BIOMARKER-ENHANCED FREE-ROAM VR TECHNOLOGY FOR TACTICAL TRAINING

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Abstract - **This paper describes the first trial of a free-roam virtual reality (FRVR) technology for military training. Eight infantry soldiers performed a series of VR-simulated room clearance tasks modelled on their live tactical training. The participants performed the tasks in pairs and could see each other's avatars and interact in VR. The complexity/stressfulness of the task was manipulated by altering the number of civilian and opposing-force avatars in the scenario and by triggering explosions of improvised explosive devices (IEDs). Immersion in combat-based FRVR scenarios resulted in robust and reproducible increases in heart and respiratory rates, compared to both resting baseline and non-tactical walk-through conditions. These results indicate that FRVR technology is capable of provoking significant stress response comparable with existing combat training modalities. Repeated exposure to the same FRVR scenarios over five days reduced the cardiac and respiratory responses, thus indicating the utility of FRVR for exposure-based combat stress inoculation training, with biometrics enhancing its capacity to track training gains and measure its overall effectiveness.**

Keywords – free-roam VR, heart rate, respiratory rate, military training.

I. INTRODUCTION

Training of military personnel is a multifaceted and complex task, which relies primarily on building a combatant's experience base before exposing them to the rigors of combat. The utility of immersive technologies was recently demonstrated by US SECDEF, General Jim Mattis who in standing up a task force to improve Infantry training expressed his vision for the infantry "to fight 25 bloodless battles" before they enter combat (Freedberg, 2018). It is long recognised by Defence that there is a mismatch between extensive physical/weapon training and relatively limited focus on developing stress-management and other mental skills (Moss, 2017).

Deployment in the zones of military conflicts or natural disasters places personnel in situations where they are repeatedly exposed to highly stressful and traumatic events. While the prevalence of stress-related mental health problems (such as post-traumatic stress disorder, PTSD) in Defence personnel has been attributed to military deployment, epidemiological evidence indicates that primary risks of PTSD are linked to combat-exposure, rather than deployment itself (Smith, Ryan, Wingard, Slymen et al., 2008). On the other hand, sub-optimal training methods have been implicated in the risk for personnel to "succumb to the stress of combat, respond inappropriately, and place themselves at greater risk of becoming a casualty and incurring PTSD" (Flanagan, Kotwal & Forsten, 2012). This emphasises the priority of programs aimed at enhancing psychological resilience such as Australian Army's BattleSMART (Moss, 2017). While BattleSMART plays an important role in introducing stress-management skillset, it offers little opportunity to practice and consolidate the learned skills.

Stress inoculation through conditioning, in addition to focussed and controlled physical training, is one of the major approaches for enhancing cognitive resilience (Asken, Christensen, Grossman, 2011). However, creating highly stressful training scenarios in the real world can result in high levels of administration and low levels of repeatability resulting in low return on investment. Rapidly expanding virtual reality (VR) technology might represent a promising solution for this problem, The utility of VR scenarios in this context depends on their capacity to induce stress. Surprisingly, recent effort to create a highly stressful VR environment produced rather modest stress-related physiological changes (Binsch, Bottenheft, Bottenheft, Boonekamp & Valk, 2017) suggesting that it may not be sufficient for stress inoculation purposes. One potential reason for such a weak stress-inducing effect observed by Binsch et al. (2018) was their use of tethered VR technology, with trainees remaining seated during the sessions. The free-roam VR (FRVR) was chosen for the current study to provide a more challenging training environment that we expected to produce deeper immersion/engagement and higher stress levels. The current trial was designed to examine whether exposure to combat-based FRVR scenarios can elicit a measurable, dose-dependent stress response.

II. METHODS

A. *Free-roam virtual reality technology*

In contrast to tethered VR systems, FRVR allows participants to move around the dedicated space, with accurate real-time spatial tracking of their bodies and weapons. FRVR environment developed by Zero Latency (ZL) consists of an array of video cameras positioned 3.0 m above the 20m x 20 m open floor grid. Tracking is achieved by monitoring position of LCD markers attached to the participant's head-mounted display (HMD) and to their simulated weapon, against the floor grid. Position updates are wirelessly transmitted to laptop computers located in participants' tactical backpacks to generate the VR content fed into their HMDs (Fig. 1).

Fig. 1. Photo of a participant engaged in a FRVR tactical training. LCD markers attached to the HMD and to the simulated weapon allow tracking of the body and the weapon position. Backpack contains a computer that is wirelessly connected to a central server and generates VR fot the HMD.

B. *Hardware and systems integration*

EquiVital telemetric system (Hidalgo, UK) was used to acquire biometric signals. It includes chest belts with embedded biosensors connected directly to a removable data logger with a Bluetooth data transmitter. Biometric data was streamed directly into LabChart 8.0 (ADInstruments, Sydney, Australia) using a USB Bluetooth receiver. The ZL system code was adjusted so that the automatically generated comments for each participants (i.e. muzzle breaches, accuracy of direct fire, threat engagements etc.) was sent from the ZL server to the EquiVital data acquisition computer. All FRVR scenarios were conducted in an enclosed 20m x 20m area. Despite the spatial displacement across such a large area, no notable dropout in wireless acquisition of the biometric data was observed.

C. *Participants and trial protocol*

The trial protocol was approved by the University of Newcastle Human Ethics Committee. Eight infantry soldiers participated in the trial. They signed an informed consent prior to the trial onset. After fitting with telemetric belts, participants were split in pairs. Each pair performed a tactical task, which specifically involved the clearing of an array of rooms within a simulated house. The participants could see each other's avatars and interact in VR. The complexity/stressfulness of the task was modified by a trainer by altering the number of civilian and enemy avatars in a scenario and/or by triggering explosions of IEDs. Each pair performed the same virtual task over five consecutive sessions (runs) separated by 5-min intervals. During Run A participants performed a warehouse walk-through. They were instructed that Run A was a non-tactical, environment familiarisation task. Run B was a tactical task with few enemies; Run C - tactical task with few civilians and many enemies; Run D - tactical task with few enemies and many civilians; Run E – same as D but with additional "live" enemy whose role was played by another participant.

D. *Data analysis*

Heart rate and respiratory rate were computed online from ECG R-waves and from the peaks of respiratory signal, respectively. One-way ANOVA was used for assessing statistical differences between baseline and each of the runs, and between stress-free Run A and Runs B-E; the latter procedure served to exclude the confounding effects of physical activity on the measured variables. Data values were considered significantly different at $p<0.05$.

III. RESULTS

The wireless data acquisition system used in this trial allowed long-term recording of excellent quality signal that was not affected by operating Zero Latency network. Wireless data transmission (max distance evaluated = 30m) was robust and reliable, with only 2 drop-offs during total recording time of ~35 hours. There was a negligible number of motion artefacts on ECG signal, and virtually no artefacts on respiratory signal indicating that the system's integrity can be maintained within the settings of FRVR training.

Our primary focus in the current trial was heart rate (HR); it was recorded at the beginning of each run (baseline), during the run and during recovery. Fig. 2 summarises the dynamics of HR obtained during the first day of training; it shows HR values averaged across the analysed periods (i.e. at baseline and during each run). At baseline, HR was 77±6 beats per min (bpm); during stress-free Run A, HR trended up to 88±7bpm ($p=0.15$). In contrast, HR was substantially and significantly higher than baseline for stress-associated tasks, being 113±8 ($p=0.0035$), 116±8 ($p=0.0037$), 119±7 ($p=0.0018$) and 120±7 ($p=0.022$) bpm during Run B-E, respectively. Likewise, these were significant differences between HR value during no-stress Run A and each of stress-related runs.

Respiratory rate largely followed the observed changes in HR – see Fig 3. At baseline, respiratory rate was 17.7±0.8 cycles per min (cpm); during the stress-free Run A it has a near-significant tendency to increase to 21.6±1.8 cpm ($p=0.07$). In contrast, respiratory was substantially and significantly higher than baseline for stress-associated tasks, being 26.5±1.4 ($p=0.0002$), 28.9±1.1 ($p<0.0001$), 28.8±1.0 (p $p<0.0001$) and 29.5±1.0 ($p=0.0001$) bpm during Run B-E, respectively. Likewise, there was significant difference between respiratory value during no-stress Run A and each of stress-related runs, with p values of 0.0026, 0.0017, 0.0121and 0.01 for Runs B-E respectively. Lastly, the respiratory rate was significantly higher for Run C compared to Run B ($p=0.044$).

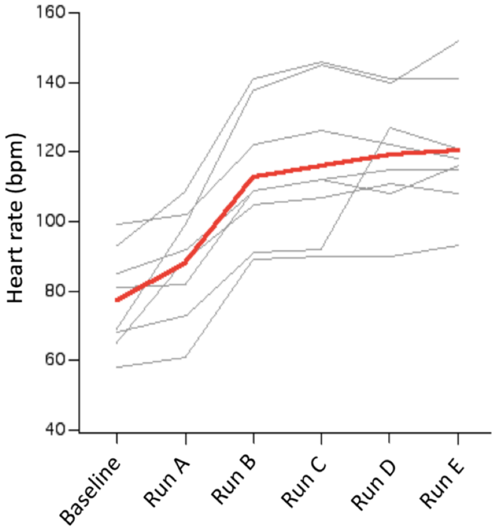

Fig. 2. HR and at Baseline, the "no stress" task (Run A) and stressful tasks (Runs B-E). Grey traces – individual data; red trace – averaged data from 8 participants during Day 1.

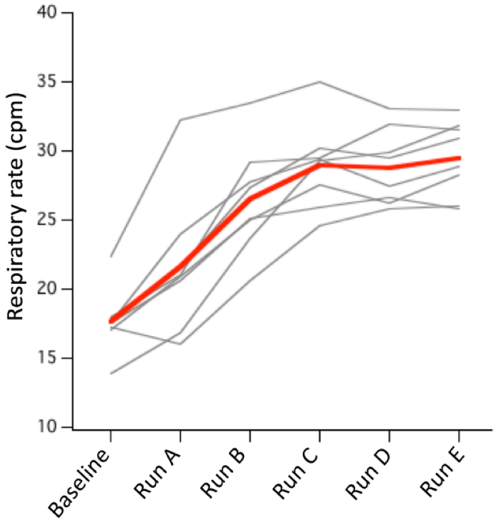

Fig. 3. Respiratory rate at Baseline, the "no stress" task (Run A) and stressful tasks (Runs B-E). Grey traces – individual data; red trace – averaged data from 8 participants during Day 1.

We also tested whether FRVR training could reduce physiological arousal. For this purpose, we compared changes in HR and respiratory rate that occurred during Day 1 vs. Day 5 of training. As shown in Fig. 4, repetitive exposure to training resulted in reductions of HR rises. Specifically, we observed that during Run A (no stress), HR increase changed from +10.9±3.8 to +3.1±1.6 bpm (a reduction of ~7 bpm, p=0.067). In Run C (mild stress condition) we observed a highly significant reduction in tachycardic responses from +41.9±6.4 to +24.7±3.5 bpm (a reduction of ~16 bpm, p=0.01) and in Run E (high stress) from +44.1±7.3 to 25.6±3.9 bpm (a reduction of ~19 bpm, p=0.004).

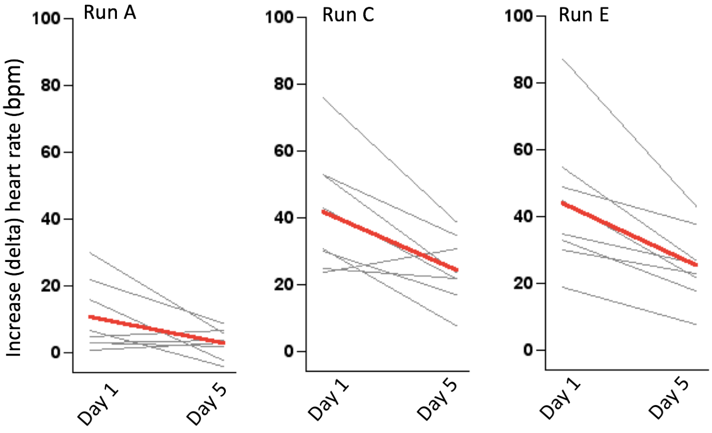

Fig. 4. FRVR training reduces cardiac acceleration (shown as deltas) during execution of tactical task (building clearing). Grey traces – individual data; red trace – averaged data from 8 participants during Day 5.

We have conducted similar analysis on respiratory data and found an even more significant effect of FRVR training (Fig. 5). Repeated exposure to training scenarios resulted in a reduction in tachypnoeic responses during Run A (no stress) from +3.9±1.1 to +1.6±0.7 cpm (p=0.1), and to a highly significant reduction during Run C (middle stress) from +11.3±0.9 to +6.4±0.6 bpm (p=0.002) and during Run E (high stress) from +11.8±1.0 to 6.3±0.5 bpm (p=0.0006).

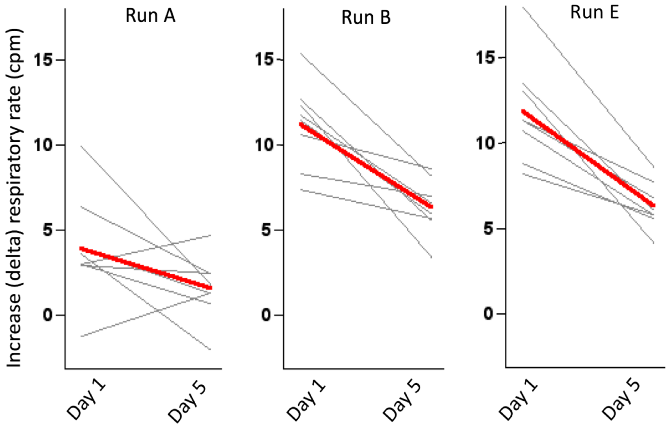

Fig. 5. FRVR training reduces rises in respiratory rate (shown as deltas) during execution of tactical task (building clearing). Grey traces – individual data; red trace – averaged data from 8 participants during Day 5.

IV. DISCUSSION AND CONCLUSIONS

Current trial represents the first attempt to incorporate biometric approach into military training based on the free-roam VR technology. The latter allows to reproduce in the most naturalistic yet safe way various combat environments. Repetitive exposure to such combat stressors forms the basis of stress inoculation – a well-recognized psychological approach for enhancing cognitive resilience ((Asken, Christensen, Grossman, 2011).

Recent study where physiological parameters were monitored during scenarios presented with a tethered VR technology revealed that in this case level of autonomic arousal was rather minimal (Binsch et al., 2018). In contrast, in our trial we have observed robust and reproducible cardiac and respiratory responses indicating that FRVR technology is capable of provoking substantial levels of stress. Importantly, since physical activity alone may cause increases in heart and respiratory rates, it is of note that increases in both variables during our stressful scenarios were found not only compared to baseline but also compared to stress-free walking. This analysis enabled us to control for confounding factor of physical activity. A direct comparison between the levels of stress response induced by FRVR and comparable scenarios delivered through existing training modalities, appears worth investigating in the future.

Another important finding was that the stress-provoking potential of FRVR scenarios could be altered by intentionally modifying their content. The computer interface developed by ZL allows such modifications to be performed during training sessions, and this represents a valuable option to adjust the provocative potential of a scenario according to individual stress sensitivity. Finally, repetition of FRVR training over five days resulted in substantial attenuation of cardiac and respiratory responses in most participants. This was an expected result of exposure to stressful contents; it provides initial evidence of the efficacy of FRVR as a stress inoculation intervention. To what extent additional instruction in arousal regulation and other psychological skills can enhance this repeat-exposure effect seems worth future investigation.

While the small number of participants (N=8) was a substantial limitation of this pilot trial, its robust results suggest that FRVR training is sufficiently immersive and engaging, and in combination with biometrics may offer a considerable technological advantage in combat stress inoculation training. To demonstrate that stress inoculation effects of FRVR are meaningful and useful, future studies should be conducted, with larger number of participants and with direct comparison of FRVR to “traditional” VR technology; they should also clarify whether these effects persist over time, and whether they generalise outside the FRVR system.

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