

Attitudes Toward Using NVGs With Adaptors

Overall, 30% (7/23) of participants indicated that they would use focusing adaptors to start an IV or IO procedure in an operational environment only reluctantly, while 57% (13/23) indicated they would do so willingly, and 13% (3/23) would do so eagerly.

Forced Choice Preference

Participants were asked to choose one combination of lighting conditions and IV or IO access to use in an operational,

TABLE 1 *Pre- and Posttesting Confidence in Obtaining Intravenous*

	IV			IO		
Lighting	Pre	Post	*p* Value	Pre	Post	*p* Value
HL	4.3† (0.2)	4.6† (0.2)	0.14	4.4† (0.2)	4.8‡ (0.2)	0.04
NVG	3.0** (0.2)	2.6 (0.2)	0.053	3.7** (0.2)	4.0 (0.2)	0.52
NVG+A	2.3 (0.3)	2.9 (0.2)	0.049	2.9 (0.3)	4.2 (0.2)	0.003

†$p < .001$ vs NVG, NVG+A.
**$p < .01$ vs NVG-A.
‡$p < .001$ vs NVG, $p < .02$ vs NVG+A.
HL = tactical headlamp; IV, intravenous; IO, intraosseous; NVG, night vision goggle; NVG+A, night vision goggle with focusing adaptor; NVG-A.

low-light setting. For those who selected one combination only, the most common combinations were the headlamp with an IO procedure (39%) and NVG with an IO procedure (26%). However, 5 of 23 participants (22%) selected more than one combination. Including these multiple combination selections, the most frequent combinations were a headlamp with an IO procedure (12/23; 48%) and NVG with an IO procedure (9/23; 39%). NVG+A with an IO procedure was included by 13% (3/23) of participants, and NVG+A with an IV procedure was included by 9% (2/23) of participants. Overall, 57% (13/23) included the headlamp in their preferred combinations, while 39% (9/23) included NVG, and 17% (4/23) included NVG+A.

Discussion

Performing medical tasks can be challenging in low-light conditions. Rapidly acquiring IV or IO access is vital toward preserving the life of the hemorrhaging warfighter. Standard tactical lighting (i.e., a tactical headlamp) may be effective in aiding IV or IO access, but standard tactical lighting does not confer light discipline, thereby risking unnecessary exposure to the enemy. NVGs confer light discipline but are not designed for close-in work, such as obtaining IV or IO access. Focusing adaptors may fill this need, but the efficacy of focusing adaptors compared to NVGs and tactical headlamp lighting in the speed and success of obtaining IV and IO access was unclear. This study makes a novel contribution to the literature by testing focusing adaptors for IV and IO access using US SO, SARC, and FMST professionals.

The tactical green-light headlamp performed best in the present study, demonstrating the fastest completion times, highest rates of success, and highest participant confidence in obtaining IV and IO access, and was the most common user preference. These findings support the use of the tactical headlamp for IV and IO access when light discipline is not of significant importance but not when light discipline is critical.

NVG results were mixed, with 100% success in obtaining IO access but the least success in obtaining IV access. Further, NVG was marginally faster than NVG+A in IO application time, but marginally slower in IV application time and somewhat worse in perceived difficulty in performing IV and IO procedures. Confidence results were also mixed for both IV and IO access, with NVG rated significantly higher than NVG+A at pretest but somewhat lower than NVG+A at posttest. Roughly 4 of every 10 participants preferred a combination that included NVG.

NVG+A results were also mixed. IO application success was identical to that of the tactical headlamp. The IV success rate was roughly one-third lower than that of the tactical headlamp but roughly one-third higher than that of NVG. NVG+A completion times were marginally slower than those of NVG for IO access but marginally faster for IV access. NVG+A was rated marginally less difficult than NVG for IV and IO procedures, and confidence ratings were somewhat higher than those for NVG at posttesting for both IV and IO procedures. These results may have been driven, at least in part, by lack of user familiarity with NVG+A because few had prior experience with focusing adaptors. This speculation is supported by participant feedback and by the statistically significant increases in pre–post changes in user confidence for both IV and IO procedures. Overall, 13% of participants indicated that they would use the focusing adaptors eagerly in an operational setting, whereas 30% indicated that they would do so reluctantly.

Participant feedback regarding the focusing adaptors varied. Some participants liked the increased near-field focus, while others had difficulty focusing the devices. Perceived brightness also varied, with some reporting improved brightness and others reporting a darkened view. Two participants were concerned with the lack of integration into the NVGs and feared that the adaptors would get lost. Three indicated that the adaptors would be valuable only if supplemented with an infrared light source. One participant revealed that "the NVG+A allows you to focus on multiple depths at the same time which is crucial for IVs. I could see flash much better with the adaptors." Another stated that the NVG+A "made it easier to see close up during the procedure." However, still another commented that NVG+A was "another piece of gear to adjust." Others reflected that they needed more repetitions with the focusing adaptors before reaching strong conclusions regarding the utility of the NVG+A.

Implications

Present findings regarding speed, success, confidence, ease of use, and user preference suggest that a tactical headlamp may be superior to NVG or NVG+A for starting IVs and IOs in low-light conditions. On the posttest exit survey, some commented that they preferred the tactical headlamp but were concerned about light discipline and being seen by the enemy. These findings imply that a tactical headlamp may be the superior choice for IV and IO access when light discipline is not paramount. However, NVG or NVG+A might be the only viable alternatives to tactical lighting when light discipline is vital or when the provider does not have access to a tactical light at the time that the IV or IO access is needed.

NVG+A should not be used for medical procedures, such as IV or IO procedures, without appropriate training and practice. This implication is based on both the observation that

confidence in NVG+A use significantly increased from pre- to posttesting for both IV and IO access and feedback from study participants. Most of the study participants were unfamiliar with the focusing adaptors prior to testing, and many had difficulty adjusting the focus. During the experiment and on the exit survey, multiple participants commented that they would have liked more time to familiarize themselves with the adaptors prior to evaluation and would have preferred more repetitions during testing. When a participant failed at IV or IO procedures, it was common for them to ask if they could try again or whether there would be a second round of testing. Combined, these findings underscore the significant learning curve and highlight the importance of training and practice with NVG focusing adaptors.

Limitations

This study was limited by the sample, which was modest in size and included only US Navy medical personnel. Further, while all participants indicated they had received TCCC training, we did not obtain data regarding exactly which TCCC courses each attended and what other relevant medical training each might have had.

It is always possible that the results of a study could be an artifact of bias. However, to guard against potential sources of bias, all participants received the identical introduction and instruction set that did not favor any specific lighting device. Participants used identical brand and model headlamps, NVG, and NVG focusing adaptors. All workstations were identical, and the same model stopwatch was used to measure time to completion. Further, this experiment employed a randomized mirrored Latin square design, so that each lighting condition had equal odds of being represented in the first, second, or third sequence position to balance order effects (e.g., warm-up effects from going first or fatigue effects from going last) and carry-over effects because each lighting condition had equal odds of going first or being preceded by either of the other two lighting conditions. However, participation in this study was voluntary, which can potentially bias results (i.e., selection bias), thereby challenging the external validity and generalizability of a study by fostering conclusions that may not be fully representative of the sampled population.[23]

This study was conducted under laboratory conditions using simulation mannequins, not live humans in battlefield or austere conditions, situations that may include, for example, genuine time stress toward preserving life in chaotic environments or inclement weather. Only one NVG model and one adaptor model were tested.

The tactical headlamp was tested with only green light to ensure that all three lighting conditions employed greet light. However, red light is commonly used, and there is empirical evidence that a red-green color mix may be more effective in low-light conditions than green-only or red-only for close-in medical procedures, such as suturing.[24] Additionally, we did not test participants under full-light conditions, which would have allowed us to assess their success rates and application times under tactical lighting conditions compared with ideal lighting conditions.

Participants were given only minimal training prior to testing, were not provided an opportunity to practice, and were allowed only one attempt per procedure per lighting condition. For standardization, participants were not allowed to mix and match or otherwise alter equipment prior to testing, as is common with personalized medical kits. No long-term follow-up data were collected to determine the stability of findings over time.

Finally, posttesting surveys were completed after the participant had completed all procedures rather than following each procedure and therefore may have suffered from recall bias. We intentionally chose this strategy because it was impractical to turn on the lights between iterations to complete survey information gathering, then re–dark-adapt participants for their next iteration, because we wanted participants to appreciate each lighting condition before rating conditions and choosing their preferences. Further, we have used this strategy of waiting until all objective data are collected before soliciting exit-survey information in previously published research from our laboratories.[25,26] Our mirrored Latin square design was chosen to foster the principle that each lighting condition would be equally represented as the first, second, and third condition in the sequence, so there was no systematic bias regarding recency of memory unduly advantaging any specific lighting condition. Regardless, recall bias may have limited our postsurvey data. For these reasons, posttesting survey findings should be only generalized with appropriate caution.

Areas for Future Research

The present study should be replicated with larger, more diverse samples, including personnel from other military Services and tactical civilian personnel, various NVG and adaptor models, and different challenging tasks under combat or simulated-combat conditions. Ideally, selection bias can potentially be avoided by testing randomly selected, stratified samples of participants from the various target populations of United States Navy medical personnel or other populations whenever feasible.

The effect of focusing adaptors on other operational procedures should be investigated, such as tourniquet application, airway procedures, thoracostomy, medication draws, map reading, and retrieval of gear from a medical bag.

This study failed to reveal systematic differences in outcomes based on demographic data. However, these null findings may have been the result, at least in part, of the modest sample size overall and the meager or nonexistent sample sizes for some included demographic items (e.g., only four SARCs and one FMST; only three with prior NVG+A operational experience; no color-blind participants). Additionally, some potentially important personal variables were not included, such as specific prior trainings (e.g., TCCC courses, type and level of SOF operator training, duration and specifics of other relevant medical training, and NVG cross-training). Future scholars may choose to seek appropriate samples to systematically assess the potential impact of demography, training, and experience on the effective use of lighting on IV and IO application in low-light conditions.

Further, confidence ratings were not significantly related to study outcomes. The reasons for these null findings are unclear. Empirical research suggests that self-assessment may be flawed in general and that there may be a confidence-competence mismatch in tourniquet application by nonmedical users.[27-29]

Furthermore, posttesting confidence generally rose compared with pretesting confidence in the present study, but somewhat declined for IV application in the NVG condition. Focused research is needed to clarify the relationship between confidence and competence in general and in the context of the effective use of tactical lighting to perform life-preserving medical tasks in low-light conditions. This line of investigation is vital because of the potentially disastrous impact of overconfidence in conducting medical procedures in low-light conditions.

Performance in obtaining IV access was relatively poor in the present study, at least in part because the IV simulation mannequins made it difficult to visualize the vein. Based on participant suggestions, using human volunteers may be more realistic for testing NVG adaptors for IV access. Other participants suggested testing focusing adaptors with supplemental infrared light or floodlights, an open area for future research.

Study participants raised concerns that the adaptors might be misplaced because they are not attached to NVGs. Additionally, attaching the adaptors on site to complete a close-in medical task during an active battlefield operation requires fine motor skills and may take time away from casualty care. It is therefore important to determine whether focusing adaptors can be effectively integrated into NVGs.

It is crucial to determine optimal training for using focusing adaptors with NVGs. This includes the number of repetitions across various tasks and the impact of bolus "just in time" predeployment and premission training and practice. As one participant stated, "With more experience using the adaptors, I may be more likely to use it." TCCC training may benefit from including a greater emphasis on performing medical tasks in low-light conditions, whether with tactical lighting, NVGs, or NVG+As. Long-term follow-up studies should be conducted to determine skill sustainment and training effects. Lastly, analysis of after-action reports may prove fruitful in determining the efficacy of focusing adaptors on care quality and casualty outcomes.

Conclusion

While this study was limited by the use of mannequins in laboratory conditions and by the lack of practice opportunities provided, present findings demonstrate some small advantages of focusing adaptors over NVGs alone but not over the tactical headlamp for IV and IO access in low-light conditions.

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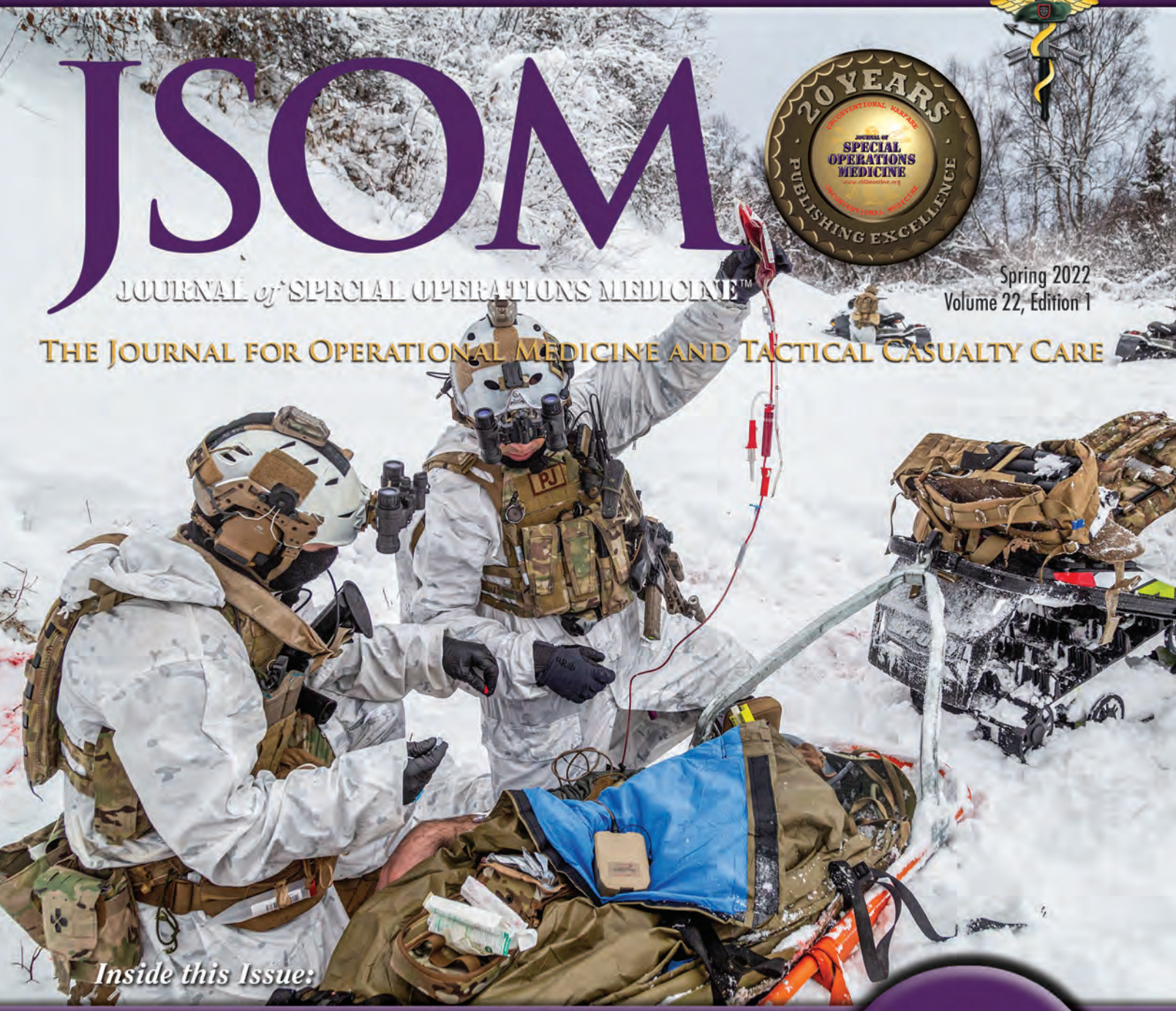

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