Addressing Tactical Combat Casualty Care in Synthetic Training Environments

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ABSTRACT

As of 2010, 90% of US service men and women who die from combat wounds do so before arriving at a medical treatment facility (Eastridge, 2012)[1]. This fact highlights the importance of battlefield trauma care provided by combat medics, corpsmen, and nonmedical unit members in improving combat-wounded survival rates. For Tactical Combat Care (TC3) mastery, curriculum should be enhanced to address higher levels of learning within the cognitive and psychomotor learning domains required for complex situations, (i.e., care under fire), which include skills related to spatial awareness, marksmanship, movement, communication and decision making under stress. To address instruction and assessment of these skills, the US Army Combat Capabilities Development Command developed a TC3-based training prototype that incorporates multiple hybrid virtual and augmented display systems, simulated weapons, and haptic devices. The paper describes the design, development, and research processes used to produce the TC3 training system. We present a formalized process for developing three training vignettes; each are a) learning objective-driven, b) rooted in task and human factors analyses, and c) integrated with multiple haptics, virtual reality (VR), augmented reality (AR) and mixed reality (MR) systems. We discuss our research-based usability study targeting multiple potential user communities practicing point of injury care procedures in a VR environment integrated with haptics gloves. While technologies employed are early in the development process, results indicate a positive experience from all tested user communities. This research effort reinforces the notion that TC3 mastery will be a key component to the design and development of next-generation synthetic training environment systems.

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[1] Eastridge, B.J., Mabry, R.L., Seguin, P., Cantrell, J., Tops, T., Uribe, P., & Blackbourne, L.H. (2012). Death on the battlefield (2001-2011): implications for the future of combat casualty care. *Trauma Acute Care Surgery*, 73(6), Suppl. 5, S431-S437). Available online at: https://pdfs.semanticscholar.org/7137/ef81ffc5c0dcc3e1e11cdee0111b5cb099b8.pdf. Viewed June 3, 2019.

University. Throughout her corporate training career, Ms. Barnieu has been involved in training content development, instructor-led presentations, online learning development, training consulting, soft skills development, technical and computer skills development, and training department management. Ms. Barnieu also has overseas experience as both an ESL instructor and a corporate trainer in France and began her career as a French instructor at the University of Delaware.

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INTRODUCTION

Haptics (the interaction and transmission of information through the sense of touch) is an emerging field that is gaining significant attention in many areas of research, such as surgical robotics, virtual reality (VR), medical training, telerobotics, and gaming (Talhan et al., 2018). Most recently, haptics research has been focusing on efforts to create a high-fidelity simulation of sensations that one might feel when interacting with real-world objects. One of the most prominent areas of research requiring high-fidelity haptic feedback is that of medical simulators (M.S.) (Larnpotangetal, 2013). In general, M.S. used for training requires realistic, subtle differences in haptic properties among various soft tissues. In many cases, the main task of a medical procedure is to discriminate between these subtle differences in human anatomy.

Haptic devices communicate to the user the sense of touch, and when combined with visual and audible cues from a virtual simulation, haptics provides the user with more immersive experiences than typically encountered using stand-alone virtual training simulators (Wang et al., 2019). Haptics has also been demonstrated to increase learning recall. For example, Feygin (2002) explained force trajectory using visual-haptic training was better at recollecting trajectory within virtual environments as compared to only visual training.

In order to achieve higher learning recall, it is important to view haptics integration as an instructional strategy that has been determined through a systematic learning objective decomposition process (Dick & Carey, 1990). Based on high level learning outcomes, such as a Soldier's ability to perform tactical combat casualty care (TC3) in simple to complex scenarios, learning objectives are derived in a systematic manner and aligned with relevant domains of learning (cognitive and psychomotor) and associated levels of learning within that domain (Anderson, et al., 2001). With this example, a Soldier's ability to make decisions based what he or she sees and feels would best align with haptics integrated with VR or possibly Augmented Reality (AR). Without haptics, the realism has declined, thus depriving the Soldier of the optimal learning and practice experience.

Cannon-Bowers and Salas (1998) stated that "Demands on the human decision maker in military tactical environments are becoming more complicated. Modern combat scenarios are often characterized by rapidly evolving and changing conditions, severe time compression, and high degrees of ambiguity and uncertainty." (p. 18). Live training exercises limit the ability to diversify scenarios or add realistic stressors such as explosions and resulting casualties. Furthermore, it is difficult to simulate rare circumstances, such as a rifle jamming, during live training in order to train on how to critically think and react to those circumstances. VR solutions can solve some of live training scenario challenges since they can increase the number of practice opportunities, provide more varied scenarios, create high stress situations (psychological fidelity of timing, explosions, casualties), and allow trainees to make mistakes in a safe environment (Brou, et al., 2018). However, mastering psychomotor skills related to TC3 Care Under Fire (CUF) are vital (e.g., weapon and equipment manipulation and interaction with human body), and VR is limited in how it can provide the necessary sensory input for realistic instruction and performance assessment. In order to resolve certain tactile input deficiencies, the Army has experimented with integrating simulated haptics into VR training.

This paper presents the culmination of a multi-year effort on designing, developing and evaluating a TC3 training system which a) uses sound instructional design principles, b) integrates high-fidelity glove based haptics into a VR medical training system, and c) presents a user evaluation study to examine the results of the system from a usability (reaction/satisfaction) perspective. Results of the usability study were developed into a research report, which provided insight into the value of VR and haptics enhanced TC3 scenarios.

INSTRUCTIONAL DESIGN

For the purpose of the prototype development, the instructional design team focused on three specific areas of TC3:

- Needle Chest Decompression (life-saving measure for a conscious, breathing casualty with penetrating torso trauma)
- Combat Application Tourniquet (life-saving measure to stop a life-threatening hemorrhage from an extremity)
- Blood Sweep (measure to check for any bleeding that was not previously controlled; gently sliding hands underneath the casualty and pulling them back to feel for any bleeding)

In order to support the design of these scenarios, the instructional design team first reviewed relevant TC3 doctrine and available training guides and then systematically derived terminal, subordinate, and enabling learning objectives for each of the topic areas and classified them according to learning domain (see Exhibit 1 for Combat Application Tourniquet Lesson).

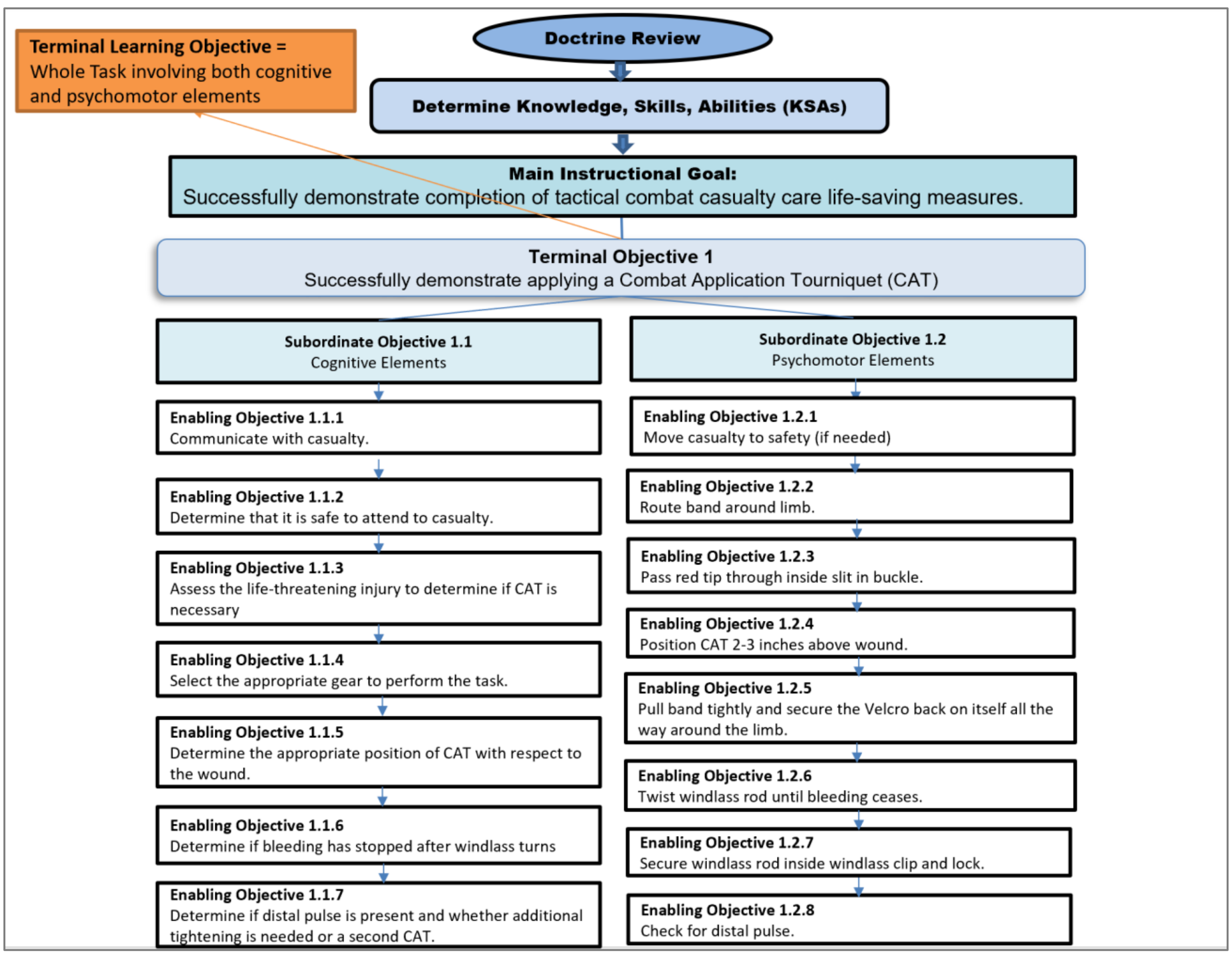

Exhibit 1. Instructional Design Map for Combat Application Tourniquet Lesson

The terminal learning objectives serve to provide structure to the learning process and provide a sequence and instructional cycle, depicting how the learner moves through the learning process. The terminal learning objectives represented the three focus areas of TC3 (also known as lessons). Each lesson consisted of a set of enabling learning objectives to support the necessary steps and skills for that procedure (Needle Chest Decompression, Combat Application Tourniquet, and Blood Sweep), and for each lesson, the learner is required to perform the whole task, not just task components or sub-skills (Merrill, 2006). Enabling learning objectives under "cognitive" involve both lower levels of learning (e.g., select, communicate) and higher levels of learning (e.g., determine, assess), and enabling learning objectives under "psychomotor" cover the lower levels of learning of imitation, manipulation, and precision (Dave, 1975), since it is challenging to cover higher levels of psychomotor learning (such as articulation and naturalization) when using VR and haptics, as it is still a stretch from interacting with the physical object. As a result of this systematic process, the instructional design and development teams worked together to determine which enabling learning objectives best aligned with VR or Haptics + VR. The result of the instructional design was a scenario storyboard which outlined three lessons, with each lesson containing exercises.

DEVELOPMENT

Relevant to the "whole task" instructional design, for each lesson, the first exercise prepared the students to learn the task by relating the identification and prioritization of training needs to similar personal experiences that the students are likely to have had in their careers. The next exercise presented a computer-animated scenario that the student responds to regarding clinical care events (See Exhibit 2). At this point, the system presented a combination of point-and-click information gathering and open-ended questions. The software is designed to query the student on possible courses of action and critical information within the environment. After the completion of each lesson, the student is given an after-action review that consolidates decisions made within the simulated environment. The lessons were designed such that users could proceed through all three lessons (Needle Chest Decompression, Combat Application Tourniquet, and Blood Sweep) during a 45-minute time period.

Exhibit 2: Computer Generated Scenario

This research leveraged recent advances in haptics, force feedback, tracking, and high-fidelity touch simulations to help identify and assess new instructional strategies that enhance learning, improve skill retention, and increase engagement. The training lessons were designed using VR and integration of a haptic glove system (See Exhibit 3[2]).

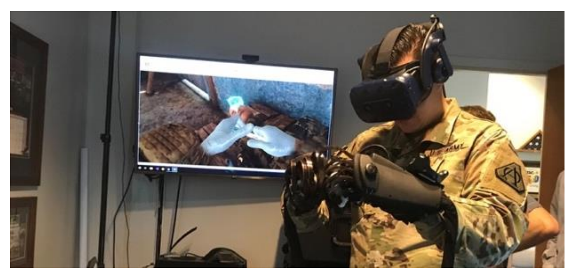

Exhibit 3: HaptX VR System Scenario

EXPERIMENTAL DESIGN

This research leveraged recent advances in haptics, force feedback, tracking, and high-fidelity touch simulations to help identify and assess new instructional strategies that enhance learning, improve skill retention, and increase training effectiveness. Tactile feedback-based hardware and software systems were integrated into existing VR

[2] Source: ecsorl.com

training to enhance U.S. Army medical training capabilities. The work built upon previous foundational research and included developing a series of immersive TC3 training scenarios. The team submitted the experimental design to the to the Army Research Laboratory Human Research & Engineering Directorate (ARL HRRD), resulting in an IRB waiver due to a non-research determination. The study offered an opportunity to gain a deeper understanding of the significance of high-fidelity touch and haptic feedback for training within a virtual reality-based environment.

Sample/Demographics

The Citi-certified research team coordinated with medical students and professionals to identify and select volunteer subjects. We then scheduled facilities and performed the data collection, selecting a schedule that presented minimal disruption to the subjects. Subjects in the study were familiar with traditional simulation-based training but may not necessarily have experience with haptics and VR equipment. Pre-evaluation demographic questions posed to the group included:

- Are you in the medical profession?
- Time spent in your current role.
- Medical background in a civilian setting?
- Years spent in a civilian setting.
- Have you ever served in the military?
- Years in Military.
- Are you an educator?
- Years as an Educator.
- Are you a student?
- What is your highest level of education completed?
- Number of years of experience with computer gaming (0 to 20+ years).

Recruitment of Subjects

Subjects were recruited based on two primary criteria; some medical experience, and some general gaming experience. Medical experience included work in the medical field as a doctor, nurse, emergency medical technician (EMT), or a caregiver. Subjects who did not have the ability to operate within a reasonable level of competency within game and simulation environments were not recruited for the study. This particular segment of the population was substantially lower than it once was due to a higher population of Soldiers with previous exposure to game technologies.

Materials, Tests, Tasks, and Stimuli

A *Haptics Usability Survey* was created as an evaluation tool for researchers. The survey questionnaire contained several profile related questions, a set of ordinal questions based on a Likert Scale with values of 1=strongly disagree to 5=strongly agree. Lastly, several open-ended questions were included in the survey. The questionnaire used for this study was not used in other research projects.

Equipment or Apparatus

For the purposes of this effort, the HaptX Glove system was used because its level of tactile resolution could span object selection, human/patient examination, and the manipulation of hard and soft structures. HaptX Glove is a pneumatically actuated, multimodal haptic device, using a combination of force and tactile feedback. The device features a silicone-based textile and integrated air channels that deliver high-resolution, high-displacement tactile feedback, combined with a biomimetic exoskeleton for resistive force feedback. The passive admittance feedback of high forces bypasses the need for high-bandwidth force control in realistic feedback. Magnetic sensors track each finger in 6-DoF with sub-millimeter accuracy and no discernible latency. The HaptX Glove includes roughly 130 microfluidic tactile actuators per hand, which can deflect the skin by up to 2 mm and deliver up to 18 N of resistive force feedback per finger. Each glove has over 60 independently controlled tactile channels with continuously variable amplitude, and receptors sensitive to vibrations of up to 1000 Hz. (Rubin et al., 2017)

Survey Instruments

Surveys were divided into two instruments, 1) Likert Scale designed to examine VR Haptics Usability and Human Factors elements (with the option for additional text descriptions by subjects) and 2) Open-ended survey questions to allow subjects to provide additional detail about their experiences. We note the research approach is not directly designed to test the effectiveness of a TC3 simulation specifically; it is a fundamental reflection on the part of the learner to comment on the added effectiveness and satisfaction in the use of the VR Haptics system.

Development of Assessment Questions

Assessment survey questions were developed and presented as both open-ended questions and Likert-based responses. The subjects were asked some initial questions before entering the study, including profile data, general experience with games and simulations, medical knowledge, and years of experience. The post-simulation survey used similar questions to the pre-simulation survey in order to be able to measure the effect of participating in the simulation. The post-simulation survey included questions about the subject's overall experience in using the VR Haptics TC3 Training Simulation. The questions in both pre-and post-simulation surveys were Likert scale or multiple-choice questions except for one short-answer question for comments and elaboration. In order to effectively utilize all of the instruments, specific procedures were followed to conduct the evaluations. Questionnaires contained short-answer questions. The post-simulation survey also contained a general comment section for subjects to provide suggestions or opinions about the application experience.

Reaction and Satisfaction Survey

The purpose of this Kirkpatrick Level I (1994) evaluation (i.e., usability study) was to assess the VR Haptics training system based on participant reactions to the hardware/software system. Learner reactions refer to what the trainees thought of the training in terms of factors, such as whether they thought it was interesting or boring, whether they liked the way the material was presented, and whether they believed the content was useful and relevant to their job. These reactions are often a critical factor in the continued success of the training program. Reactions of learners focused on explicit dimensions, such as engagement and satisfaction with the training, issues and challenges, and perceived utility.

To respond to the majority of these items, learners indicated their agreement with each statement on a 5-point Likert scale where 1=Strongly Disagree and 5=Strongly Agree. Currently, the measure includes items on usability, content, perceived learning and perceived learning transfer, satisfaction with training, technical issues encountered, and general comments. Based upon the research questions proposed in this plan, the reaction items included, at a minimum, measures of learner engagement, learner motivation, and learner boredom; items that assess the perceived effectiveness of the overall training; and items that address satisfaction with the organization of the training. However, the appropriate dimensions for the learner reaction items were refined in light of final evaluation goals and objectives.

DATA COLLECTION

Study Participation

The target subjects consisted of medical students and medical professionals – namely three instances of the course (n = ~100 students). The participant distribution provides an ample sample size for a survey-based qualitative study. Subjects were identified and recruited through coordination with the Mayo Clinic Jacksonville, training instructors at the Navy Hospital Jacksonville (NHJAX), and training instructors and students at the U.S. Army Medical Center of Excellence (MEDCoE). Information regarding the training was provided to all subjects using a consent form, which was collected upon the signature of the participant and the researchers prior to participation.

Instrumentation and Facilities

The VR Haptics training evaluation was developed within the Unity game environment. Other instruments included a written explanation of the training system and the purpose of the study, a demographics questionnaire, and a user reaction questionnaire. An initial 15-minute orientation informed the subjects of the purpose of the study, the hardware and software equipment, the general procedure(s), and administrative instructions for the survey. After providing a demonstration and instructions, subjects completed three scenarios to expose them to the system features and capabilities. After the initial orientation, subjects were asked to don the haptics and VR equipment. Each subject was then asked to run through three training procedures in succession: A) Needle Chest Decompression (NCD), B) Blood Sweep Tutorial (BST) and C) Combat Application Tourniquet (CAT).

Once participants completed each of the scenarios, the researcher asked him or her to complete a questionnaire to assess reaction to the system in terms of system favorability, level of engagement the system provided, and whether the system was relevant to the user's job. Data was stored in Excel and cleaned for overlaps, errors, and inconsistencies. Likert data was imported and coded using Python descriptive and inferential statistics and gathered all survey results across the instruments.

ANALYSIS

We encoded descriptive statistics for survey values (e.g., mean, standard deviation, mode, etc.). Open-ended questions were evaluated through automated keyword searches and sentiment analysis software (NLP Toolkit). Some descriptive analysis was employed in order to find key terms and phrases in the open-ended text. We employed a second review, manually verifying the automation process, to ensure key themes were captured. All statistical analysis results were coded in Python using open source statistics and visualization libraries, as were the generated visualization results. The preliminary exploratory analysis involved reading the results and interviews and recording initial data (Clark, 2014). This helped ensure an overall knowledge of the data before evaluating different perspectives and ideas. Next, we looked for evidence of this exploratory analysis in research reports (Clark, 2014). This included short phrases, ideas, concepts, or hunches, which were then consolidated into specific sub-categories.

Demographic data helped to decompose the general population of subjects into subgroups to respond to research questions. Descriptive statistics included graphs and charts demonstrating how subpopulations may react differently. For example, subjects with gaming experience may react more favorably to a VR Haptics system than those with no gaming experience.

Examining Likert Scores

24 Likert scale questions were clustered into the seven categories (See Exhibit 4). We then returned mean scores for each question across subjects and tabulated overall mean scores.

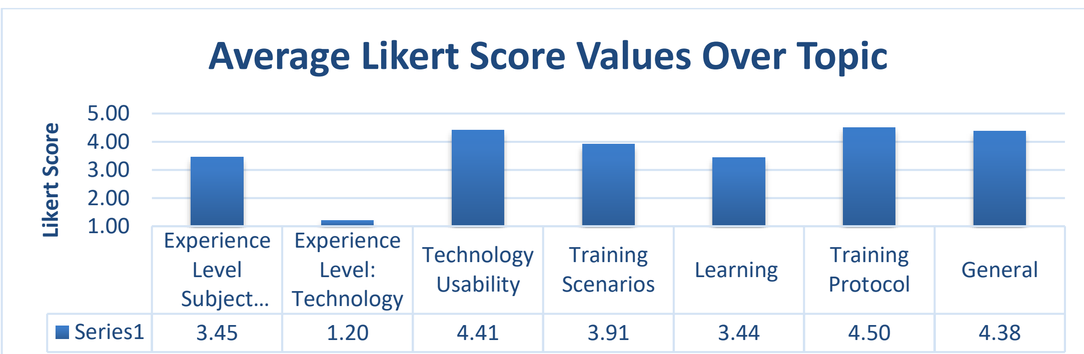

Exhibit 4: Likert population results by questions

Clustering Populations for Statistical Analysis

We were interested in examining several subpopulations and determine if Likert scale results proved statistically different between these populations. Using a k-means clustering algorithm, we developed a set of three sub-populations based on demographics, as described in Table 1.

Table 1: Subpopulation Demographics

Subpopulation Demographics				
Group	Measure	1	2	3
Experience Level	Months	10 -36	44 - 85	97 - 135

Subpopulation Demographics				
Group	Measure	1	2	3
Time Civilian Setting	Months	0 - 10	11-33	72-127
Time Spent in Military	Years	0 - 2	3 - 6	7 - 11
Are you an Educator?	Boolean	Yes	No	N/A
Time Spent as an Educator	Months	0 - 25	48 - 85	96 - 132

From here, we were able to calculate that respondent reaction to survey questions were not significant across populations. For example, Table 2 explains results from question 11 are consistent amongst three groups of experience levels. Results were consistent across all Likert scale questions.

Table 2: Example Statistical Results Between Experience Level Populations (Question 11)

Q 11. I was engaged with the virtual reality training scenarios using haptic gloves (Experience Level)			
Population 1 (months)	Population 2 (months)	U Test Results	Hypothesis
10-36	44–85	S=587.000, p=0.252	accept H0: same distribution
44–85	97-135	S=162.000, p=0.245	accept H0: same distribution
97-135	10-36	S=94.000, p=0.298	accept H0: same distribution

Sentiment Analysis

Sentiment analysis is the task of identifying positive and negative emotions, opinions, and evaluations (Turney, 2002). Open-ended questions were reviewed for sentiment and coded under the following categories: Usability/Ergonomics, Technology, and Scenario Development/Training. Researchers then coded responses as either -1 (negative), 0 (Neutral), or 1 (Positive).

For text description and sentiment analysis, we developed two separate measures for this effort. The first used a natural language parsing system that found the most common nouns and adjectives from the responses. We then determined which of the reactions contained one or more, or preferably both, and listed those as "Key Responses." This helped the reader to examine generalized focus areas when considering participant responses. The most used answers were put in a table.

The second Phase was to hand-code positive, negative, or neutral statements related to Usability/Ergonomics, Haptics and General and Technology, Scenario/Training. This allowed us to observe how the subjects reviewed each of these elements. Lastly, for each question, we included a summary report for sentiment results.

Example of Sentiment Analysis

For each question, a summary sentiment analysis was derived from both hand-coded and sentiment analysis data:

Q14. Was there anything encountered during the training that interfered with your learning experience? If yes, please specify how.

For example, data from Question 14 describes two primary areas of correction that could enhance the existing training. From a usability vantage point, users often felt there was some awkwardness with the haptic device as well as a need to produce higher-resolution feedback. Some issues of lagging were presented as well. Sentiment values were determined to be generally good.

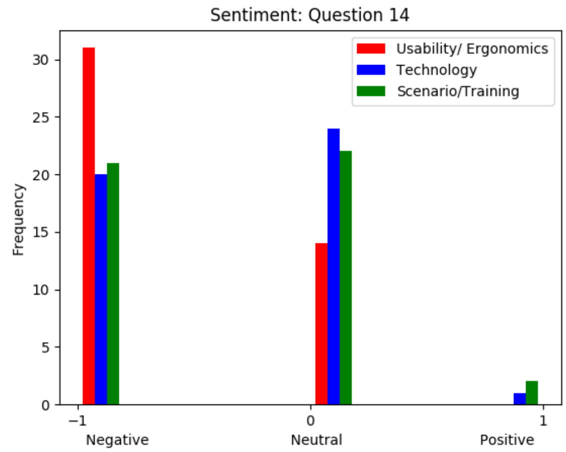

Exhibit 5: Summary Sentiment Analysis Graph

Table 3: Example Most Used Words Analysis

Question 14: Most Used Word Analysis			
Nouns	Freq	Adjectives	Freq
hands	9	hard	7
patient	5	difficult	4
experience	4	little	3
needle	4	minor	2

DISCUSSION

When considering key attributes associated with descriptive, statistical, and semantic analysis for a learner population, scores were generally above 3.0, even with minimal experience using VR technologies. The graph presented in Exhibit 4 demonstrates Experience Level: Technology (for VR) is low (1.20), although low VR experience did not appear to affect results of high Likert scale results across technology, usability, scenario development, and learning. Our decision to cluster sub-populations and analyze Likert scale results between these populations provided indications that Likert scale responses were consistent between these groups. The implication being that experience level, technology acumen, and experience in the military or educator did not appear to affect our results.

Open-ended questions provided additional information that helped to elucidate the reactions. Subjects felt that without the help of a guide, it was challenging to navigate the scenario on their own. Additionally, examining the general Likert score results proved high across technology, usability, and training/scenarios. In terms of the gloves themselves, the average Likert score was high, given this was a novel experience from several seasoned professionals with minimal VR experience (mean score = 4.38). We decomposed each question into positive, neutral, and negative responses, which provided some insight as to where results a) were consistent with Likert scores and b) were consistent amongst subjects.

Example Positive Responses

Overall, reactions to haptics during training were generally positive. For example, in response to the question "Was there anything that stood out as far as the haptics during your training experience?", we did a simple word frequency search and uncovered repeated words such as realistic, amazing, impressive, and real.

Areas of Improvement – Usability/Technology:

Although generally the experience of training, scenarios, and the use of the gloves were positive, several shortfalls were described by the subjects. Usability and ergonomics were an important topic when considering enhancing training through haptics. Without having a full grasp of how the HaptX technology works, many subjects were trying to reconcile tactile experiences and make recommendations to improve the approach. Example participant statements included:

Table 4: Example Areas of Improvement

Question 14: Most Used Word Analysis		
Adjectives	**Freq**	**Example Statement**
hard	7	"Hard to use – would like to see more fidelity."
difficult	4	"Although I liked the overall experience of having tactile feedback during the scenarios, there was some difficulty with retrieving the supplies and properly placing them on the patient."
little/low	3	"Some of the items and interventions had low tactile feedback that I was expecting."
refine	2	"Seems like a bit more fine-tuning (refinement) could help on the fine motor."

CONCLUSION

In summary, the novel experience provided some realistic and engaging learning while leaving room for work towards refining the HaptX devices for better user experience. We wished to examine how certain populations may differ in Likert scale results, so we began by clustering results based on the following topic areas below and used a k-means clustering algorithm to determine subpopulations. The results of our statistical tests indicate that there were no significant differences in survey scores across sub-populations. The implication being that the positive user experience may not be limited to a particular sub-population.

The results of this evaluation provide an insight into a generally positive, consistent experience across learners of varying demographics, experience, and education levels. Our ideal outcome would be to ensure learning using VR Haptics would not be encumbered for any particular population, but this will require additional investigation. We believe there are several additional areas of research that should be considered. In future work, we will review new haptics devices that may be appropriate across several disparate (and sometimes interconnected) tasks, and we plan to integrate haptics with weapons, AR, and mixed reality (MR) technologies, as this will improve the chances of addressing higher levels of learning in the psychomotor domain (articulation and naturalization) due to interaction with physical real world objects.

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