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TITLE: The Use of Mobile Visual and Auditory Technologies to Implement Augmented Reality Tasks for Vestibular Physical Therapy

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CONTRACTING ORGANIZATION: Naval Health Research Center, San Diego, CA

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14. ABSTRACT

The Military Health System (MHS) has made investments in developing multimodal virtual reality (VR) systems that can address the unique challenges faced by service members (SMs) suffering from vestibular and sensory issues related to traumatic brain injury (TBI). VR systems have emerged as tools in rehabilitation that can be used independently or as an adjunct to traditional TBI therapies. The Computer Assisted Rehabilitation Environment (CAREN) is a fixed, large-scale, sophisticated VR-based system that allows SMs to interact with virtual environments using body movement. In this research study, virtual applications will be custom designed to work with both the CAREN and a mobile system (i.e., augmented reality {AR}/VR head mounted display with 3D audio) to assess visual, auditory, and vestibular impairments in those with TBI as well as provide the necessary tools to individualize each participant's therapeutic goals for rehabilitation. The overall aim is to improve neurosensory symptoms in service members with a history of TBI through the use of more accessible and affordable mobile AR/VR technologies that can be utilized in clinics and potentially in the home.

15. SUBJECT TERMS
Vestibular Physical Therapy, Traumatic Brain Injury, Concussion, Virtual Reality, Augmented Reality.

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1. INTRODUCTION:

Over the past decade the Military Health System (MHS) has made investments in developing sophisticated multimodal virtual reality (VR) systems that can address the unique challenges faced by service members suffering from vestibular and sensory issues related to traumatic brain injury (TBI). VR-based systems have emerged as a tool in rehabilitation that can be used independently or as an adjunct to traditional TBI therapies. The Computer Assisted Rehabilitation Environment (CAREN) is a fixed, large-scale, sophisticated VR-based system that includes a six degree-of-freedom motion platform, an instrumented treadmill, immersive visuals projected onto a 180-degree screen, and a motion capture system which allows for interaction with each virtual environment through body movement. In this research study, both the CAREN and a portable system, comprised of mobile visual and auditory technologies, will be developed and refined to meet the requirements of skilled clinical providers, and then further customized to meet the individual visual, auditory and vestibular therapeutic needs of each service member. The overall aim is to improve neurosensory symptoms in service members with TBI through the use of more accessible and affordable mobile visual and auditory technologies that can be utilized as a modality to standard care in clinical settings and at home.

2. KEYWORDS:

Mild traumatic brain injury; virtual reality; augmented reality; Computer Assisted Rehabilitation Environment; rehabilitation; mobile technologies; operational assessment; operational readiness; concussion; vestibular physical therapy.

3. ACCOMPLISHMENTS:

What were the major goals of the project?

There are two major goals of this project:

Aim 1: To test the hypothesis that mobile visual and auditory technologies (e.g., head mounted displays) provide similar feedback to the user when compared with visual and auditory inputs from a large-scale immersive VR system (e.g., CAREN).

Aim 2: To conduct a small randomized clinical trial (N=36) that will evaluate the efficacy of using mobile visual and auditory technologies for service members with TBI participating in vestibular therapy.

What was accomplished under these goals?

In order to accomplish our goals, the project was broken down into eight (8) tasks (Aim 1 – Tasks 1 through 4; Aim 2 – Tasks 5 through 8). The status of each task is as follows:

Major Task 1: IRB, CRADA/MOA Approval (15 months; 100% completion).

Subtask 1: Prepare Regulatory Documents for Research Agreements
All Aim 1 agreements have been obtained and reported in previous reports. However, the original MOA between NHRC and WRNMMC/NICoE was amended to include both protocols; the amended MOA was approved on 22DEC2021.

Subtask 2: Finalize consent form & human subjects' protocol including Military 2nd level IRB review (ORP/HRPO)
The initial IRB protocol for this project – the first of two study related protocols – was approved by the NHRC IRB on 17DEC2018 (NHRC.2019.0002 – "Comparison of visual and auditory technologies in large scale and mobile virtual reality systems"). Informed consent forms and study participant recruitment flyers were also IRB approved. NHRC IRB approved the Continuing Review of the study on 17DEC2019 and determined no further Continuing Review is necessary until the completion of the study. The IRB offices of Naval Medical Center San Diego (NMCSD) and WRNMMC/NICoE approved to defer oversight of this study to NHRC IRB. The U.S. Army Medical Research and Materiel Command's Office of Research Protections and Human Research Protections Office (USAMRMC ORP HRPO) approved the initial study protocol on 06JAN2020, and the IRB-approved Continuing Review was provided to their office on 06JAN2020.

Most recently, separate Aim 1 study protocol modifications were submitted for IRB review to incorporate the following changes: 1) addition of COVID-19 safety guidelines; 2) additional study questionnaires; and 3) personnel changes due to staff turnover. IRB approvals for these protocol modifications were granted on 10MAR2022.

Major Task 2: Coordinate Study Staff and Equipment (14 months; 100% completion).

Subtask 1: Staff training and coordination of sites.
All staff positions have been filled and all study team members have completed required trainings. Meetings and trainings have occurred with staff at all sites to communicate about progress and discuss pending taskers. The most recent in-person meeting between WRNMMC/NICoE and NHRC was held in January 2020. Due to COVID-19-related travel restrictions, all meetings since February 2020 have been held via teleconference or video conference at least every two weeks with representatives from project sites to discuss troubleshooting and progress status toward project milestones. Physical Therapist and Research Assistant personnel have been hired and onboarded at both sites.

Subtask 2: Development of hardware and virtual applications.
Development and final testing of virtual applications for Aim 1 is complete (Figure 1). Applications have been finished with integrated motion capture, event time stamping, and performance metrics integrated.

Several accomplishments have been made since the last annual report:

- We established an integrated file saving structure to keep all collected data in a single hierarchy for each participant, breaking down performance and motion capture data based on the device (CAREN, HMD), Task (1 or 2), and specific subtasks within each application. Data transfers occur between WRNMMC and NHRC every Friday.

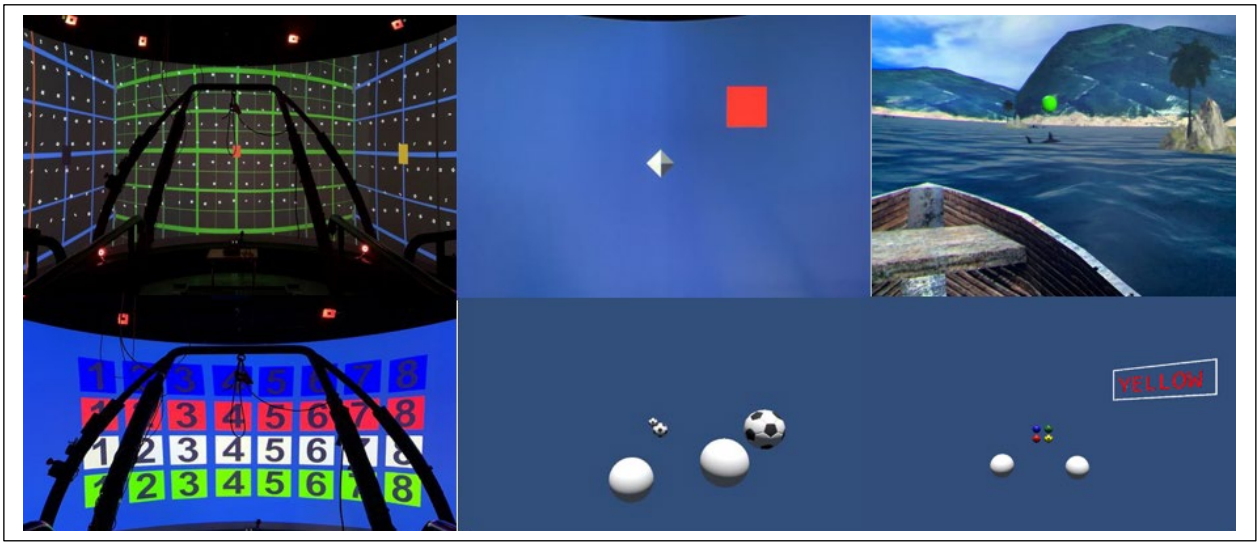

Figure 1: *Applications created for the study: Clockwise from the top-right, the Aurally Aided Visual Search task, Balance Cubes, Shark Hunt, Stroop Soccer Task, Soccer Task, and Number Wall task. This encompasses both Aim 1 and Aim 2 applications.*

Major Task 3: Establish secure data storage location and create study in FITBIR (12 months; 100% completion).

Subtask 1: Establish secure storage location for data.
Data are being stored on approved servers at project sites (NHRC and WRNMMC/NICoE).

Subtask 2: Submit data into repository as collected.
Federal Interagency Traumatic Brain Injury Research (FITBIR) accounts were established for all NHRC personnel and trainings were attended via FITBIR video conference seminars on use of FITBIR.

Major Task 4: Collect and analyze data for validation with enrolled research participants (27 months; 15% completion).

Data collection is ongoing at both WRNMMC/NICoE and NHRC, detailed in Figure 1 below. Data collection is occurring at a rate of 2 participants per week across sites. Data collection is projected to increase to 4 participants per week across two sites starting in April 2022.

	Task 1 Control	Task 2 Control	Task 2 mTBI
Subjects Collected, NHRC	7	4	1
Subjects Collected, NICoE	1	1	0
Total Collected	8	5	1
Total Goal	60	20	20
Percent Collected	13.3	25	5

Figure 2: *Phase 1 Data Collection totals as of 18MAR2022. Data collection occurring at a rate of 2 participants per week, must scale to 4 per week in order to complete project within performance period.*

The following tasks for Aim 2 (randomized clinical trial for TBI participants undergoing vestibular therapy) have been accomplished:

Major Task 5: Development of a battery of virtual applications to be used by the CAREN and portable system (mobile visual and auditory technologies) for treatment of vestibular symptoms in service members with complex TBI (90% completed).

All of the applications from Aim 1 (Major Task 2, Subtask 2) have been expanded for Aim 2. Enhanced features were added to better support therapy sessions (i.e., different background options, visual cognitive tasks, etc.). These changes were made to allow for flexibility so that our therapists could change each environment based on the individualized needs of each participant (i.e., reported symptoms, functional goals). All applications are currently being optimized for both the CAREN and AR HMD systems. Therapy carried out with these tools will be compared to Traditional vestibular physical therapy in the coming months (Figure 3 – images courtesy of WRNMMC/NICoE).

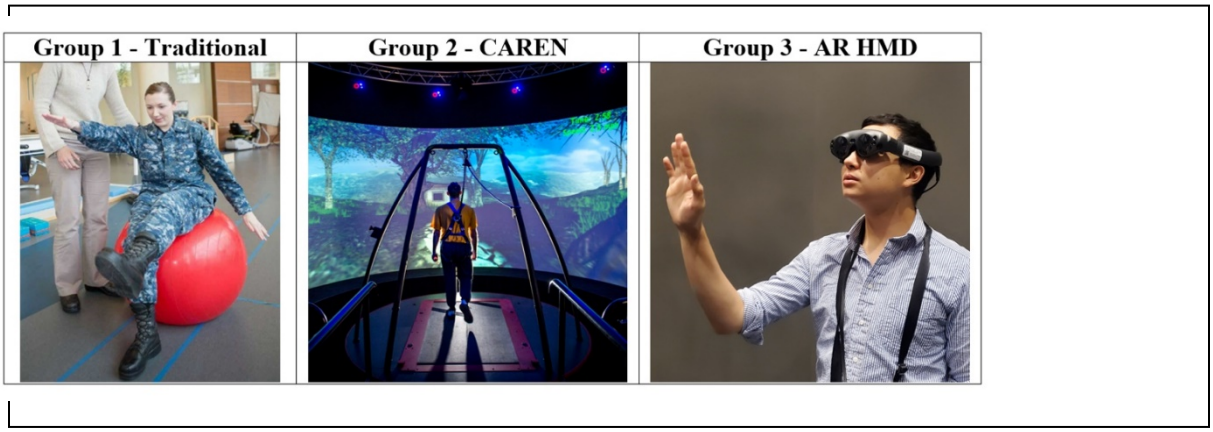

Figure 3. *In Aim 2 of the study, study participants will be randomized into three different treatment groups: Traditional therapy only, CAREN-based therapy, and AR HMD-based therapy.*

New applications for Aim 2 include the Ski Hill, Grocery Store, Maze, OPK (optokinetic), and Walking (Figure 4). Ski Hill is a weight-shifting application that requires participants to slalom through a series of gates over uneven terrain (three levels of difficulty are available). The application can be modified to include the Wisconsin Card Sorting task, where participants must match a cue card to one of four stimuli cards that appear in place of the gates. Matches are randomized between shape, color, and number. Grocery Store (adapted from VMart Virtual Grocery Shop) is a virtual representation of a full store which has multiple aisles with dozens of different items, where participants are given a list of items that they must find and place in their cart (using upper extremity reaching). The lists can be categorical or item specific. Additionally, there are options to increase or decrease the visual complexity of the scene (sparse/dense items on shelves, different floor textures, and people can be added throughout the store). Maze is a weight-shifting application which requires participants to act as a human joystick to move a ball through a maze. An overhead view of the maze is provided with the ability to increase the complexity (larger maze, various background options). Additionally, the start/end positions can be changed and tokens (incentives) can be added throughout the maze to increase the overall score. OPK has several background options (plain, stripes, and various

patterns of increasing complexity) which can rotate in different directions, at different speeds, and with oscillations, if desired. This is ideal for layering cognitive tasks (described below). Walking has three different scenarios available: 1) countryside, 2) city, and 3) rope bridge. The speed of the application (optical flow of the display) can be set to match the speed of a treadmill. The level of stimuli can be increased/decreased and cognitive layers can easily be layered in.

For all applications, additional visual cognitive tasks can be layered in (during the primary functional tasks for each application) to systematically increase the level of challenge over the course of treatment. These tasks include: Stroop, Hart Chart, Math Problems, Random Letters, Rank Insignia (identification/discrimination), and Visual Acuity. The display locations of these visuals have been optimized for both the CAREN and AR HMD, with regard to the field of view of each; the CAREN version has additional peripheral options. Additionally, the new background options include several patterns with increasing visual complexity.

Figure 4: *Three additional applications: Maze, Grocery Store, and Ski Hill, developed for both CAREN and AR Device. Cognitive loading tasks are integrated across each application via a single application launcher to optimize therapist input.*

Major Task 6: Prepare research protocol for the treatment portion of the study and obtain IRB approval.

For Aim 2 of this study, NHRC's IRB requested that we obtain a Study Risk Determination from the U.S Food and Drug Administration (FDA). On 03MAR2020, the FDA provided a written determination that Aim 2 of the study was a nonsignificant risk (NSR), and a copy of the determination was provided to both NHRC and WRNMMC/NICoE IRB offices.

WRNMMC/NICoE serves as the IRB of record for the Aim 2 study protocol. The IRB protocol, WRNMMC-2021-0332: "Use of Virtual and Augmented Reality Devices in Vestibular Physical Therapy for mTBI" was approved by WRNMMC on 16MAR2021. The site-specific protocol for NHRC, was reviewed and acknowledged by the NHRC IRB on 07SEPT2021. The final site-specific protocol submission was approved by WRNMMC on 28OCT2021. Most recently, the WRNMMC IRB approved a modification to add study personnel on 21JAN2022 and the Continuing Review for the Core/Lead Site Protocol on 17FEB2022. HRPO approval is ongoing.

The initial submission to ClinicalTrials.gov occurred on 28FEB2022. Pre-review comments from the site have been addressed and submission occurred again on 14MAR2022.

Major Task 7: Data collection on both CAREN and portable systems.

This task has not yet been initiated.

Major Task 8: Data analysis and interpretation.

This task has not yet been initiated.

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

Study team members including clinicians have attended several professional conferences and educational trainings to share study information, ideas and technologies. These include the following to date:

i. February 2019: Technical Exchange on Augmented Reality in Maintenance and Material Management (TEAR 3M) in San Diego CA.
ii. May 2019: Vestibular Oriented Research Meeting in Dayton, OH.
iii. June 2019: Collaborative Auditory and Vestibular Research Network (CAVRN) in Lexington, MA.
iv. August 2019: Military Health Systems Research Symposium (MHSRS) in Orlando, FL.
v. December 2019: Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), Orlando, FL.
vi. January 2020: Military Vestibular Assessment and Rehabilitation (MVAR) advanced training course in Bethesda, MD.
vii. March 2020: National Capitol Area TBI Symposium, Bethesda, MD
viii. April 2020: Vestibular Health Summit (virtual)
ix. September 2020: Concussion Health Summit (virtual)
x. September 2020: NICoE Annual Research Fair (virtual)
xi. February 2021: American Physical Therapy Association Combined Sections Meeting (virtual)
xii. July 2021: Society for Brain Mapping and Therapeutics (Los Angeles)
xiii. July 2021 International Congress on Virtual Rehabilitation (virtual)

How were the results disseminated to communities of interest?

Project overview presentations were given at the 2018 and 2019 Collaborative Auditory and Vestibular Research Network (CAVRN) meetings as well as the Interservice/Industry Training, Simulation and Education Conference 2019 (I/ITSEC) meeting. A Symposium was presented at the 2021 International Congress on Virtual Rehabilitation, "Developing Immersive Vestibular Rehabilitation Tools: Hardware, Comparison, Software Refinement, and Lessons Learned." Multiple abstracts have been submitted to both the 2022 Military Health System Research Symposium and 2022 International Conference for Vestibular Rehabilitation. Demonstration of the systems and applications has been performed for visitors from TBI Center of Excellence, local clinicians, and other DoD communities of interest.

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

Data collection will continue to complete Aim 1 enrollment goals. Weekly goals of 2 participants per week are being collected with the aim of upping to 4 participants per week across both sites. Aim 2 applications with cross-platform integration will be optimized and tested by June 2022.

Submission of Aim 2 protocol to HRPO will be finalized and it is expected that protocol will be published in clinicaltrials.gov by July 2022.

4. IMPACT:

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

We are in discussions with other related researchers in the field, who are utilizing VR and AR for vestibular therapy.

What was the impact on other disciplines?

Development of a method to integrate the Unity platform within the CAREN system allows the CAREN to be utilized in many more ways, from human and cognitive performance testing to various rehabilitation protocols that were more difficult or not possible to be done within the CAREN's traditional D-flow software. This has expanded potential for use of the CAREN, as well as HMD systems, in a variety of disciplines from neuropsychological testing to biomechanical and fatigue analysis.

What was the impact on technology transfer?

Nothing to report.

What was the impact on society beyond science and technology?

Nothing to report.

5. CHANGES/PROBLEMS:

Due to delays caused by the COVID-19 pandemic and technical issues, a no-cost extension was granted for the extension of this project on 14MAR2022.

On 23FEB2022 an error was recognized at the WRNNMC Site with the Task 1 AAVS Application. The Head Related Transfer Function (HRTF) used in the application was producing results that indicated there was an error in Elevation values with the virtual audio conditions for both the CAREN and AR HMD. Data collection is currently paused for Task 1 (but ongoing for Task 2) while this issue is being examined.

Changes in approach and reasons for change.

In September 2019, the study team agreed to change the type of AR HMD being used in this study from the Microsoft HoloLens to the Magic Leap. There were a variety of reasons for this change, most notably that the Magic Leap has integrated hand-tracking and eye-tracking, a larger field of view, and improved comfort when wearing for an extended period of time, as noted by the clinicians. No other changes in approach for Aim 1 or Aim 2 have been made.

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

WRNMMC/NICoE and NHRC software developers completed the reprogramming of all virtual applications to function properly on the both the AR HMD and CAREN, which was the primary source of delay and was further compounded by COVID-19-related onsite work restrictions during most of the 2020 calendar year. Onsite work restrictions due to COVID-19 are still in place at NHRC and WRNMMC/NICoE; NICoE personnel is onsite 50% of the time.

Engineers have been assessing the HRTF issue (described above). A new HRTF conversion has been created and new HRTFs have been generated for Unity. The Steam VR audio libraries have been recompiled for the virtual audio conditions, have been redeployed and built to the application, and are currently being tested at both sites. Fixes to the HRTF applications should be corrected by April 2022 to continue Task 1 data collection.

Changes that had a significant impact on expenditures.

Nothing to report.

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

Nothing to report.

Significant changes in use or care of human subjects.

Nothing to report.

Significant changes in use or care of vertebrate animals.

N/A.

Significant changes in use of biohazards and/or select agents.

N/A.

6. PRODUCTS:

This project will result in the development of Unity virtual applications for use in AR HMDs and the CAREN to perform vestibular therapy tests by multiple collaborators. The applications developed for this project include: 1) AAVS; 2) Balance Cubes; 3) Soccer Balls w/ Stroop; 4) Shark Hunt; 5) Number Wall; 6) Ski Hill; 7) Grocery Store; 8) Maze; 9) OPK; and 10) Walking.

Publications, conference papers, and presentations.

1. Jacob Van Dehy and Dawn Bodell. What Work is Being Done to Improve Vestibular Physical Therapy for Service Members? Collaborative Auditory and Vestibular Research Network (CAVRN), 06 June 2019.

2. Sarah Kruger, Kathleen Delpy, Kerry Rosen, and Kyle Fitzgibbons. Comparison of visual and auditory technologies in large scale and mobile virtual reality systems. NICoE Research Roundtable, 11 December 2019.

3. Pinata Sessoms. Use of Virtual Reality Systems for Care of the Injured Warfighter. Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), 05 December 2019.

4. Sarah Kruger, Kathleen Delpy, Kerry Rosen, and Kyle Fitzgibbons. Comparison of visual and auditory technologies in large scale and mobile virtual reality systems. NICoE Research Roundtable, 3 March 2020.

5. Sarah E. Kruger. Conducting Translational Research through Collaborative Innovation. NICoE Annual Research Fair. Bethesda, MD, 24 September 2020.

6. Kerry B. Rosen, Kathleen B. Delpy, Marcy M. Pape, Paula N. Kodosky, Sarah E. Kruger. Examining the Relationship between Conventional Outcomes and Immersive Balance Task Performance in Service Members with Mild Traumatic Brain Injury. *Military Medicine.* 2021; 186(5-6): 577-586.

7. Pinata H Sessoms. Rehabilitation and Neuromarker Identification for MTBI Patients using Immersive Virtual Reality Experiments. *Society for Brain Mapping and Therapeutics.* July 2021.

8. Kerry B. Rosen, Dawn Bodell, Vrajeshri Ordek, Jacob VanDehy, Sarah E. Kruger, Pinata H. Sessoms. Developing Immersive Vestibular Rehabilitation Tools: Hardware Comparison, Software Refinement, and Lessons Learned. *International Conference on Virtual Rehabilitation.* July 2021.

Website(s) or other Internet site(s)

Nothing to report.

Technologies or techniques

This project will develop a new technical capability by utilizing virtual environments developed in Unity 3D (game engine software) on the CAREN system and with AR HMDs to perform therapeutic tasks that help physical therapists assess and treat vestibular symptoms in participants with TBI. This technology can potentially be used in other military patient populations for other clinical issues or return to duty assessments.

Lessons learned in this project have sped the process for developing new applications for other rehabilitation projects. This work has served as a template for our future work in using mixed Virtual and Augmented reality platforms. We have developed novel PTSD treatments using VR/AR technology much faster because of the gains made by this project. We have synchronized and integrated Bluetooth-based heartrate monitoring into load carriage studies because of gains made on this project.

Inventions, patent applications, and/or licenses

Nothing to report.

Other Products

Nothing to report.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name:	*Pinata H. Sessoms, PhD*
Project Role:	*Principal Investigator (NHRC)*
Researcher Identifier (e.g. ORCID ID):	*0000-0002-6960-0659*
Nearest person month worked:	*3*
Contribution to Project:	*Dr. Sessoms has held in-person meetings and regular teleconferences with the Co-Investigators and collective study team across all sites. She has submitted materials for support agreements and contracts needed to execute funds and work to collaborating sites. She has directed the development of the technical infrastructure, overseen all regulatory submissions and approvals, and managed all study funding and equipment purchases.*
Fundi Support:	*Joint Program Committee-8, Clinical and Rehabilitative Medicine Research Program (JPC-8 CRMRP), Psychological Health and Traumatic Brain Injury Research Program (PH/TBI RP)*

Name:	Dawn Bodell, DPT
Project Role:	*Co-Investigator (NHRC)*
Researcher Identifier (e.g. ORCID ID):	*TBD*
Nearest person month worked:	*4*
Name: *Paula Poh, PhD* Project Role: *Data Core Manager (NHRC)* Researcher Identifier (e.g. ORCID ID): *0000-0003-0915-6119* Nearest person month worked: *1*	*Dr. Bodell is the Research Physical Therapist on the project at NHRC. She has been working collaboratively to develop eligibility criteria and methodology related to the vestibular rehabilitation portion of the project, as well as provide feedback to the technology, applications, and protocol for the project. She also attends the regularly scheduled group meetings for the project, and works with potential mTBI patients for the study within NMCSD's vestibular physical therapy clinic.*

Contribution to Project:	*Dr. Poh is the Data Core Manager on the project at NHRC. She has been working collaboratively with the team at NICoE to develop and prepare the research protocol documents required for IRB submission at both sites. She has completed FITBIR online and video conference trainings and communicated directly with FITBIR and project staff to establish and maintain the project's FITBIR account.*	
Funding Support:	*JPC-8 CRMRP PH/TBI RP*	
Contribution to Project:		
Funding Support:		*JPC-8 CRMRP PH/TBI RP*

Name:		*Amanda Markham, MPH*
Project Role:		*Project Manager/Coordinator (NHRC)*
Researcher Identifier (e.g. ORCID ID):		*0000-0002-5761-4068*
Nearest person month worked:		*1*
		Ms. Markham has served as the Project Manager on this project. She has attended meetings with project staff. She assisted with the development and submission of support agreements and contracts related to this project. She has also supported the purchase of project equipment and contract staffing.
Name:	*Jacob Van Dehy, MS*	
Project Role:	*Biomedical Engineer (NHRC)*	
Researcher Identifier (e.g. ORCID ID):	*0000-0003-2471-0528*	
Nearest person month worked:	*5*	

Contribution to Project:	*Mr. Van Dehy is the biomedical engineer/CAREN Operator at NHRC. He has been creating and validating software applications for use in the VR and CAREN systems. He has attended all study meetings, coordinates the hardware and software components needed for the project with the other collaborating sites, and oversees all software development aspects of the study at NHRC.*
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Contribution to Project:	
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Name:	*Vrajeshri Ordek, PhD*
Project Role:	*Biomedical Engineer (NHRC)*
Researcher Identifier (e.g. ORCID ID):	*0000-0003-4398-484X*
Nearest person month worked:	*5*
Contribution to Project:	*Dr. Ordek is the biomedical engineer at NHRC. She has been creating and validating software applications for use in the VR and CAREN systems. She has attended all study meetings and coordinates the hardware and software components needed for the project.*

Name:	*Yusuf Khan, BS*
Project Role:	*Software Developer (NHRC)*
Researcher Identifier (e.g. ORCID ID):	*N/A*
Nearest person	*2*

JPC-8 CRMRP PH/TBI RP

month worked:	
Contribution to Project:	*Mr. Khan is a developer at NHRC. He has been creating and validating software applications for use in the VR and CAREN systems. He has attended all study meetings and coordinates the hardware and software components needed for the project, and serves as a developer for the centralized database for administration of electronic informed consent and electronic data capture.*
Funding Support:	*JPC-8 CRMRP PH/TBI RP*
Funding Support:	

Name:	*Kim Gottshall, PhD, PT*
Project Role:	*Clinician/consultant (NHRC)*
Researcher Identifier (e.g. ORCID ID):	*0000-0003-3031-873*
Nearest person month worked:	*1*
Contribution to Project:	*Dr. Gottshall is a clinician with expertise in vestibular physical therapy. She has helped develop Aim 1 and Aim 2 study protocols. She has also evaluated all of the Aim 1 applications on both the CAREN and AR HMD for both Task 1 and Task 2 and provided detailed feedback. She will continue to support the project by speaking with other clinicians and providing her subject matter expertise.*
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Name:	*Kerry Rosen, PhD*
Project Role:	*Research Assistant (WRNMMC/NICoE)*
Researcher Identifier (e.g. ORCID ID):	*0000-0002-3353-6528*
Nearest person month worked:	*9*
Contribution to Project:	*Dr. Rosen has participated in regular project meetings and has assisted with the WRNMMC IRB submission of the Phase 1 and 2 protocols. She provided support in the development of electronic methods of collecting data and helped with the preparation for recruitment and data collection for Phase 1. She was involved in the collection of pilot data, the refinement of task and setup SOPs, the review of data output, and the analysis of preliminary data. She has consented and completed data collection for participants at WRNMMC/NICoE.*
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Name:	*Kyle Fitzgibbons, BS*
Project Role:	*Application Developer (WRNMMC/NICoE)*
Researcher Identifier (e.g. ORCID ID):	*TBD*
Nearest person month worked:	*9*
Contribution to Project:	*Mr. Fitzgibbons continues to participate in regular meetings about the project. He has been programming in Unity, re-creating virtual environments currently used in the CAREN as well as developing new software applications for use with both virtual reality and augmented reality-based head mounted displays as well as developing support documentation for these applications. He has also been actively collaborating with the NHRC developers and attending tech telecons regularly.*
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Name:	*Sarah Kruger, MS*
Project Role:	*Co-Investigator (WRNMMC/NICoE)*
Researcher Identifier (e.g. ORCID ID):	*0000-0003-4366-8505*
Nearest person month worked:	*3*
Contribution to Project:	*Ms. Kruger continues to participate in regular meetings with the Co-Investigators. She worked collaboratively to develop and revise the Phase 1 protocol and facilitated the approval of support agreements and contracts necessary for the Phase 2 protocol. She worked to submit the Phase 2 protocol to the WRNMMC IRB and continues to supervise the development of the technical infrastructure at NICoE, directing software development efforts, and assisting with hardware integration.*

	She also helped collect pilot data and develop recruitment strategies for Phase 1.
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Name:	*Pooja Patel, DPT*
Project Role:	*Research Physical Therapist (WRNMMC/NICoE)*
Researcher Identifier (e.g. ORCID ID):	*TBD*
Nearest person month worked:	*5*
Contribution to Project:	*Dr. Patel participated in regular meetings about the project. She worked with Mr. Fitzgibbons on the development of new virtual environments for Aim 2 as well as their refinement. She also helped to collect pilot data and compiled feedback to refine the task SOPs.*
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Name:	*Douglas Brungart, PhD*
Project Role:	*Co-Investigator (WRNMMC/NICoE)*
Researcher Identifier (e.g. ORCID ID):	*0000-0002-0163-2734*
Nearest person month worked:	*1*
Contribution to Project:	*Dr. Brungart attended auditory-related project meetings and has provided direction on project methodology for the mobile visual and audio components of the project. He also assists in managing the contract for the WRNMMC portion of the project.*
Funding Support:	*JPC-8 CRMRP PH/TBI RP*

Name:	Grant Meisenholder, DPT
Project Role:	*Co-Investigator (NMCSD)*
Researcher Identifier (e.g. ORCID ID):	*TBD*
Nearest person month worked:	*1*
Contribution to Project:	*Dr. Meisenholder directs the vestibular physical therapy clinic at Naval Medical Center San Diego (NMCSD). He provides clinically related updates to Dr. Bodell that may be related to this project.*
Funding Support:	*Naval Medical Center San Diego*

Name:	Griffin Romigh, PhD
Project Role:	*Co-Investigator (AFRL)*
Researcher Identifier (e.g. ORCID ID):	0000-0002-6341-6762
Nearest person month worked:	*1*
Contribution to Project:	*Dr. Romigh has attended project meetings and has provided direction on project methodology for the mobile audio testing and validation component of the project.*
JPC-8 CRMRP PH/TBI RP	*JPC-8 CRMRP PH/TBI RP*

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

Pooja Patel, DPT has been hired to replace Kathleen Delpy, DPT at the WRNMMC Site. Jefferey Pawelek has left as Project Manager at NHRC and Mr. VanDehy has taken over many of these responsibilities. Yusuf Khan has been hired on as a developer at NHRC.

b) What other organizations were involved as partners?

Organization Name: Creare, LLC

i. **Location of Organization:** Hanover, NH

ii. **Partner's contribution to the project:** Enhanced audio capabilities for applications.

iii. **Financial support:** N/A

iv. **In-kind support**: Company has provided several speech-based cognitive task applications within Unity to use in the rehabilitation portion of the study. Has likewise provided audio-screening headset and tablet application for assessing both basline hearing and subject Signal-to-Noise Ratio filtering capabilities.

v. **Facilities:** N/A

vi. **Collaboration**: N/A.

vii. **Personnel exchanges**: N/A

viii. **Other:** N/A

Organization Name: Dr. Charles Levy

ix. **Location of Organization:** Formerly with Northern Florida Southern Georgia VA in collaboration with University of Florida

x. **Partner's contribution to the project:** Unity assets for virtual grocery store environment.

xi. **Financial support:** N/A

xii. **In-kind support**: Company has provided suite of 3D assets for a virtual grocery store (modified from VETS VMart Virtual Grocery Store). Assets have been modified to fit on the CAREN and MagicLeap applications and used in Phase 2 application development.

xiii. **Facilities:** N/A

xiv. **Collaboration**: N/A.

xv. **Personnel exchanges**: N/A

xvi. **Other:** N/A

8. SPECIAL REPORTING REQUIREMENTS

Collaborative Awards: N/A.

Quad Chart: See attached.

9. **APPENDICES "**Developing Immersive Vestibular Rehabilitation Tools: Hardware Comparison, Software Refinement, and Lessons Learned." *International Conference on Virtual Rehabilitation Presentation.* 2021.