

AWARD NUMBER: W81XWH-19-1-0637

TITLE: Identifying the Sources of Degraded Speech-in-Noise Understanding and Individualized Therapeutic Options

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CONTRACTING ORGANIZATION: University of Iowa

REPORT DATE: October 2020

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Development Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE October 2020		2. REPORT TYPE Annual		3. DATES COVERED 09/01/2019-08/31/2020	
4. TITLE AND SUBTITLE Identifying the Sources of Degraded Speech-in-Noise Understanding and Individualized Therapeutic Options				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER W81XWH-19-1-0637	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Inyong Choi, Ph.D. Assistant Professor Department of Communication Sciences and Disorders E-Mail: inyong-choi@uiowa.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Iowa 2 Gilmore Hall Iowa City, IA 52242-1320				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Development Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This project will identify the peripheral and central factors that predict the variance of speech-in-noise (SiN) understanding ability among normal hearing listeners. To achieve this goal, in Aim 1, neural substrates of all the key stages along the proposed SiN processing model will be characterized through within-subject design experiments of human electrophysiology. In Aim 2, a correlational study, we will characterize a hierarchical regression model that adopts the measures of auditory neural processes as independent variables and electrophysiological responses and behavioral performance during phonological and lexical processing as dependent variables. Finally, Aim 3 will seek an optimal, clinically applicable set of test batteries and measures that identifies 1) the sources of degraded speech-in-noise understanding and 2) the most effective, individualized therapeutic options.					
15. SUBJECT TERMS NONE LISTED					
16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT Unclassified	18. NUMBER OF PAGES 14	19a. NAME OF RESPONSIBLE PERSON USAMRMC
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)

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1. INTRODUCTION: *Narrative that briefly (one paragraph) describes the subject, purpose and scope of the research.*

Even among young "normal hearing" people, there is great variation in the ability to understand speech in noisy real-world settings. However, current audiology practice does not have the methods to diagnose and treat speech-in-noise (SiN) problems in normal hearing listeners because of the uncertain etiology of SiN disorders. This project will identify the peripheral and central factors that predict the variance of SiN understanding ability among normal hearing listeners. To achieve this goal, in Aim 1, neural substrates of all the key stages along the proposed SiN processing model will be characterized through within-subject design experiments of human electrophysiology. In Aim 2, a correlational study, we will characterize a hierarchical regression model that adopts the measures of peripheral encoding, auditory grouping, and selective attention processes as independent variables, cortical responses during speech unmasking as a mediator, and electrophysiological responses and behavioral performance during phonological and lexical processing as dependent variables. Finally, Aim 3 will seek an optimal, clinically applicable set of test batteries and measures that identifies 1) the sources of degraded speech-in-noise understanding and 2) the most effective, individualized therapeutic options. This study will characterize several key neural processes required for successful speech understanding in social settings, and will promote our understanding of how peripheral and central processing deteriorates in listeners with degraded ability.

2. KEYWORDS: *Provide a brief list of keywords (limit to 20 words).*

Speech in noise, peripheral auditory encoding, auditory grouping, auditory selective attention, phonological processing, lexical processing, electroencephalography (EEG), electrocorticography (ECoG)

3. ACCOMPLISHMENTS: *The PI is reminded that the recipient organization is required to obtain prior written approval from the awarding agency grants official whenever there are significant changes in the project or its direction.*

What were the major goals of the project?

List the major goals of the project as stated in the approved SOW. If the application listed milestones/target dates for important activities or phases of the project, identify these dates and show actual completion dates or the percentage of completion.

This is the first-year annual report. For the first year, the following two milestones were listed in the approved SOW:

1. Local IRB approval (By Month 3. The percentage of completion: 100%)
2. HRPO approval (By Month 6. The percentage of completion: 100%)

In addition, the following activities were planned to be started in the first year, aimed to be completed by the end of Year 3:

3. Aim 1: Within-subject data collection on auditory grouping
4. Aim 1: Within-subject data collection on selective attention
5. Aim 2: Data collection on peripheral auditory encoding correlational study
6. Aim 2: Data collection on auditory grouping and attention correlational study
7. Aim 2: Data collection on speech-in-noise correlational study

What was accomplished under these goals?

For this reporting period describe: 1) major activities; 2) specific objectives; 3) significant results or key outcomes, including major findings, developments, or conclusions (both positive and negative); and/or 4) other achievements. Include a discussion of stated goals not met. Description shall include pertinent data and graphs in sufficient detail to explain any significant results achieved. A succinct description of the methodology used shall be provided. As the project progresses to completion, the emphasis in reporting in this section should shift from reporting activities to reporting accomplishments.

1) Major activities

As it was planned, local IRB approval was completed by Month 3 for the human subject studies.

As it was planned, HRPO approval was completed by Month 6 for the human subject studies.

For the Aims 1 and 2 within- and across- subject studies, we have collected simultaneous behavioral (auditory grouping, selective attention, and speech-in-noise) and EEG data from 26 subjects, completing 21.6% of the data collection goal. Key outcomes from the data analysis is described in the following sub-section (Section 3: Significant results and key outcomes).

2) Specific objectives

Objectives of the local IRB and HRPO approval was to ensure establishing safety and ethical guideline for the proposed human subject electrophysiological studies.

Objectives of the Aims 1 and 2 within- and across- subject studies were to identify neural markers of speech-in-noise variance in normal hearing listeners.

3) Significant results and key outcomes

For the Aim 1 within-subject studies, we analyzed the effect of increased SiN difficulty on cortical activities through speech processing regions. We converted sensor-space EEG signals to whole-brain source time courses to localize the effects of signal-to-noise ratio (SNR) on evoked responses within targeted regions of interest (ROIs). Within left supra-marginal gyrus (SMG), the cluster-based permutation test revealed that the high SNR condition (i.e., +3dB) evokes significantly greater activity than the low SNR condition (i.e., -3dB) from 270 to 340 ms ($p = 0.0020$). Such a significant SNR effect was not found in the left inferior frontal gyrus (IFG).

To address our primary research question in the Aim 2 correlational study, which was to evaluate the simultaneous contribution of speech unmasking and recognition processes to SiN performance, we conducted a linear regression analysis in which the amplitude ratio between cortical responses to the target speech and background noise (i.e. henceforth referred to as “internal SNR”) and SMG activation were used as independent variables. SiN performance in low SNR condition, which showed larger variance (high SNR SD = 7.81%; low SNR: SD = 8.92%), was used as the dependent variable. We extracted the internal SNR from the low SNR and the SMG activity from the high SNR condition, as we expected that the internal SNR captures how well listeners unmask speech from the noisy background while the SMG activity reflects the processing of relatively clean speech signal. As expected, those two metrics extracted from different trials did not show a correlation ($r = -0.04$, $p = 0.863$, the left panel of Figure 1D). Both internal SNR ($t(23) =$

3.35, $p = 0.003$) and SMG activity ($t(23) = 2.29$, $p = 0.031$) were significant predictors of SiN performance (Figure 1A). The linear combination of those predictors accounted for a large proportion of the variance ($r = 0.64$, $p = 0.00043$, Figure 1B).

Figure 1C and D show results from post-hoc correlational analyses. Internal SNR showed a significant correlation with accuracy, while SMG activation did not (despite its significant contribution to the model). There was no correlation between internal SNR and SMG activation, as described above. A semi-partial correlation between SMG activation and the residual of accuracy after regressing out internal SNR was significant, which confirmed that the SMG activation accounted for an extra amount of variance in SiN performance (the right panel of Figure 6D). This suggests that in order to identify the contribution of downstream recognition areas like SMG, models must account for the contribution of earlier upstream speech-unmasking (i.e., auditory grouping and selective attention) processes.

To visualize the contribution of internal SNR to SiN performance, Figure 1E showed evoked response differences between good and poor performers (based on a median split on the low-SNR condition accuracy). This reveals dramatic differences in the magnitude of noise onset-related potentials: despite the same physical noise level for each group, good performers exhibited less strong evoked response to noise onset, measured by the envelope peak magnitude within N1-P2 time range in the frontal-central channels (two-sample t -test $t(24) = -2.60$, $p = 0.016$). In contrast, the word-evoked ERP envelope did not show a significant difference between the two groups ($t(24) = 0.21$, $p = 0.84$, two-sample t -test). This suggests that the neural mechanism underlying the internal SNR variance is the suppression of noise (rather than the enhancement of the target).

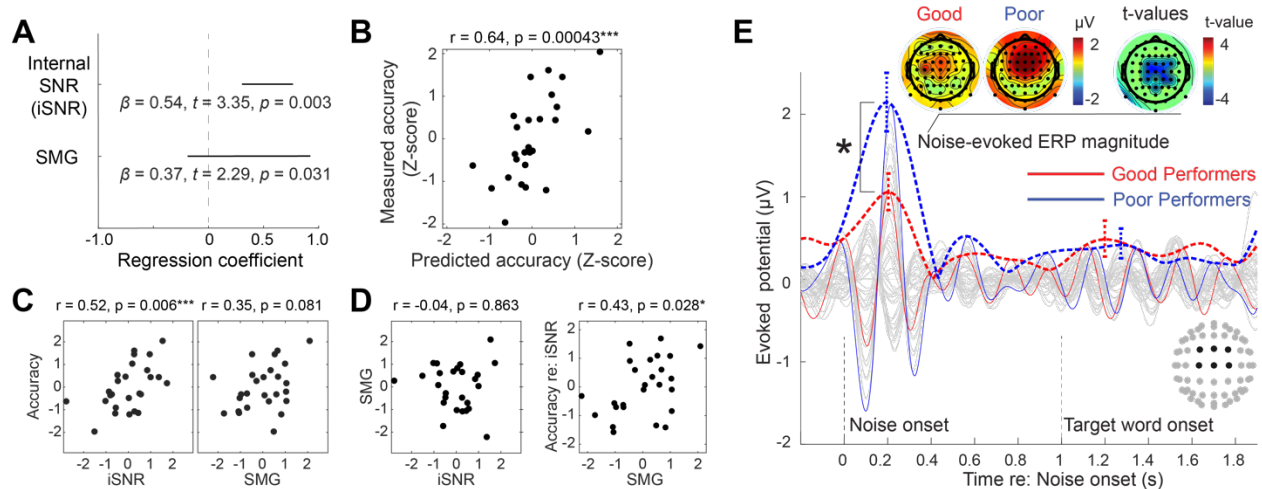


Figure 1. Individual differences in speech-in-noise processing. **A.** Regression coefficients and their standard errors. **B.** A scatter plot showing the relationship between predicted and measured accuracy in -3 dB SNR condition. **C.** Post-hoc correlation analyses: Raw correlations between each independent variable and the dependent variable. **D.** Left: Relationship between independent variables shows no correlation between internal SNR and SMG evoked source current. Right: Semi-partial correlation between SMG evoked source current and the residual of accuracy after regressing out internal SNR. **E.** The time course of the auditory event-related potential and its envelope, with the standard error of the mean (± 1 SEM) at the peak magnitude in -3 dB SNR condition (red color: good performers, blue color: poor performers). An asterisk shows a significant difference in the magnitude between two groups (two-sample t -test).

What opportunities for training and professional development has the project provided?

If the project was not intended to provide training and professional development opportunities or there is nothing significant to report during this reporting period, state “Nothing to Report.”

Describe opportunities for training and professional development provided to anyone who worked on the project or anyone who was involved in the activities supported by the project. “Training” activities are those in which individuals with advanced professional skills and experience assist others in attaining greater proficiency. Training activities may include, for example, courses or one-on-one work with a mentor. “Professional development” activities result in increased knowledge or skill in one’s area of expertise and may include workshops, conferences, seminars, study groups, and individual study. Include participation in conferences, workshops, and seminars not listed under major activities.

This project has been providing research experiences to three graduate (Doctor of Audiology) students, a post-bachelor research assistant, and four undergraduate students. The provided research experiences include EEG and behavioral data collection from human subjects, theoretical training of hearing science, and computational analyses of electrophysiological data.

How were the results disseminated to communities of interest?

If there is nothing significant to report during this reporting period, state “Nothing to Report.”

Describe how the results were disseminated to communities of interest. Include any outreach activities that were undertaken to reach members of communities who are not usually aware of these project activities, for the purpose of enhancing public understanding and increasing interest in learning and careers in science, technology, and the humanities.

One manuscript has been submitted to a peer reviewed journal. While the manuscript is currently under review, its preprint is available at:

<https://www.biorxiv.org/content/10.1101/817460v2>

S Kim, AT Schwalje, AS Liu, PE Gander, B McMurray, TD Griffiths, I Choi, Pre-and post-target cortical processes predict speech-in-noise performance, bioRxiv, 817460

What do you plan to do during the next reporting period to accomplish the goals?

If this is the final report, state “Nothing to Report.”

Describe briefly what you plan to do during the next reporting period to accomplish the goals and objectives.

In the next project year, we are planning to submit four manuscripts to peer-reviewed journals. The very next manuscript that proves the concept of neurofeedback training on auditory selective attention is currently being prepared for the submission. The second next manuscript will describe the development of novel speech testing materials for testing phonetic and lexical processing. Last two papers will demonstrate the effect of speaker-identity encoding on speech-in-noise perception.

4. IMPACT: Describe distinctive contributions, major accomplishments, innovations, successes, or any change in practice or behavior that has come about as a result of the project relative to:

What was the impact on the development of the principal discipline(s) of the project?

If there is nothing significant to report during this reporting period, state “Nothing to Report.”

Describe how findings, results, techniques that were developed or extended, or other products from the project made an impact or are likely to make an impact on the base of knowledge, theory, and research in the principal disciplinary field(s) of the project. Summarize using language that an intelligent lay audience can understand (Scientific American style).

Our key outcomes so far demonstrated that better speech unmasking in good performers modulated the ratio of cortical evoked responses to the background noise and target sound, which effectively changed SNR internally, resulting in better performance. We also found that clean, intelligible speech elicits early processing at supramarginal gyrus, which explained an extra amount of variance in speech-in-noise (SiN) performance. These findings may collectively form a neural substrate of individual differences in SiN understanding ability and may lead to the development of a novel clinical test battery for SiN disorders.

What was the impact on other disciplines?

If there is nothing significant to report during this reporting period, state “Nothing to Report.”

Describe how the findings, results, or techniques that were developed or improved, or other products from the project made an impact or are likely to make an impact on other disciplines.

Nothing to Report.

What was the impact on technology transfer?

If there is nothing significant to report during this reporting period, state “Nothing to Report.”

Describe ways in which the project made an impact, or is likely to make an impact, on commercial technology or public use, including:

- *transfer of results to entities in government or industry;*
- *instances where the research has led to the initiation of a start-up company; or*
- *adoption of new practices.*

Nothing to Report.

What was the impact on society beyond science and technology?

If there is nothing significant to report during this reporting period, state “Nothing to Report.”

Describe how results from the project made an impact, or are likely to make an impact, beyond the bounds of science, engineering, and the academic world on areas such as:

- *improving public knowledge, attitudes, skills, and abilities;*
- *changing behavior, practices, decision making, policies (including regulatory policies), or social actions; or*
- *improving social, economic, civic, or environmental conditions.*

Nothing to Report.

- 5. CHANGES/PROBLEMS:** *The PD/PI is reminded that the recipient organization is required to obtain prior written approval from the awarding agency grants official whenever there are significant changes in the project or its direction. If not previously reported in writing, provide the following additional information or state, “Nothing to Report,” if applicable:*

Changes in approach and reasons for change

Describe any changes in approach during the reporting period and reasons for these changes. Remember that significant changes in objectives and scope require prior approval of the agency.

Nothing to Report.

Actual or anticipated problems or delays and actions or plans to resolve them

Describe problems or delays encountered during the reporting period and actions or plans to resolve them.

Because human subject research has been suspended university-wide due to the COVID-19 pandemic from March to June 2020 and still slowed down due to the continued social distancing, data collection has been slower than expected in the first year (Planned: 48 subjects, Completed: 26 subjects).
To achieve all the planned research goals with a less-than 12 month delay, we have updated the number of subject enrollment for the remaining periods accordingly. Under the revised plan, we will achieve the same 132 subjects by the 4th quarter of Year 3. Then the final large-cohort regression analyses and disseminations of results will be performed in Year 4.

Changes that had a significant impact on expenditures

Describe changes during the reporting period that may have had a significant impact on expenditures, for example, delays in hiring staff or favorable developments that enable meeting objectives at less cost than anticipated.

None.

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Describe significant deviations, unexpected outcomes, or changes in approved protocols for the use or care of human subjects, vertebrate animals, biohazards, and/or select agents during the reporting period. If required, were these changes approved by the applicable institution committee (or equivalent) and reported to the agency? Also specify the applicable Institutional Review Board/Institutional Animal Care and Use Committee approval dates.

Significant changes in use or care of human subjects

None.

Significant changes in use or care of vertebrate animals

Not Applicable.

Significant changes in use of biohazards and/or select agents

Not Applicable.

6. PRODUCTS: *List any products resulting from the project during the reporting period. If there is nothing to report under a particular item, state "Nothing to Report."*

- **Publications, conference papers, and presentations**

Report only the major publication(s) resulting from the work under this award.

Journal publications. *List peer-reviewed articles or papers appearing in scientific, technical, or professional journals. Identify for each publication: Author(s); title; journal; volume: year; page numbers; status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).*

Nothing to Report.

Books or other non-periodical, one-time publications. *Report any book, monograph, dissertation, abstract, or the like published as or in a separate publication, rather than a periodical or series. Include any significant publication in the proceedings of a one-time conference or in the report of a one-time study, commission, or the like. Identify for each one-time publication: author(s); title; editor; title of collection, if applicable; bibliographic information; year; type of publication (e.g., book, thesis or dissertation); status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).*

Nothing to Report.

Other publications, conference papers and presentations. *Identify any other publications, conference papers and/or presentations not reported above. Specify the status of the publication as noted above. List presentations made during the last year (international, national, local societies, military meetings, etc.). Use an asterisk (*) if presentation produced a manuscript.*

Poster presentations at the Association for Research in Otolaryngology (ARO) 43rd Annual MidWinter Meeting, Feb 2020, San Jose, CA:

1. Holmes, A., Geller, J., Schwalje, A., Choi, I., McMurray, B., Assessing the Reliability and Validity of the Iowa Test of Consonant Confusion
2. Sarow, A., Kim, S., Geller, J., Choi, I., The Effect of Selective Attention Training on Effort during Speech-in-noise Perception.

- **Website(s) or other Internet site(s)**

List the URL for any Internet site(s) that disseminates the results of the research activities. A short description of each site should be provided. It is not necessary to include the publications already specified above in this section.

Nothing to Report.

- **Technologies or techniques**

Identify technologies or techniques that resulted from the research activities. Describe the technologies or techniques were shared.

Nothing to Report.

- **Inventions, patent applications, and/or licenses**

Identify inventions, patent applications with date, and/or licenses that have resulted from the research. Submission of this information as part of an interim research performance progress report is not a substitute for any other invention reporting required under the terms and conditions of an award.

Nothing to Report.

- **Other Products**

Identify any other reportable outcomes that were developed under this project. Reportable outcomes are defined as a research result that is or relates to a product, scientific advance, or research tool that makes a meaningful contribution toward the understanding, prevention, diagnosis, prognosis, treatment and /or rehabilitation of a disease, injury or condition, or to improve the quality of life. Examples include:

- *data or databases;*
- *physical collections;*
- *audio or video products;*
- *software;*
- *models;*
- *educational aids or curricula;*

- instruments or equipment;
- research material (e.g., Germplasm; cell lines, DNA probes, animal models);
- clinical interventions;
- new business creation; and
- other.

Nothing to Report.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Provide the following information for: (1) PDs/PIs; and (2) each person who has worked at least one person month per year on the project during the reporting period, regardless of the source of compensation (a person month equals approximately 160 hours of effort). If information is unchanged from a previous submission, provide the name only and indicate “no change”.

Example:

Name: Mary Smith
 Project Role: Graduate Student
 Researcher Identifier (e.g. ORCID ID): 1234567
 Nearest person month worked: 5
 Contribution to Project: Ms. Smith has performed work in the area of combined error-control and constrained coding.
 Funding Support: The Ford Foundation (Complete only if the funding support is provided from other than this award.)

Name: Inyong Choi
 Project Role: PI
 Researcher Identifier: ORCID 0000-0002-6663-9152
 Nearest person months worked: 3
 Contribution to Project: Conducting all the research activities.

Name: Phillip Gander
 Project Role: Co-investigator
 Researcher Identifier: ORCID 0000-0003-3945-8820
 Nearest person months worked: 1
 Contribution to Project: Developed stimuli and experiment scripts for the ECoG study.

Name: Adam Schwalje
 Project Role: Resident
 Nearest person months worked: 1
 Contribution to Project: Developed speech materials for both EEG and ECoG studies.

Name: Sungyoung Kim
 Project Role: Subaward PI
 Nearest person months worked: 3
 Contribution to Project: Developed a wireless EEG system (i.e., a preparation for Aim 3).

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

If there is nothing significant to report during this reporting period, state “Nothing to Report.”

If the active support has changed for the PD/PI(s) or senior/key personnel, then describe what the change has been. Changes may occur, for example, if a previously active grant has closed and/or if a previously pending grant is now active. Annotate this information so it is clear what has changed from the previous submission. Submission of other support information is not necessary for pending changes or for changes in the level of effort for active support reported previously. The awarding agency may require prior written approval if a change in active other support significantly impacts the effort on the project that is the subject of the project report.

Nothing to Report.

What other organizations were involved as partners?

If there is nothing significant to report during this reporting period, state “Nothing to Report.”

Describe partner organizations – academic institutions, other nonprofits, industrial or commercial firms, state or local governments, schools or school systems, or other organizations (foreign or domestic) – that were involved with the project. Partner organizations may have provided financial or in-kind support, supplied facilities or equipment, collaborated in the research, exchanged personnel, or otherwise contributed.

Provide the following information for each partnership:

Organization Name:

Location of Organization: (if foreign location list country)

Partner’s contribution to the project (identify one or more)

- *Financial support;*
- *In-kind support (e.g., partner makes software, computers, equipment, etc., available to project staff);*
- *Facilities (e.g., project staff use the partner’s facilities for project activities);*
- *Collaboration (e.g., partner’s staff work with project staff on the project);*
- *Personnel exchanges (e.g., project staff and/or partner’s staff use each other’s facilities, work at each other’s site); and*
- *Other.*

Organization Name: Rochester Institute of Technology

Location of Organization: Rochester, NY

Partner’s contribution to the project: Collaboration.

8. SPECIAL REPORTING REQUIREMENTS

COLLABORATIVE AWARDS: *For collaborative awards, independent reports are required from BOTH the Initiating Principal Investigator (PI) and the Collaborating/Partnering PI. A duplicative report is acceptable; however, tasks shall be clearly marked with the responsible PI and research site. A report shall be submitted to <https://ers.amedd.army.mil> for each unique award.*

QUAD CHARTS: *If applicable, the Quad Chart (available on <https://www.usamraa.army.mil>) should be updated and submitted with attachments.*

9. **APPENDICES:** *Attach all appendices that contain information that supplements, clarifies or supports the text. Examples include original copies of journal articles, reprints of manuscripts and abstracts, a curriculum vitae, patent applications, study questionnaires, and surveys, etc.*