Using the Immersive Cognitive Readiness Simulator to Validate the ThreatFire™ Belt as an Operational Stressor: A Pilot Study

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Abstract: The Army is in need of a stressor for use in experimentation that is safe but operationally relevant. Until recently, it was not possible without human interaction to simulate return fire from a combatant. The Army Research Laboratory’s 300-degree simulator is capable of providing return fire simulated as a small shock from the ThreatFire™ Belt. A pilot study used the simulator and the ThreatFire™ Belt to investigate the level of stress on cognitive performance. As the first study using the simulator for cognitive research, information gained from this investigation will ensure that future scenario and external equipment can work both independently and integrated. The LifeShirt™ was used to collect physiological responses to arousal. The study was a mixed design with Group (non-shock vs. shock) as the between-subjects variable and Session (pre/during/recovery) as the within-subjects variable. The hypothesis was that the shock group would elicit higher heart rate (HR) and heart rate variability (RR) compared to the non-shock group. The results, although preliminary, support the hypothesis with higher HR and RR during the simulation for the shock group. Preliminary results support the idea that the shock belt may be a more realistic operational stressor compared to a simulation without feedback. Plans for a formal investigation to test the robustness of the shock belt as an operational stressor are being developed.

1. Background

Returning Soldiers and Officers have shared their opinions that the training received in simulations helped them in theatre. Replicating the extreme environment of theatre would pose unacceptable levels of risk; therefore training tools in a safe setting that can simulate an extreme environment are needed. According to Army Regulation 350-1, 18 Dec 09, the Army will “train units and staffs in their core competencies under conditions that accurately portray the operational environment.” The training must also “realistically portray the operational environment for threats” in targeted regions that exist within the operational environment to integrate observations, insights, and lessons learned in order to adapt training based on the operational condition. Currently there is no low cost immersive virtual reality (IVR) system that accurately portrays the adverse operational conditions a Soldier will encounter in theater. The available IVR systems used in training have not been investigated to determine the degree to which they replicate the harsh conditions of war.

The goal of this pilot research was to examine the level of stress created by the threat-fire shock capability of the CASEL’s ICORS system by comparing stress levels resulting from the ThreatFire™ Belt against a Non-shock group. A secondary objective was to assess the level of “realism” as determined by participants’ responses to questions in an exit survey and in a presence questionnaire. The independent variable is group, (shock or non-shock) and the dependent variables are the stress responses (psychological and physiological) and performance (decision to shoot or shoot) on the task. The shock group (wearing the ThreatFire™ Belt) received 4 small shocks from the belt at pre-determined times. The Non-shock group did not receive any shocks.

We make two hypotheses. First, participants’ stress arousal will increase both psychologically
and physiologically as a result of the small shock administered by the ThreatFire™ Belt and that the increase will be higher than the Non-shock group. Second, the Non-shock groups’ stress arousal will increase as a result of the immersion provided by the simulation.

2. Facilities and Instrumentation

2.1 Cognitive Assessment Simulation and Engineering Laboratory (CASEL)

The research was conducted in the Army Research Laboratory’s (ARL) Cognitive Assessment Simulation and Engineering Laboratory’s (CASEL) 300-degree IVR system, Immersive Cognitive Readiness Simulator (ICORS). See Figure 1.

Figure 1. Immersive Cognitive Readiness Simulator (ICORS)

While originally designed for training applications by VirTra Systems, Inc., ARL has obtained this IVR system as a research tool to provide an immersive environment in which to conduct research on Soldier performance. The system uses a rear projection system to display various scenes on each screen. It is capable of showing from one screen scene up to a five-screened 300-degree scene. The system has a weapons-fire detection system and uses modified real weapons (M-4 carbine & Beretta M9). Weapons are modified with a CO2 cartridge to provide the sense of recoil that would be experienced in live fire. The weapons are also modified in that the ammunition is replaced with a laser beam. An infrared camera behind the screen detects the laser and registers a hit. Depending on the scenario, a hit target may be incapacitated. In addition to registering hits, the participant can be ‘fired’ upon through the use of a ThreatFire™ Belt. This belt uses wireless communications with the software to administer a small shock if the participant gets hit. The ThreatFire™ Belt is a wirelessly controlled system that simulates return weapon fire.

2.2. Simulation Scenario Development

The scenario development constituted the creation of three scenario elements; characters, environment, and logic.

Characters: Character creation consisted of videotaping volunteers performing scripted actions (e.g., brandishing a weapon, cell phone, or cup) in front of a green screen. The videos were imported into Adobe Premiere where the green screen key was applied before the scenes were cropped and converted into a video sequence of tagged image file format (TIFF). The resulting files were imported into the Epiphany Editor, developed by the VirTra character creation tool. Each character had the three required “actions” created to function within the scenario: a friend/foe action, an idle action, and a die action. Additionally the “hit zones” of the character, the locations on the character that register a shot as a hit or miss, were created using the default settings – a shot landing anywhere on the character will register as a hit, otherwise it is a miss.

Environment: One of the stock VirTra backgrounds, the “bombed street”, was used to create the environment in which the characters would appear. Several locations on each of the five screens were identified as possible hiding places for the characters (e.g., a crate, a vehicle, or a 2nd floor stone balcony). At each location, the Epiphany Editor background tool was used to generate layers that behind which a character could be placed. Once the layers were finalized, the characters could be placed in a location and scaled to the appropriate size.

Logic: A bug in the Epiphany Editor logic manager required use of an outside application for nearly all of the scenario logic. The Epiphany Editor logic manager was utilized to display a blank background preventing the participant from viewing the scenario background before the study began, and again to hide the blank background when the scenario began. The more than 1100 other lines of logic were fed to the simulator using the ARLLogger, an application developed by the ARL. The ARLLogger reads a preformatted spreadsheet and sends character actions or sets character attributes via a User Datagram Protocol (UDP). The ARLLogger’s
secondary use was to capture all scenario events (i.e., character actions, pauses for changing the ammunition clip, and shot tracking). In the event a participant would shoot outside the borders of a screen, a button was added to the ARLLogger controlled by the operator to signify that a shot happened but was not registered by the simulator.

2.3. Data Retrieval
As the IVR scenarios “run” event data is published across the systems’ network of computers, actions are triggered within the simulated environment. These events come from three sources; the IVR system logic, scenario logic and the shot tracking system.

The IRV system logic events consist of scenario specific data such as the scenario name, current weapons in use and the scenario start and end events. Scenario logic events consist of character actions, sound cues and execution of shocks from the ThreatFire™ Belt. The shot tracking system events occur when a weapon is fired at one of the screens and contains the screen identifier and the position on the screen that was hit. As these events are published, they are captured by a data collection utility and stored in a Microsoft Access database. For each run of a scenario, all events generated are associated to the participant interacting with the IVR system using a unique identifier for each subject as well as a time-stamp that is accurate within one millisecond.

3. Method

3.1 Participants

Twenty-four male civilian volunteers were recruited for this research. Due to missing data and other technical issues, complete data was obtained for 5 participants in the Non-shock group and 6 participants in the shock group. All participants were informed which group they were assigned after baseline data collection.

3.2 Psychological Surveys and Physiological Instruments

Health Screening Form: The health screening form was used to identify issues that would have precluded participation (e.g., heart conditions, pace maker). The ICORS ThreatFire™ Belt documentation states that persons with a pace maker or heart condition cannot participate.

ARL-HRED does not have the expertise to assess an individual’s physical fitness and therefore, relied on volunteer self-reports of their condition. If a participant answered yes to either question, then they were released from participation.

Demographic Questionnaire: The demographic questionnaire asked general demographic information such as age, virtual game play, and hours of game play. The demographic questionnaire responses are not discussed in this paper.

Immersive Tendencies Questionnaire (ITQ): (Witmer & Singer, 1998) The ITQ measured the participant’s capability or tendency to be involved or immersed in a simulation. It consists of 29 questions about involvement in common activities (e.g., identifying with a character in a movie, a video game, current fitness and alertness). The questions are rated on a 7-point Likert scale (e.g., Never – Always). This was given one time after the baseline data collection.

Presence Questionnaire (PQ): (Witmer & Singer, 1998) The PQ has 32 questions that measure the degree to which one experiences presence while in a virtual environment and the influence of possible contributing factors (Control factors, sensory factors, distraction factors and realism factors) on the intensity of the experience. The questions are rated on a 7-point Likert scale (e.g., Not At All – The Whole Time). This was given one time at the end of the experimental scenario.

Multiple Affect Adjective Check List – Revised (MAACL-R), Today Form (Lubin & Zuckerman, 1999): The MAACL-R is an interval questionnaire that consists of five primary subscales: Anxiety (response to emotional uncertainty), Depression (ceaseless striving or a sense of self failure), Hostility (frustration), Positive Affect (positive mood or well-being), and Sensation Seeking (sense of adventure), derived from a one-page check list of 132 adjectives. An overall distress score, Dysphoria or Negative Affect, is a composite of the Anxiety, Depression, and Hostility scores. The form requires only one to two minutes to complete. Respondents check all the words that describe how they feel “right now” or “during the simulation you just completed.” The MAACL-R Today form was administered at
baseline, prior to simulation, immediately upon simulation end, and at recovery.

**Exit Survey**: The exit survey was administered to all participants upon completing the simulation. The shock group had additional questions regarding the ThreatFire™ Belt. The survey asked on a scale from one to ten about perceived level of immersion, perceived performance, and has open space for any additional comments. Participants will select their response on a scale of one to ten. The exit survey is not discussed in this paper.

**LifeShirt™**: The LifeShirt™ provided data recordings of heart rate (HR), heart rate variability (RR), respiration rate, and galvanic skin response. Only HR and RR are discussed in this paper. Heart rate variability is used to test for significant changes in sympathetic activity. As HR increases RR decreases in timing and frequency. These changes are indicative of short-term stress. See Figure 2.

**Salivary Amylase**: The salivary amylase field test was administered to derive a quantifiable level of stress. α-Amylase is produced in the salivary glands in response to circulating epinephrine and norepinephrine and hydrolyzes starch to oligosaccharides and then slowly to maltose and glucose. Salivary amylase concentrations are predictive of plasma catecholamine levels and can be used as a measure of stress (Chatterton, Vogelsong, Lu, Ellman & Hudgens, 1996; Skosnik, Chatterton, Swisher & Park, 2000). We employed a new methodology to measure α-amylase concentration in saliva. The method includes the observation of chemical color change according to standard photometric procedures developed by Andrology Labs and Northwestern University (Jeyendran, Ramu, S. & Chatterton, R.T., 2011). The concentration of amylase is then determined from a table of values relating time of color change to amylase activity. This measurement is a quantifiable physiological measurement of stress arousal.

**ThreatFire™ Belt**: The ThreatFire™ safe return fire system uses a rechargeable battery pack and delivers a 200 millisecond to 2.5 second electric shock to simulate the pain of hostile return fire. The system comes with a dual built-in safety control that will not allow a continuous electric shock to be delivered and will only fire once every 15 seconds at the earliest, alternating between the two electricity housing units. See Figure 3.

![LifeShirt™](image)

**Figure 2. LifeShirt™**

**Figure 3. ThreatFire™**

### 3.3 Procedures

All participants wore an Army over-shirt, t-shirt underneath, pants, socks, and rubber-soled shoes. They answered the Health Screening form to determine possible risk to participants (no participants were removed from the study as a result). All participants were instructed not to eat or drink for 30 minutes prior to arrival at the testing facility. This requirement ensured that the saliva was not washed out of their mouth. They received no monetary compensation.

All participants engaged individually. Each participant began by being shown to the changing room where they donned the LifeShirt™. Next, the participant was instructed to sit quietly for 10 minutes. At the end of the 10-minute baseline the participant completed the baseline MAACL-R, provided a saliva sample and completed the demographic and ITQ. After the baseline collection, the participants were offered a bathroom break. Next the participant was assigned to one of the groups as determined
by draw of card marked with the condition. If they were assigned to the shock group, the researcher placed the ThreatFire™ Belt on the participant just above the top of the pants and on the outside of all clothing. Then the participant received one (200 millisecond) shock. This shock was used to fully inform the participant exactly what they would experience inside the simulator. Although at any time participants were allowed to withdrawal, at this time the participant was asked if he would like to withdraw. No participants withdrew. The Non-shock group followed the same procedures except for the ThreatFire™ Belt aspects.

Breaks were highly discouraged after this point until data collection following the end of the test scenario was complete. All participants then engaged in two pre-programmed scenarios. The first scenario was a shooting task followed by the “bombed street” scenario. The modified M4 Carbine rifle was used for all scenarios. For the shooting task, the simulation was a precise representation of an actual outdoor pop-up target facility as was used in the simulation fidelity validation study (Patton and Avery, 2011). Targets appeared at ranges 50m, 100m, 150m and 200 m. This scenario lasted approximately 10 – 15 minutes. Targets remained upright for two seconds with a three-second inter-target interval. There were a total of 24 targets. Participants were in an unsupported standing position for all trials. This scenario was used to familiarize the participants with the weapon and the simulator. After the familiarization, participants were offered a break.

Then they were asked to complete the “right now” form of the MAACL-R and provide a saliva sample. This data collection served as the pre session. Next the participant engaged in the second pre-programmed scenario. The “bombed street” scenario was used to explore the effects of the ThreatFire™ Belt and the level of immersion experienced in the simulator. No practice trials were offered so to better simulate situations and stressors in the field in which Soldiers have little to no advanced knowledge of what the situation might entail. This scenario used all five screens to provide 300 degrees of visibility. The background scene was a computer-generated replication of a bombed street in the Middle East. In the scene were numerous locations where the targets would appear. These targets were videos of real people performing friend (checking wristwatch, lifting a cup or cell phone) and foe (raising a weapon) actions. The scenario ran for 16 - 18 minutes.

All targets were presented one at a time within the various locations across the scene. Each target was presented for 2 seconds. If any target was hit or not fired upon within the 2-seconds, they disappeared. At randomized pre-programmed times (4 or 6 seconds) a new target appeared. Participants were instructed to only shoot at the foe targets. At approximately the 4, 7, 12 and 16-minute marks, a foe target was presented. The foe targets raised a weapon and fired at the participant and were programmed such that the participant could not hit it. This was accomplished by turning off the shot detection in the software. If they were in the shock group this target “shot” at the participant and they received a small shock presented by the ThreatFire™ Belt. All participants in the shock group received a total of four shocks during the simulation. If the participant was in the non-shock group, they did not experience returned threat-fire via a shock for the same 4 targets. After completing the scenario, each participant was instructed to complete the MAACL-R (how you felt during the scenario) and provide a saliva sample. This data collection served as the simulation session. A researcher removed the ThreatFire™ Belt just prior to saliva collection and questionnaire completion. Then the participant moved to the waiting room where they answered the exit survey and presence questionnaire. During this 2-hour recovery time, they continued to wear the LifeShirt™ and were allowed to play games on the x-box, read, step outside, close their eyes, etc. They were instructed 30 minutes prior to the recovery data collection not to eat or drink anything. At the 2-hour mark, each participant provided a final saliva sample and completed the final “right now” version of the MAACL-R. This data collection served as the recovery session. The LifeShirt™ data collection device was switched off and the participant changed back into their regular clothing. At this time, barring any questions, they were released from the study and were free to leave.

4. Results

Due to the nature of a pilot study and the small $n$ acquired, the results presented here are preliminary. Statistical tests of significance were conducted to verify whether the presence of
threat-fire elicited increased arousal and to ascertain its effect on performance.

All analyses of variance (ANOVAs) were mixed design with Group (non-shock vs. shock) as the between-subjects variable and Sessions (pre/during/recovery) as the within-subjects variable for the MAACL-R, salivary amylase, and LifeShirt™ measures. Pre measures were collected just prior to the start of the experimental scenario. The during measures were taken immediately following the experimental scenario. The recovery measures were taken two hours after the experimental scenario. T-tests were performed to investigate differences between groups on immersion.

4.1 Immersion Measures

For purposes of this paper, the immersion data is a total score. A t-test performed on the immersion data did not yield significant difference between groups. The mean for ITQ for the non-shock group is $M = 96.4$, $SEM = 5.38$, and for the shock group is $M = 86.17$, $SEM = 3.18$. The mean of the PQ that reflects participants’ sense of immersion during the simulation for the non-shock group is $M = 84.80$, $SEM = 6.42$, and for the shock group is $M = 96.67$, $SEM = 2.99$. A Pearson bivariate correlation was performed between the ITQ and PQ. The correlation did not show a significant relationship.

4.2 Psychological and Physiological Measures

MAACL-R. A three-way Multivariate Analysis of Variance (MANOVA), Group x Sessions x MAACL-R Subscales, was conducted on the MAACL-R and indicated no significant interactions.

Heart Rate (HR). Due to the small $n$, significance tests were not performed on HR data by Group across Session. Means for HR by Group across Session are presented in Figure 4.

To account for individual variability in HR and RR, the percent change from baseline was calculated and this value was used for the analysis. A t-test conducted on HR scores averaged over the whole simulation period indicate a significant difference between groups $t(9) = -3.255$, $p = .010$. See Figure 5.

Heart Rate Variability (RR). A t-test conducted on RR scores averaged over the whole simulation period indicate a significant differences between groups $t(9) = 3.429$, $p = .008$. See Figure 6.
Salivary Amylase. A two-way Multivariate Analysis of Variance (MANOVA) on salivary amylase as a function of Group x Sessions was performed and did not yield significant results.

Immersion and Arousal. Pearson bivariate correlations were used to investigate the relationship between immersion and arousal. The results for the non-shock group show a positive correlation between pre-immersion (ITQ) and Sensation Seeking during the simulation $r(5) = .945, p = .015$ and a negative correlation with sensation seeking at recovery $r(5) = .956, p = .011$. Anxiety felt during the simulation negatively correlated with post-immersion (PQ) measures, $r(5) = -.884, p = .046$. No other significant correlations were found.

Pearson bivariate correlations by group were performed to investigate the relationship between psychological arousal, as measured by the MAACL-R, and physiological arousal, as measured by HR, RR, and salivary amylase. The results for the non-shock group did not yield significant results. The results for the shock group show a positive correlation between HR and depression $r(5) .819, p = .046$.

4.3 Performance

Analysis of variance performed on the performance data (accuracy of decision to shoot) did not yield significant results between groups.

Discussion

The Army’s experimental need for a safe more operational stressor led the use of a 300-degree immersive simulation with threat of return fire capability. To research this capability as an operational stress, this pilot study investigated the effects of arousal on performance.

Performance data did not seem to be affected by the shock delivered by the ThreatFire™ Belt. One possible reason for this is that only one target was presented at a time and that an indicator sound preceded all targets. This sound alerted the participant to the screen where the target would appear. Further research is needed to investigate target presentation procedures.

Although the t-test performed on the immersion data indicated no significant difference between groups, the means do trend in the expected directions. The shock group’s means increased during the simulation whereas the non-shock group’s decreased. However, the non-shock group reported an increase in feelings to take more risks, as measured by the Sensation Seeking subscale scale of the MAACL-R, during the simulation if they reported higher propensities to immersion. They also reported lower levels of anxiety if they felt more immersed during the simulation. The negative correlation between immersion tendency and risk-taking at the recovery indicate that after the simulation was over, feelings of risk-taking diminished. This result supports the idea that the simulation is immersive. This is also supported by the non-significant result of affect between groups during the simulation. Moreover, the mean levels of affect for both groups are similar to another stressful situation, Special Forces Assessment Selection (Hudgens, Malkin, and Fatkin, 1992).

The correlation data shows that the MAACL-R is sensitive to immersion as shown in previous research using a full-spectrum (e.g., pre-deployment, deployment) training simulation (Dixon, Patton, Fatkin, Grynovichki, and Hernandez, 2006).

The authors understand that this group of participants was not a homogeneous group and many lacked any experience with firearms while others were proficient. Therefore, future research needs to be performed with a homogeneous group such as military personnel or police officers. Another possible reason that significance was not reached on some tests may be because the “bombed street” background was computer generated and only one target was presented at a time. It may be worth investigating the other types of backgrounds available (i.e., video and real photos) or the influence of multiple targets on performance in a shoot-don’t-shoot simulation under stress.
References


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