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Feasibility of Electronic Stethoscope for En Route and Combat Casualty Care

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14. ABSTRACT

In the En Route and Combat Casualty Care environments, occupational stressors can complicate the ability to perform medical interventions which are often used in civilian ground healthcare facilities. Conventional stethoscopes are the primary diagnostic tool for patient assessment and triage, but during aeromedical transport high noise limits the ability to auscultate patients to assess cardiovascular, respiratory, and gastrointestinal systems for clinically relevant abnormalities. To address this gap, this research effort aimed to investigate the feasibility of an electronic stethoscope designed for high noise environments during flights on En Route and Combat Casualty Care transport vehicles. Six Pararescue providers and three Aeromedical Evacuation providers performed cardiopulmonary auscultation on two mock patients using an electronic stethoscope on the HH-60G, and C-130H airframes, respectively. The nine providers assessed the stethoscope using a questionnaire and provided feedback about the usability and applicability of the stethoscope within the En Route and Combat Casualty Care environments. Results from the study highlighted the feasibility of an electronic stethoscope for use in high noise military environments such as En Route and Combat Casualty Care and provided recommendations for future research efforts. The ability to accurately identify clinical irregularities using an essential diagnostic tool and medically intervene when necessary may reduce the number of preventable deaths from the battlefield and, ultimately, improve patient outcomes.

15. SUBJECT TERMS

high noise; stethoscope; en route; combat casualty; auscultation

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1.0 SUMMARY

In the En Route and Combat Casualty Care environments, occupational stressors can complicate the ability to perform medical interventions which are often used in civilian ground healthcare facilities. Conventional stethoscopes are the primary diagnostic tool for patient assessment and triage, but during aeromedical transport, high noise limits the ability to auscultate patients to assess cardiovascular, respiratory, and gastrointestinal systems for clinically relevant abnormalities. The ability to accurately identify these abnormalities using an essential diagnostic tool and medically intervene when necessary may reduce the number of preventable deaths from the battlefield and ultimately, improve patient outcomes. To address this gap, this research effort aimed to investigate the feasibility of an electronic stethoscope designed for high noise environments during flights on En Route and Combat Casualty Care transport vehicles. Six Pararescue providers and three Aeromedical Evacuation providers performed cardiopulmonary auscultation on two mock patients using an electronic stethoscope on the HH-60G, and C-130H airframes, respectively. The nine providers assessed the stethoscope using a questionnaire and provided feedback about the usability and applicability of the stethoscope within the En Route and Combat Casualty Care environments. Results from the study highlighted the feasibility of an electronic stethoscope for use in high noise military environments such as En Route and Combat Casualty Care and provided recommendations for future research efforts.

2.0 BACKGROUND

In high noise environments, such as those associated with transport on ground and air vehicles, the functionality of conventional stethoscopes is limited. At the skin surface, sounds range from 22-30 decibels (dB) and amplified to 65-70 dB through a stethoscope making them audible to the listener [1]. In environments exceeding 60 dB, such as those associated with ground and air transport, heart and lung sounds are inaudible with conventional auscultation methods [2] as the signals corresponding to biological sounds are often within the spectrum of ambient noise [3]. In the En Route Care (ERC) and Combat Casualty Care domains, medical providers care for patients transported from point of injury to definitive care. Coupled with potentially long transport distances, a variety of occupational stressors encumbers providers during the continuum of ERC. To transport patients to higher levels of care, ground vehicles such as ambulances, retrofitted school buses, and air vehicles such as rotary-wing and fixed-wing airframes may be used. The C-130 and C-17 are commonly used fixed-wing airframes used in ERC and have average noise levels of 90-100 dB on the C-130 [1] and 86 dB on the C-17, well above the 60 dB threshold for using conventional auscultation methods [1, 4]. The commonly used rotary aircraft for ERC, the HH-60G, has noise levels ranging between 90 and 120 dB, also well above the 60 dB threshold for conventional auscultation [1]. Structural vibration due to aircraft propulsion and weapons systems, and airborne vibration may negatively affect the ability to use conventional stethoscopes to assess patients as the design of stethoscopes makes them susceptible to noise and vibration through multiple transmission pathways including through earpieces, acoustic tubing, sensor housing, or the body of the person being assessed [5].

During ERC and Combat Casualty Care, it may be necessary for healthcare providers to listen to heart and lung sounds to identify abnormalities, such as listening to lung sounds to identify a collapsed lung and provide life-saving medical intervention. The accurate identification and rapid medical intervention of emergent clinical issues may significantly reduce the number of preventable deaths from the battlefield [2]. Unfortunately, noise and vibration in current ERC and Combat Casualty Care operations hinders auscultation with conventional stethoscopes. Due to advancements in technology and better understanding of noise levels within ERC and Combat Casualty Care transport vehicles, commercial off-the-shelf stethoscope technology has been developed specially for auscultation in high noise environments.

3.0 METHODS

The Air Force Research Laboratory Institutional Review Board approved this mixed-methods descriptive study. This study was a follow-on effort to a previously approved study, which investigated the use of two high noise stethoscopes in a simulated ERC environment on a C-130 training platform. The previous study found ERC providers were able to identify heart and lung sounds using a digital stethoscope called the Thinklabs™ One Digital Stethoscope (Figure 1) in a high noise simulated ERC environment. Based on the previous study's findings, the research team completed a follow-on effort to evaluate the feasibility of the Thinklabs One Digital Stethoscope during actual flights on airframes used for ERC and Combat Casualty Care. This device was selected because it is a commercial off-the-shelf stethoscope specifically developed for civilian high noise environments. The Thinklabs One Digital Stethoscope was designed for high power output, with dedicated headphone amplifiers and has fully adjustable volume levels (1-10). The Thinklabs One Digital Stethoscope can produce very high sound pressure levels and can exceed 100 times the decibel level of a conventional stethoscope. Five different filters allow the user to switch between listening for heart and lung sounds. In addition to filtering operations, adjusting the amount of pressure applied to the diaphragm alters the frequency response. Filter one ranges from 30 to 500Hz and filter two ranges from 60 to 500Hz, these low-pitched filters provide optimal auscultation for heart sounds. Filter three ranges from 80 to 500Hz and filter four ranges from 100 to 1000Hz, these filters are at a higher pitch, providing optimal auscultation for lung sounds. The fifth filter is a broadband filter ranging from 20Hz to 2000Hz +/- 3dB. The broad range of this filter lacks the specificity to filter out ambient noise, but is ideal for recordings. The Thinklabs One allows providers to select two filters as their "favorites" and set them for easy transition between the two filters. The Thinklabs One has LED lights to serve as a visual indicator that the stethoscope is functioning. These LEDs also serve to indicate the volume level, current filter selection, and the device's battery life. The stethoscope contains a rechargeable lithium ion battery that can be recharged through a USB port. A full battery charge provides four continuous hours of auscultation time, which provides 100+ patient assessments. To save battery life, the Thinklabs One has a customizable timer shut off that can be set between 1 and 10 minutes. If the user prefers, the stethoscope can be placed in a continuous "on" mode where the provider can manually turn the stethoscope off when not in use. The Thinklabs One is designed to resemble the tactile shape and features of a traditional stethoscope, making it intuitive for users. The Thinklabs One was designed to be able to create audio recordings while auscultating. The stethoscope is compatible with both Mac and Android software. Thinklabs has designed an application (app) that allows audio recordings to be made with visual indicators [6]. The Thinklabs One comes with an adaptor that allows it to be connected directly into the Bose®™ (Framingham, MA) A20® headsets and the communication system used by ERC users. This feature gives users the ability to auscultate while remaining on communication channels. The communication will override the auscultation, allowing users to be aware of important communication while still performing auscultations if desired.

Figure 1. Thinklabs One digital stethoscope.

Combat Casualty participants were recruited from available Pararescue providers located at Nellis Air Force Base in Nevada. ERC participants were recruited from available Aeromedical Evacuation (AE) providers located at the Kentucky Air National Guard in Louisville, Kentucky. The research team aimed to receive feedback from at least 10 Pararescue providers and at least 10 AE providers. Both Pararescue and AE providers have medical training and are familiar with using a stethoscope for cardiopulmonary assessments in the military operational health care environment.

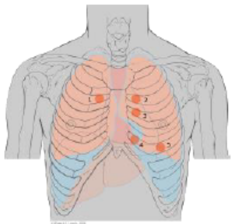
Prior to data collection, the Combat Casualty Pararescue participants and ERC AE participants were provided with a training session on proper use of the Thinklabs One Digital Stethoscope. The training session included a verbal introduction to the study, an introduction to the Thinklabs One Digital Stethoscope, and review of a questionnaire (Figures 2-5). Participants were then able to have hands on practice using the Thinklabs One Digital Stethoscope on two adult human volunteers (one male and one female) in a classroom setting. Members of the research team were available to answer any questions during the practice sessions.

Questionnaire

Please utilize the stethoscope to respond to the following questions. Feel free to record any comments or suggestions you have regarding the device in the space provided below.

Auscultation is being performed on a MALE OR FEMALE *please circle*

Cardiac Assessment



Please auscultate at the following locations:
(1) Aortic area, right 2nd intercostal space (ICS)
(2) Pulmonic area, left 2nd ICS
(3) Erb's point, left 3rd ICS
(4) Tricuspid area, right 4th ICS
(5) Mitral area, apex

1. Please rate your ability to identify heart sounds using the device:

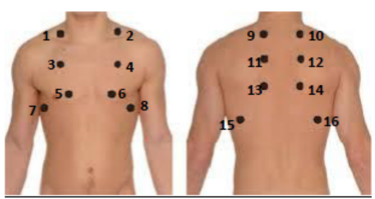
Spot 1:	Excellent	Good	Fair	Poor	Unable
Spot 2:	Excellent	Good	Fair	Poor	Unable
Spot 3:	Excellent	Good	Fair	Poor	Unable
Spot 4:	Excellent	Good	Fair	Poor	Unable
Spot 5:	Excellent	Good	Fair	Poor	Unable

Comments/Suggestions:
____

Figure 2. Cardiac assessment questionnaire page.

Auscultation is being performed on a MALE OR FEMALE *please circle*

Pulmonary Assessment



Anterior and Posterior

2. Please rate your ability to identify lung sounds using the device:

Spot 1:	Excellent	Good	Fair	Poor	Unable
Spot 2:	Excellent	Good	Fair	Poor	Unable
Spot 3:	Excellent	Good	Fair	Poor	Unable
Spot 4:	Excellent	Good	Fair	Poor	Unable
Spot 5:	Excellent	Good	Fair	Poor	Unable
Spot 6:	Excellent	Good	Fair	Poor	Unable
Spot 7:	Excellent	Good	Fair	Poor	Unable
Spot 8:	Excellent	Good	Fair	Poor	Unable
Spot 9:	Excellent	Good	Fair	Poor	Unable
Spot 10:	Excellent	Good	Fair	Poor	Unable
Spot 11:	Excellent	Good	Fair	Poor	Unable
Spot 12:	Excellent	Good	Fair	Poor	Unable
Spot 13:	Excellent	Good	Fair	Poor	Unable
Spot 14:	Excellent	Good	Fair	Poor	Unable
Spot 15:	Excellent	Good	Fair	Poor	Unable
Spot 16:	Excellent	Good	Fair	Poor	Unable

Comments/Suggestions:
____

Figure 3. Pulmonary assessment questionnaire page.

***Overall* Device**

5. Please rate your confidence in using the device for auscultations:
   Excellent Good Fair Poor Unable

   Comments/Suggestions:
   ____
   ____

6. Please rate the ease of the device for performing auscultations:
   Excellent Good Fair Poor Unable

   Comments/Suggestions:
   ____
   ____

7. Please rate the sound quality of the device:
   Excellent Good Fair Poor Unable

   Comments/Suggestions:
   ____
   ____

8. Please rate the sound volume of the device:
   Excellent Good Fair Poor Unable

   Comments/Suggestions:
   ____
   ____

9. Please rate the applicability of this device to Aeromedical Evacuation:
   Excellent Good Fair Poor Unable

   Comments/Suggestions:
   ____
   ____

10. Please rate the ease of cleaning the device:
    Excellent Good Fair Poor Unable

    Comments/Suggestions:
    ____
    ____

11. Please rate the portability of the device:
    Excellent Good Fair Poor Unable

    Comments/Suggestions:
    ____
    ____

Figure 4. Overall device assessment questionnaire page.

12. Please rate the durability of the device:
Excellent Good Fair Poor Unable

Comments/Suggestions:
____
____

13. How likely are you to use this device for en route care:
Extremely Likely Likely Neutral Unlikely Unable

Comments/Suggestions:
____
____

14. What changes would you suggest to make this product meet the needs for auscultation in en route care?
____
____

15. Please comment on the amount and quality of training received for use of this device i.e. type, amount, recommendations, etc.:
____
____

16. Please describe the current practice you are using to perform auscultation during en route care:
____
____

17. What technologies do you currently utilize for auscultation during en route care?
____
____

Additional Comments or Suggestions
____
____

Please CIRCLE your current profession:

AE medical technician AE nurse CCAT respiratory therapy

CCAT nurse CCAT physician Pararescue Jumpers

Thank you for your participation in this questionnaire.

Figure 5. Overall device assessment questionnaire page and demographics.

During data collection, the Pararescue participants used the communications earplugs (CEP) provided in the Thinklabs One Digital Stethoscope kits plugged into the stethoscope and then had 3M™ PELTOR™ COMTAC™ III headsets (Figure 6) on top of the CEPs for added ear protection. Pararescue providers commonly use PELTOR headsets during Combat Casualty Care. The AE participants performed auscultation using Bose A20 headsets (Figure 7) plugged directly into the adapter on the stethoscope. Bose A20 headsets are commonly used by ERC providers and due to the adapter located on the stethoscope, Bose A20 headsets can be directly connected to the stethoscope without the use of CEPs.

Figure 6. 3M PELTOR COMTAC III headset.

Figure 7. Bose A20 aviation headset.

During data collection in the Combat Casualty Care environment, the Pararescue participants were asked to board a HH-60G airframe located at Nellis Air Force Base, Nevada two at a time and perform cardiopulmonary auscultation on two human volunteers using the Thinklabs One Digital Stethoscope during flight. Both human volunteers laid in the supine position on litters commonly used for aeromedical transport. The litters were placed directly on the floor of the HH-60G airframe. During data collection in the ERC environment, the AE participants were asked to board a C-130H airframe located at the Kentucky Air National Guard in Louisville, Kentucky. Data collection was completed in parallel of an ongoing training mission with the unit.

The research team instructed both Pararescue and AE participants to auscultate using a comfortable volume level of the stethoscope that was loud enough for them to hear heart and lung sounds but not too loud to cause discomfort. Cardiac assessment was completed in the five traditional anterior auscultation regions including: aortic, pulmonic, Erb's point, tricuspid, and mitral regions. Pulmonary assessments were completed in the 16 traditional auscultation regions on the anterior and posterior surfaces [7]. Participants provided quantitative feedback about their ability to identify heart and lung sounds at the specific auscultation regions and qualitative feedback about the durability of the device, sound quality, sound volume, and applicability of the stethoscope to their specific military environments.

IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY) was used to analyze the quantitative data. Participants rated their ability to auscultate at the standardized locations using a Likert scale ranging from 1 to 5 (1 – unable to hear, 2 – poor, 3 – fair, 4 – good, and 5 – excellent). For all analyses, a p-value less than 0.05 was considered statistically significant and the exact values were reported along with medians and interquartile ranges.

The qualitative data obtained from the open-ended responses on the provided questionnaire was analyzed using a typology methodology. Typology was the chosen methodology as the goal of the qualitative data analysis was to develop a set of related, but distinct, categories to identify and understand any themes present in participants' feedback [8]. The steps of the typology analysis were: (1) identify an organizing framework, (2) identify a source of commonality and variation that occurs in a data set, (3) look within these areas of commonality or variation for similarities and differences, and (4) look at similarities and differences to reconstruct into types or model cases [8]. The open-ended responses were transcribed verbatim into Microsoft Excel and transferred to Microsoft Word for line-by-line analysis. Inter-rater reliability of 80% or more was used for consistency of themes for each question's comment [9]. Analysis of the comments were conducted by the research team using the steps identified above, and opposing analysis was discussed until consensus was reached among the research team.

4.0 RESULTS

Due to conflicting mission and humanitarian requirements the research team received feedback from only six Pararescue participants located at Nellis AFB, Nevada and three AE participants located at the Kentucky Air National Guard in Louisville, Kentucky. Reported results are in the form of median values; interquartile ranges were unobtainable for the cardiac and pulmonary assessments because of the limited subject number. Interquartile ranges, in the Pararescue group, for the questions pertaining to the user's confidence in using the stethoscope to auscultate, ease of using the stethoscope to auscultate; sound quality, sound volume, and applicability of the device to the environment are shown in Table 1.

While limited, feedback from the Pararescue and AE participants provided valuable insight about the feasibility of using the stethoscope in high noise military environments. The median response from the six Pararescue participants for both the male and female mock patients was 1 – "unable to hear" for the five cardiac and sixteen pulmonary auscultation locations. AE participants rated their ability to identify heart and lung sounds at the majority of locations with a median of 2 – "poor." Cardiac spots 1-3, and pulmonary spots 11-12, were rated as 1.5 during the assessments on the female mock patient and pulmonary spots 13-14 were rated as 2.5 during the assessments on the male mock patient. Ease of use and sound volume were the two questions that received the highest ratings by the Pararescue and AE participants. Table 1 shows the median values for each question on the questionnaire.

Table 1. Median Results from Stethoscope Assessment

Region	Pararescue Providers (n=6)		AE Providers (n=3)	
Cardiac	Male Median	Female Median	Male Median	Female Median
Spot 1	1	1	2	1.5
Spot 2	1	1	2	1.5
Spot 3	1	1	2	1.5
Spot 4	1	1	2	2
Spot 5	1	1	2	2
Pulmonary				
Spot 1	1	1	2	2
Spot 2	1	1	2	2
Spot 3	1	1	2	2
Spot 4	1	1	2	2
Spot 5	1	1	2	2
Spot 6	1	1	2	2
Spot 7	1	1	2	2
Spot 8	1	1	2	2
Spot 9	1	1	2	2
Spot 10	1	1	2	2
Spot 11	1	1	2	1.5
Spot 12	1	1	2	1.5
Spot 13	1	1	2.5	2
Spot 14	1	1	2.5	2
Spot 15	1	1	2	2
Spot 16	1	1	2	2
Confidence in using device to auscultate	1.5 [1,2]		1	
Ease of using	3 [1,4]		3	
Sound quality	1 [1,1]		2	
Sound volume	4 [2,4]		3	
Applicability to environment	1 [1,2]		2	

Based on the typology methodology, the qualitative data analysis began with line-by-line analysis of each participant's response. After all three researchers reviewed the responses line-by-line; all researchers assembled and discussed themes that were present. The following categories of themes emerged: 1) Environment; 2) Mechanics; and 3) Training. Environment was defined as the setting in which auscultation occurred. Participants in both the HH-60 and C-130 reported vibration and aircraft sound impeding the ability to auscultate adequately in both sitting and lying positions by the mock patients. Free text respondents from a few participants did record some ability to hear pulmonary and cardiac sounds but their confidence was low for diagnostic capabilities. Modification suggestions were made for an outer rubber cover to dampen noise entering the device or other noise/vibration altering equipment such as a rubber mat to place the patient on or the provider to stand on or alterations to the filters within the device to filter aircraft noise and vibration. Participants reported current auscultation practice as nonexistent during flight due to extraneous noise and vibration. All participants reported the mechanics of the device was easy to use; suggested improvements could be slightly larger and more rugged with bigger buttons. Training was evaluated as adequate with minimal training necessary due to the device mimicking innate stethoscope qualities. Comments included “it took less than 5 minutes to learn how to use it” and “it was easy’ to learn to use.

5.0 DISCUSSION

This study aimed to investigate the feasibility of a commercial off-the-shelf high noise stethoscope during flights on ERC and Combat Casualty Care airframes. In current operations, auscultation using a conventional stethoscope is limited during ERC and Combat Casualty Care due to extraneous noise present during ground and in-flight transport. ERC and Combat Casualty Care providers are only able to use a conventional stethoscope to assess their patients when ambient noise is low and have to rely on other assessment skills such as visually assessing their patient, often in low light situations, or performing palpation in environments where vibration is present. In both the male and female mock patient volunteers and in both Pararescue and ERC environments, the ability to identify heart and lung sounds using the Thinklabs One was rated as 1 – “unable” or 2 – “poor” and confidence in using the device for performing auscultation was also rated as 1 – “unable”. The highest rated areas in both environments were ease of use and the sound volume.

Qualitative data revealed information informing researchers on the specific limitations of the device in the AE environment and suggestions from operational relevant users to overcome these obstacles if device modifications will be sought. While there were some auscultated sound reported by some participants, responses indicated that the specific filters to attenuate extraneous sounds and permit heart and lung sounds to be heard seemed to actually accentuate the aircraft noise rather than filter or decrease it. Participants indicated that they were unsure whether it was aircraft sound or vibration sound that was the most problematic and prevented heart and lung sounds to be heard. Open-ended responses indicated that participants would be open to utilizing a stethoscope device during AE transport even though current environmental noise and vibration prevent its use. In addition, participants provided multiple suggestions for device modifications that could help to inform future efforts for an optimal solution to auscultation in AE.

6.0 LIMITATIONS

The goal of this research study was to assess the feasibility of using a commercial off-the-shelf stethoscope for patient auscultation in Combat Casualty Care and ERC flight environments. Unfortunately, only six Combat Casualty Care Pararescue providers and three AE providers completed the assessment of the stethoscope. The research team aimed to collect feedback from at least ten Pararescue providers, ten AE providers, and ten Critical Care Air Transport (CCAT) providers as both AE and CCAT providers are integral to the en route continuum of care and have the ability to auscultate during ERC transport. Limited Pararescue, AE, and CCAT providers located at Nellis AFB and the Kentucky Air National Guard were available to assist with the study during the data collection period as providers were already assisting with real-world humanitarian efforts. As such, the number of subjects available to assess the stethoscope during flight and provide feedback was much lower than originally anticipated. This limits the ability of findings to be generalizable to the ERC and Combat Casualty Care environments. There is need for future research studies to investigate the use of high noise stethoscope(s) for use in ERC and Combat Casualty Care by additional providers as well as expand the research to additional high noise military environments. One of the major themes, which emerged from analysis of the open-ended responses, was the presence and impact of vibration. Vibration was not measured in either airframe, and as such, it is unknown if the transmission of vibration to the provider, to the mock patient, or to the stethoscope degraded subjects' ability to identify heart and lung sounds using the device. There is need for additional research studies to characterize the impact of vibration on the ability to auscultate in high noise military environments.

7.0 CONCLUSION

Patient auscultation with a conventional stethoscope, which is a primary diagnostic tool in the majority of healthcare environments, is not feasible in high noise military environments. The ability to identify clinical abnormalities using a stethoscope and provide appropriate medical intervention may improve patient outcomes. The Thinklabs One Digital Stethoscope was developed for use in high noise civilian medical facilities and enables users to choose from five filters for cardiopulmonary assessment. To the authors' knowledge, this research study was the first to examine the feasibility of the Thinklabs One for use in high noise military environments. A total of six Pararescue and three AE providers assessed the ability to identify heart and lung sounds using the Thinklabs One in their respective high noise flight environments. Qualitative feedback from providers indicated future research is needed to characterize the influence of noise and vibration on the ability to auscultate during flight as well as to investigate device modifications that could improve usability of the device for high noise military operations.

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LIST OF ABBREVIATIONS AND ACRONYMS

AE	aeromedical evacuation
CCAT	critical care air transport
CEP	communications earplugs
ERC	enroute care