Tablet Computer Call for Fire Simulation: Proof of Concept Study Results

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ABSTRACT

Call for fire (CFF), the coordination of indirect artillery and mortar fires by a ground observer, is an ideal mission set for virtual environment (VE) training. CFF is a United States Marine Corps (USMC) core competency and is a perishable skill that requires frequent reinforcement training. The requirement to expose Marines to initial and recurrent CFF training is hampered by the expensive and time-consuming nature of live indirect fire training. The USMC currently has a CFF simulation training capability, but access is limited by the fixed site nature of the simulations.

This paper presents the results of a proof-of-concept study that developed and tested a tablet-based CFF training simulation. The objective of this study was to investigate the comparative value of tablet-based CFF VE training. The research team designed and developed a tablet-based CFF prototype and then executed a user feedback experiment that compared the tablet solution to the USMC's current personal computer (PC) based CFF simulation, ObserverSim. The comparison focused on end user opinions regarding the training value and effectiveness of the tablet's multifunction interface relative to ObserverSim's traditional mouse and keyboard interface.

End users with and without previous CFF experience registered an overwhelming preference for the CFF tablet prototype ($p=0.002$). While the tablet prototype was primitive and of much lower fidelity than ObserverSim, participants liked the tablet's ability to mimic real world physical motion, its ease of use, and shallow learning curve. These study results offer the modeling and simulation community important lessons learned and a realistic example of how to exploit the tablet's multifunction user interface to further training simulation development efforts.

ABOUT THE AUTHORS

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INTRODUCTION

"Hurry Up and Wait!" may be the most consistent and appropriate description of any military training exercise. Training exercises involve a great deal of time moving between venues and waiting for the next event to begin. To take advantage of these idle times, small unit leaders often conduct impromptu classes to discuss pertinent tactics, techniques and procedures.

The fidelity of these "hip-pocket" classes are limited by the on-hand resources. Training methods such as throwing little rocks at big rocks are commonly used to simulate call for fire (CFF). The rocks provide a field expedient prop to deliver a certain level of detailed instruction, but pale in comparison to the quality of training available in a simulation-training center. The rocks might not come close to the training fidelity offered in a virtual environment (VE), but rocks are quite literally everywhere whereas a VE can only be found at a fixed site.

The United States Marine Corps' (USMC) version of the *"Hurry Up and Wait!"* adage is: *"Killing Time Kills Marines."* This harsh reality puts the tradeoff between availability and fidelity into its proper perspective. It is incumbent upon the Department of Defense's modeling and simulation community to better balance this trade-space in order to effectively support the broad set of skills Marines need to succeed on the modern battlefield. One potential solution is to bring the simulation-training center to the Marine, by developing training simulations for common mobile devices.

This paper presents the results of a proof-of-concept study that developed and tested a tablet-based CFF training simulation. The objective of this study was to investigate the feasibility of tablet-based CFF VE training. The research team designed and developed a CFF tablet-based prototype and then executed a user feedback experiment that compared the tablet solution to the USMC's current personal computer (PC) based CFF simulation, ObserverSim. The comparison focused on end user opinions regarding the training value and effectiveness of the tablet's touch screen, gyroscopes, and accelerometer interface relative to the PC's traditional mouse and keyboard interface.

Due to the high demand for the skill, the existing body of work on CFF simulation training, and the authors' experience as joint tactical air controllers, CFF was chosen as the skill for evaluating the value of tablet-based VE training.

The goals of the project were:
(1) Design and develop a tablet-based CFF training simulation prototype.
(2) Conduct an end user experiment to assess the training effectiveness of the tablet-based prototype relative to the USMC's current PC-based simulation standard, ObserverSim.
(3) Solicit feedback from end users, with and without previous CFF experience, in order to determine the perceived training value of the CFF tablet-based simulation.

During the prototype development processes a great deal of effort was expended to ensure that the tablet input modalities were leveraged to the greatest effect. The desire was to have an interface that wasn't simply mapping a mouse and keyboard onto a touch screen. The user interface development focused on the tablet's accelerometers and gyroscopes. To change the view within the tablet's first person VE, the tablet is physically rotated around the user's body. The accelerometers and gyroscopes register the degree of movement and adjust the perspective in the VE at a 1:1 ratio. In essence the tablet works like a window into the VE. The user must move their body, arms, head and eyes, a far more dynamic experience than a PC-based simulation, where the user's head and eyes are always looking forward at a stationary monitor. Throughout the paper, this concept is referred to as window to the world (W2W). Figure 1 illustrates W2W, it is a screen capture of the tablet CFF prototype. The inset picture shows the user holding the tablet when the capture was taken.

Figure 1. Example of Window to the World

BACKGROUND

In 2002, David Brannon and Michael Villandre investigated the potential for a virtual CFF procedure trainer. Their effort was a proof of concept that demonstrated computer simulation could effectively reproduce the tasks required of a joint fires observer (JFO) to conduct CFF. A thorough cognitive task analysis (CTA) was conducted which established that many CFF procedures can be trained by using a PC-based VE (Brannon & Villandre, 2002). This led to the development of Forward Observer Personal Computer Simulation (FOPCSim).

Brannon and Villandre conducted experimentation with this prototype software and experienced JFOs, finding that "individuals trained in the forward observer task can use the FOPCSim to maintain and improve proficiency for a skill set that is perishable without regular practice" (Brannon & Villandre, 2002). It is important to note that at the time the Marine Corps had few digital CFF VE resources available.

In 2005, James McDonough and Mark Strom conducted follow up work with FOPCSim. Their research extended Brannon and Villandre's previous work, transitioning FOPCSim from a prototype to a complete simulation that could run on existing computer equipment in the Marine Corps' inventory, resulting in FOPCSim 2. McDonough and Strom began with the cognitive task analysis conducted by Brannon and Villandre and then applied a human ability requirements (HARs) assessment to determine the degree to which FOPCSim tasks map to the execution of the real world tasks. Subsequently, software was developed and tested. Based on the results of this experiment McDonough and Strom determined that FOPCSim, when used as a training tool, performed as well as and in some cases better than the legacy training method used in the control group (McDonough & Strom, 2005).

In 2003, the Marine Corps started development of the Deployable Virtual Training Environment (DVTE). In 2008 ObserverSim was incorporated into the DVTE. Commercially developed, ObserverSim improves on many of the early design elements of FOPCSim. It uses High Level Architecture and is integrated with a suite of training simulations all running the same image generator and Joint Semi-Automated Forces. This set of software is called the Combined Arms Network (CAN). The CAN portion of the DVTE was validated as a close air support simulation by Joint Close Air Support (JCAS) Action Plan Memorandum of Agreement (AP MOA) 2004-01 dated 1 Sept 2010.

PROTOTYPE DEVELOPMENT

ObserverSim was the basis from which the tablet CFF prototype was developed. Before code was written an extensive task analysis was conducted.

Task analysis

McDonough and Strom's HARs absence / presence assessment revealed that psychomotor and sensory perceptual tasks are not well replicated within a PC-based VE CFF simulation (McDonough & Strom, 2005). A HARs assessment compares the execution of a real world task to the execution of that task in a VE (Cockayne & Darken, 2003). The authors extended the HARs assessment to tablet-based devices; specifically how a tablet's input modalities change the mapping of the tasks.

Human Ability Requirements Review

When McDonough and Strom conducted their HARs assessment they found that 27 skills are required to conduct basic CFF (see Table 1). The skills fall into four broad categories: twelve cognitive tasks, ten sensory-perceptual, three psychomotor, and two that require special knowledge or skill. During further analysis it was determined that cognitive tasks match well between simulation and the real world; however, psychomotor and sensory-perception related tasks do not. These results were supported by Brannon and Vilandre's findings when they developed the first version of FOPCSim.

Table 1. Skills Required to Perform CFF

Cognitive Skills		Sensory / Perceptual Skills	
Oral Comprehension	Deductive Reasoning	Near Vision	Hearing Sensitivity
Oral Expression	Information Ordering	Far Vision	Auditory Attention
Memorization	Spatial Orientation	Night Vision	Sound Localization
Problem Sensitivity	Visualization	Depth Perception	Speech Recognition
Mathematical Reasoning	Perceptual Speed	Glare Sensitivity	Speech Clarity
Number Faculty	Time Sharing	Psychomotor Skills	
Specific Knowledge Skills		Control Precision	Arm / Hand Steadiness
Map reading	Electronic Knowledge	Reaction Time	

Development of the CFF tablet prototype focused on psychomotor skills, specifically arm / hand steadiness, with the belief that the tablet's ability to register motion could be used to better train the use of a compass or a set of range finding binoculars. The touch screen, when used to conduct mission planning, might train control precision skill. Due to budget and time restrictions the development effort was only able to target arm / hand steadiness.

System development

The prototype was written using the Unity Engine, allowing it to be easily ported from one platform to another. The development effort was designed using the Model-View-Controller (MVC) design pattern (Apple Inc., 2013). The design pattern was used to explore the differences and similarities between PC-based and tablet VE trainers. This assisted in deciding where to focus limited resources in order to maximize development efforts.

The effort started by mapping the mouse and keyboard inputs of ObserverSim to one of the tablet's input modalities. These modalities included the multi-touch enabled touchscreen, accelerometers, and gyroscopes. From inception there was a desire to control the user's visual perspective with the accelerometers and gyroscopes.

Once it was established that accelerometers and gyroscopes would control perspective, the remaining inputs were either mapped to the multi-touch enabled touchscreen or eliminated. Translating the mouse input for ObserverSim to the tablet was relatively easy: instead of pointing and clicking, the user touches the screen in the area of the desired button icon. There are some challenges with this methodology: a finger occludes the screen, and is less precise than a mouse pointer. The buttons were made large and placed near the edge of the screen, thereby allowing users to hold the tablet with one hand and press the buttons with their thumb. Figure 2 is a screen shot of the tablet prototype in Vector 21B view. The Vector 21B is a common range finding binocular used by Marine JFOs.

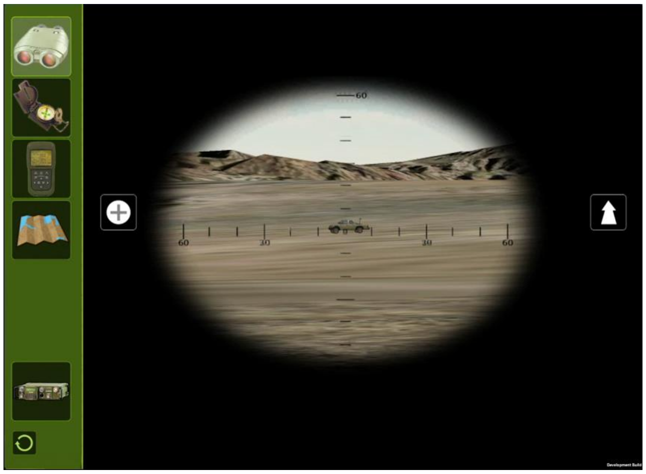

Figure 2. Screen Capture of Tablet CFF Prototype in Vector 21B View

Mapping the keyboard from ObserverSim to the tablet prototype was more difficult than mapping the mouse. Due to the limited development time, drop-down menus were used to fill in the three CFF transmissions. The drop-down menus limited the flexibility of the software but allowed the tablet prototype to avoid the implementation of a virtual keyboard and the underlying logic for parsing the inputs.

The laptops that are part of the DVTE suite on which ObserverSim runs have 17” displays, this equates to three times the area of a 10” display, typical of a tablet computer. To compensate for the small screen size, the mapping of icons and viewable area was altered. Figure 3 shows screen captures from the two, ObserverSim on the left and the tablet prototype on the right, both taken in the naked eye view. Differences between the two include the placement of the JFO tool icons, the relative size of the icons, and the decision to have the tablets prototype’s icon tool bar occlude the background. Having the icons on the side of the screen makes them easier to select when the user holds the tablet. The background occluding toolbar creates a region of the screen where the user’s only interaction is tool selection. This prevents the user from accidently sending another command if they missed the desired tool. For instance, if the tablet interface allowed for finger swiping to change viewing perspective, the system might infer a missed tool touch as a finger swipe, changing the viewer’s perspective and potentially disorienting them.

Figure 3. Screen Captures of the Naked Eye Views of ObserverSim and the Tablet CFF Prototype

The prototype’s icons are larger, relative to the screen, than ObserverSim’s icons. If they had maintained the same size ratio they would be difficult to select. A fortunate side effect of the larger icons is that they do not need to have extra text describing the icons, as can be seen in ObserverSim’s screen capture (see Figure 3).

Once the tablet CFF prototype was stable and developed to the point that it could be used to execute CFF, a controlled experimental study was conducted.

EXPERIMENTAL STUDY

Study Objectives

The study objectives were to:

- Evaluate the difference in preference between using a PC-based VE CFF trainer and using a tablet-based VE CFF trainer (hypothesis 1, primary objective).
- Determine if user experience level in CFF has any effect on system preference (hypothesis 2, tertiary objective).
- Determine if there is a difference in the perception of the PC-based VE CFF trainer’s and a tablet-based VE CFF trainer’s ability to accurately represent the real world physical motion required to conduct the task (hypothesis 3, secondary objective).

Participants

A total of 32 active duty personnel participated in the study. They varied in grade from O-1 to O-4, one was female. The participants were drawn from two populations: those trained in CFF and those not trained in CFF. An individual was considered trained if they had been to a school dedicated to combined arms training, e.g., Field Artillery School, JFO course, or Tactical Air Control Party course, or had been designated by their commanding officer to conduct CFF.

Apparatus and Location

Equipment used for the study included a standard USMC issued DVTE laptop, running the ObserverSim software and the tablet CFF prototype running on an ASUS Transformer Pad Infinity, model TF700.

Despite the difference between graphical representations, the goal was to make the scenarios on the PC and the tablet as similar as possible. The scenario placed the user at a Marine Corps Base Twentynine Palms CFF range with two available targets: an open back pick-up truck that represented a technical vehicle, and a T-72 Russian main battle tank. The targets were placed far enough apart so that the user could not see both at once. The targets were close enough to be within visual range but far enough away that they were not danger close, i.e. outside 600 meters. The scenario was set in the day. The indirect fire unit was “kilo” battery, consisting of 155 mm howitzers.

Procedures

Tasks conducted were derived from the Brannon and Villandre’s CTA. The tasks included the use of GPS for self-location, use of a compass to determine bearing to a target, use of a Vector 21-B common laser range finder to determine bearing and distance to a target, and the use of the software to generate, send, then execute a CFF mission. These are common tasks that a JFO would complete in order to build and execute a fire mission.

Experiment Conditions

The experiment was a two by two cross-over design as shown in Table 2. This allowed the authors to control for the possibility a participant might prefer one of the devices over the other due to the order they were presented and determine if user experience level in CFF has any effect on preference.

Table 2. Two by Two Cross-Over Design

	Experience	
Device	**Trained**	**Untrained**
Tablet	Trained Observer using Tablet First	Untrained Observer using Tablet First
PC	Trained Observer using PC First	Untrained Observer using PC First

Survey Questions

After completing each protocol, the participants answered 10 Likert Scale questions and an open-ended question. Upon completion of the final protocol four dichotomous questions were asked.

Likert Scale Questions

Following are the seven point Likert scale questions. Six questions deal with the interface, two pertain to the systems effectiveness as a CFF trainer, and two are related the system’s ability to mimic the real world physical activity and motion required to execute the tasks:

L1. Training with this device on a regular basis will improve my ability to conduct CFF in the field.
L2. It was difficult navigating through the device to find the appropriate information while completing the tasks.
L3. The real world physical actions and conducting a task in the virtual environment are the same.
L4. The button icons provide intuitive inference of what would happen when they are pressed.
L5. It is easy to move though the screens without losing one’s place.

L6. Having this software available at my unit would improve my unit's ability to perform its mission.
L7. It was hard to understand what the buttons did.
L8. The 3D view interface was intuitive.
L9. The device accurately represents the real world physical motion required to conduct the task.
L10. The overall interface is intuitive.

Dichotomous Questions

Choices for the following four dichotomous questions were either "Laptop" or "Tablet":

D1. Which device was more intuitive to use?
D2. If the software on both devices were about equivalent I would prefer to use?
D3. If each device had the same feature set I would prefer to use?
D4. This device is more convenient to train with?

Open-Ended Questions

The open-ended question, asked at the end of each protocol, was phrased to allow participants the opportunity to express what they felt was most pertinent from their experience with the systems.

O1. Please provide any additional comments about your experience with the device(s) here.

EXPERIMENT RESULTS

Likert Scale Questions

The authors analyzed the Likert scale questions using a Wilcoxon Signed-Rank test. A two-tailed **α** of 0.05 was used. Table 3 contains the results of this analysis. Five out of the ten questions had a statistically significant difference between the participant's answers at the two-tailed 0.05 threshold. In all five cases, the participants preferred the tablet system over the PC system.

Table 3. Wilcoxon Signed-Rank Test Results for Likert Scale Questions Asked Post Protocol.

		Summed singed ranks		
	n	**Tablet System**	**PC System**	**2 tailed p-value**
L1	13	91	0	0.0013
L2	22	180.5	72.5	0.0794
L3	21	215.5	15.5	0.0005
L4	18	103.5	67.5	0.4362
L5	22	164.5	88.5	0.2168
L6	11	55	11	0.0511
L7	24	191	109	0.2388
L8	21	173.5	57.5	0.0392
L9	23	241	35	0.0015
L10	23	223.5	52.5	0.0083
All	30	383.5	81.5	0.0019
Eliminate Redundant Questions	29	371	64	0.0009

The authors ran two additional Wilcoxon Signed-Rank tests to see if there was an overall device preference. The first was on a summation of all ten Likert questions. With a two-tailed p-value of less than 0.002, the participants' responses indicated an overall preference for the tablet system over the PC system. The second test was similar, except as some of the Likert questions were very similar to each other, the average scores of these questions were used. This was done to eliminate the possibility that the same sort of question was overly influencing the results. The similar questions are L2 and L5, L3 and L9, L4 and L7, and L8 and L10. Questions L1 and L6 were unique and their values were added as is. The resulting two-tailed p-value was less than 0.001.

The data was analyzed in R using the "Wilcox.test" function. Histograms were generated to determine symmetry around the median using JMP. Ideally when conducting a Wilcoxon Signed-Rank test, the data will have no zeros, there will be no ties, and the data will be symmetric around the median. In the case of this data there were ties, zeros and in some cases the data was not perfectly symmetric. However, when the test indicated that the results were significant, except for Q8, the p-value were all less than 0.01. Q8 was symmetric around the median and the authors feel comfortable stating that there is significant difference between the medians of the participants' answers as it pertains to this question**.**

Dichotomous Questions

The authors analyzed the dichotomous questions using a two-sample *t*-test. In all four questions the participants preferred the tablet over the laptop (see Table 4).

Table 4. Two-Sample *t*-Test Results for Dichotomous Questions Asked Post Experiment.

	Tablet System	**PC System**	**p-value**
D1	24	7	0.003327
D2	26	6	0.000535
D3	27	5	0.000113
D4	23	9	0.020062

Training and Order

To determine if order or previous CFF training had an effect on how the users answered the post protocol questions the authors ran two-sample *t*-tests on the difference values between the Likert scale questions. Using a two-tailed **α** of 0.05 they found no evidence that order or prior training had any effect on how the Likert scale questions were answered.

Hypothesis Results

Hypothesis 1 was "There is no difference in preference between the PC-based VE CFF trainer and the tablet-based VE CFF trainer." With an overwhelming preference for the tablet in both the Likert scale questions ($p = 0.002$, see Table 3) and the dichotomous question (see Table 4), the authors reject this hypothesis. There is a preference for the tablet-based VE CFF trainer over the PC VE CFF trainer.

Hypothesis 2 was "There does not exist a relationship between an individual's evaluation of the tablet-based VE CFF trainer and their CFF experience level." Analysis was conducted to investigate if order of system or previous CFF training had any effect on how the questions were answered. Two-sample *t*-tests were run on the difference values between the Likert scale questions in the two protocols, using a two-tailed **α** of 0.05 the results found nothing of significance. The authors fail to reject this hypothesis.

Hypothesis 3 was "The tablet-based VE CFF trainer is better able to represent the real world physical motion required to conduct CFF than the PC-based VE CFF trainer does." Looking at the analysis of the answers to L3 (*The real world physical actions and conducting a task in the virtual environment are the same*) and L9 (*The device accurately represents the real world physical motion required to conduct the task*), with p-values of 0.0005 and 0.0015 (see Table 3), the authors accept this hypothesis.

Open Ended Questions

After each protocol the participants were asked to provide additional comments about their experience with the device. As expected, there were a variety of answers. Some related directly to certain features of the software, for example “Compass should have metal filament that lined over radial direction to aid in giving accurate report”. Such statements are interesting in terms of how accurately digitized equipment represents real world equipment, but they do not drive at the authors’ research objectives. Fortunately, many of the remarks not only confirmed the results of the Likert scale and dichotomous questions but also provided some surprising insights.

The majority of comments were on the physical motion required by the tablet system. These ranged from simple statements, such as “tablet has more realistic feel due to physical activity required as in the real world,” to more thoughtful ones, such as noticing increased opportunities for training. Some of the more nuanced comments related to the differences between using the Vector 21B and compass on the tablet system and using the two virtual devices on the PC system. It is time consuming to ensure that the “pointing circle,” the laser recital, is over the target when using a physical Vector 21B. This task frequently requires more than one “squirt”, a colloquialism for ranging the target, and multiple confirmation “squirts” to ensure that one has the right distance and heading. In the PC system, the 3D view is controlled with a mouse, when using this input modality the “pointing circle” of the Vector 21B stays exactly where it is placed and perfectly still. This makes determining the heading and distance unrealistically easy, and there is no need to confirm with a second or third “squirt”. A similar issue occurs when using a floating bezel compass on the PC system. When using a physical compass, it takes time for the floating dial to come to a rest and requires a steady hand to ensure the reading is accurate. When using the PC system, the compass always gives a perfect bearing to whatever is lined up with the sighting wire. To get a good bearing with the tablet system the user needs to steady the system gyroscopes and accelerometers. Although the Vector 21B and compass are not particularly challenging to use, it is harder than the PC system makes it appear, whereas the tablet system replicates some of the real world motor skills required to conduct the task. A comment from one of the participants summed this notion up nicely “The laptop was easier to manage in terms of pointing and clicking, but the tablet better approximates holding up the vector”.

Analysis of questions L3 and L9 show that participants believed the tablet system was more representative of real world physical action and motions required for task execution. A number of statements supported this finding. “I liked the tablet a little more b/c it did a little better mimicking actual use of hands and some of the physical motion of looking around & up/down”. Participants also liked the physical motion that the tablet system requires because it helped them maintain their orientation within the 3D world, “It was much easier to locate targets and not get disoriented when using the tablet”. Other comments related to the way the physical motion helped maintain participant attention, such as “Tablet was generally better in that it kept my attention through the requirement of movement”.

The authors were surprised with how much participants cited W2W as having helped them maintain their orientation in the VE and increased their attention. This is especially interesting when considering how the tablet system was significantly less refined than the PC system, with a crude interface and simple and repetitive 3D terrain.

A number of remarks related to the advantages of training with a tablet system over a PC system. Others commented on the mobility and ease of access for a tablet system, “Very easy to use. Small & portable – convenience factor is huge”. One participant stated how the mobility of the tablet allows the trainee to get out of the classroom and practice in more realistic conditions, “You could take it outside put soldiers in full body armor & simulate a CFF w/out the range”.

Discussion

Almost all answers to the open ended questions indicated a positive response to the W2W paradigm. W2W on the tablet system makes the simulation more than just a cognitive skill and specific knowledge trainer. W2W has the potential to train some of the physical skills needed to execute a CFF mission.

The developers of the DVTE suite recognized that negative training could occur when the user stares at a stationary monitor, which is why each DVTE suite includes a head mounted display (HMD). With the HMD, the user moves his head to look around in the VE as he would in the real world. This places the user directly into the VE.

Unfortunately, this makes it hard to see anything in the real world, including the CFF he carefully wrote down and the keyboard for typing instructions. Due to these limitations, the HMD is only worn in the final portion of the DVTE mission, when there is little need to double check notes and finger placement. W2W does not have any of these issues; the multi-touch screen is both the user's view of the world and interface.

CONCLUSION

The overarching objective of this project was to evaluate the value of tablet-based VE training. After completing the experimental study and sifting through the data the authors have verified the potential value of tablet-based VE training. The observations of the 32 participants executing the same mission on both the tablet and the PC systems lead the authors to conclude three important points:

- Software or system fidelity did not affect user preference.
- Although not proven by the experiment, the authors believe that Cognitive Load Theory could explain why users preferred the tablet system (Clark, Nguyen, & Sweller, 2006). It reduced the amount of extraneous load, allowing the participants to focus their mental efforts on executing the mission.
- "Hip-pocket" training does not need to mean inferior training. Tablet VE simulation training software can be more than a stripped-down version of PC-based simulation software. If the tablet's input modalities are used smartly the tablet can train some skill better than a PC can, and it can do so in a more intuitive and immersive fashion.

Future Work

The tablet CFF simulation was able to train the "arm / hand steadiness" psycho motor skill. It would be interesting to explore the ability for a tablet to train the other two psycho motor skills: control precision and reaction time. Additional work would be to determine if W2W reduces extraneous cognitive load by a measurable amount, and if so by how much?

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