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Teaching stress management skills to soldiers

A virtual reality approach

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Technical Report
DRDC Valcartier TR 2013-057
April 2013

Canada

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This document results from S&T work conducted under DRDC project 14da (Psycho-physiological Readiness). In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

Abstract

There is a strong movement in the military to implement programs that foster mental resilience and readiness. One key ingredient in these programs is stress management training (SMT). Traditional approaches to training are limited because of the lack of practice of the skills in stressful situations and of resistance with approaches related to emotion. Virtual reality (VR) and video games (VGs) can help to overcome such limitations; these technologies are appreciated by their users and their effectiveness for training is proven. This report presents the results of a three-year research project on creating and assessing the efficacy of an immersive VG-based training system augmented with biofeedback (Immersion and Practice of Arousal Control Training; ImPACT) for learning to master SMT. Aspects discussed include a review of SMT and the validation of the potential of VGs and VR to induce stress. Also presented are the possible designs for adding biofeedback to VGs. This report concludes with a randomized control trial of ImPACT. Statistical analyses of the heart rate (HR) and salivary cortisol revealed significantly less stress for soldiers trained with ImPACT than those trained as usual. In addition, soldiers trained with ImPACT performed better and were more confident in their stress coping skills. The immersion in a stressful VG, coupled with biofeedback, was shown to be more effective than training as usual and it has the additional advantage of favouring the "buy-in" of emotion management by soldiers. More studies could be conducted to refine ImPACT. In the meantime, the Canadian Forces (CF) should consider implementing this approach on a larger basis.

Résumé

On note une vague de popularité dans les milieux militaires à implanter des programmes ciblant la résilience psychologique. L'utilisation de techniques de gestion de stress (TGS) demeure un concept clé dans ces programmes. Toutefois, les approches traditionnelles souffrent de l'absence de pratique dans des situations stressantes ainsi qu'une certaine aversion pour les approches liées aux émotions. La réalité virtuelle (RV) et les jeux vidéo (JV) peuvent aider à combler de telles lacunes. Ces technologies sont appréciées et ont démontré leur efficacité pour l'entraînement. Ce rapport présente les résultats d'un projet de recherche de trois ans sur la création et la validation d'une plateforme d'entraînement immersive basée sur les JV et augmentée de bio-rétroaction (Immersion and Practice of Arousal Control Training; ImPACT) afin d'enseigner les TGS. Les éléments présentés inclus une validation de l'efficacité des TGS et du potentiel de certains JV et de la RV à induire du stress suivis. Une analyse d'options sur l'extension des JV avec la bio-rétroaction est également présentée. Ce rapport conclu avec un essai clinique aléatoire d'ImPACT. Les analyses statistiques du rythme cardiaque et du cortisol salivaire ont révélé un stress significativement plus bas pour les soldats entraînés avec ImPACT en comparaison avec ceux entrainés comme d'habitude. Aussi, les soldats entraînés avec ImPACT ont mieux performé et ont développé une plus grande confiance à appliquer les TGS. L'immersion dans un jeu vidéo stressant étendu avec de la bio-rétroaction a été plus efficace que l'entraînement théorique habituel et comporte l'avantage d'être plus attrayante comme outil de régulation émotionnelle pour la population militaire. Des recherches complémentaires pourraient être effectuées pour affiner ImPACT, mais entre temps, les Forces Canadiennes se doivent de considérer l'implantation de cette approche à plus grande échelle.

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Executive summary

Teaching stress management skills to soldiers: a virtual reality approach

François Bernier; Stéphane Bouchard, Éric Boivin; DRDC Valcartier TR 2013- 057; Defence R&D Canada – Valcartier; April 2013.

Introduction or background: There is a very strong movement in the military to implement programs that foster mental resilience and readiness. One key ingredient in these programs is the use of emotion regulation tools such as stress management training (SMT). Traditional approaches to training are limited because of the lack of practice of the skills in stressful situations and of soldiers' resistance to approaches related to emotions. Virtual reality (VR) and video games (VGs) can provide a solution to these problems. These technologies are popular and have shown to be effective in many similar contexts like PTSD treatment and the acquisition of military skills. This report presents a three-year research project on creating and assessing the effectiveness of an immersive VG-based training system augmented with biofeedback (Immersion and Practice of Arousal Control Training; ImPACT) for learning to master SMT.

Results: A systematic literature review confirmed that SMT is effective to regulate stress and anxiety, even in cases of acute stress. Then, another literature review and two experiments confirmed the potential of stressful VGs and VR to induce stress for training. More precisely, a first experiment showed that low-cost recent VR technologies and some commercial VGs can induce moderate stress. A second experiment found that empathy caused by a realistic suffering avatar is able to induce stress, though using the avatar of a known person is no more stressful and therefore not essential for inclusion in a VG used for SMT. Additional investigations revealed that although there are plenty of available options to implement a training system in an existing VG, the openness of the VG dictates what is feasible. Biofeedback can incorporated into the VG, but there are no straightforward recipes available yet.

A randomized control trial with 41 soldiers tested whether ImPACT would increase the efficacy of SMT compared to usual training (a 15-minute refresher session). ImPACT training consisted in three daily sessions to practice SMT while using biofeedback to provide information on current level of arousal and while being immersed in a VG to induce stress. All soldiers had to accomplish a stressful first aid scenario so that their stress coping skills could be assessed. Statistical analyses of the heart rate (HR) and cortisol levels revealed significantly less stress among soldiers who have trained with ImPACT. In addition, these soldiers performed better and were more confident in their stress coping skills. As a result, they are more likely to apply tactical breathing in the future. Finally, a survey confirmed the attractiveness of ImPACT for users.

Significance and future plans: It is doubtful that limiting the training of military personnel to teaching SMT in a classroom would be sufficient to master SMT techniques. Practice when dealing with stressors is essential; yet it may be insufficient unless there is objective information about the level of arousal and the immediate impact of the technique. The immersion in a stressful VG, coupled with biofeedback, was shown to be more effective than training as usual and it has the additional advantage of favouring the "buy-in" of emotion management tools by soldiers. Studies could be conducted to refine ImPACT but, in the meantime, the Canadian Forces (CFs) should consider implementing this approach on a larger basis.

Sommaire

Teaching stress management skills to soldiers: a virtual reality approach

François Bernier; Stéphane Bouchard, Éric Boivin; DRDC Valcartier TR 2013- 057; R & D pour la défense Canada – Valcartier; avril 2013.

Introduction ou contexte: On note une vague de popularité dans les milieux militaires à implanter des programmes ciblant la résilience psychologique. L'utilisation d'outils de régulation émotionnelle tels que l'enseignement de techniques de gestion de stress (TGS) demeure un concept clé dans ces programmes. Toutefois, les approches traditionnelles sont limitées en raison de l'absence de pratique dans des situations stressantes ainsi qu'une résistance des soldats face aux approches liées aux émotions. La réalité virtuelle (RV) et les jeux vidéo (JV) peuvent aider à résoudre de telles limitations. Ces technologies sont appréciées et ont démontré leur efficacité dans des contextes similaires comme le traitement du PTSD et le développement d'habilités militaires. Ce rapport présente un résumé d'un projet de recherche de trois ans sur la création et la validation d'une plateforme immersive basée sur les JV et augmentée de bio-rétroaction (Immersion and practice of arousal control training; ImPACT) afin d'enseigner les TGS.

Une revue de littérature systématique a d'abord confirmé que les TGS sont efficaces pour réguler le stress et l'anxiété, même lors de stress aigu. Ensuite, une revue de littérature et deux expérimentations ont confirmé le potentiel de certains JV et de la RV afin d'induire du stress lors de l'entraînement. Plus précisément, une première expérience a montré que les technologies peu dispendieuses et récentes de RV ainsi que certains JV commerciaux peuvent induire un stress modéré. Une seconde expérience a montré que l'empathie causée par un avatar réaliste en souffrance peut induire du stress, quoique le fait d'utiliser une personne connue comme avatar ne soit pas plus stressant et donc pas essentielle à intégrer dans un programme de JV pour maitriser les TGS. Des investigations supplémentaires ont révélé le large éventail d'options pour implanter une plateforme d'entraînement dans un JV. Cependant, l'ouverture du JV reste la principale contrainte. Finement, la bio-rétroaction peut être ajoutée à des JV mais il n'existe présentement pas de méthode standard pour y arriver.

Un essai clinique aléatoire avec 41 soldats a testé si ImPACT augmente l'efficacité des TGS en comparaison avec l'entraînement habituel (une session de rappel de 15 minutes). L'entraînement avec ImPACT incluait trois sessions quotidiennes pour pratiquer les TGS tout en étant immergé dans un JV stressant et en utilisant de la bio-rétroaction. Après l'entraînement, tous les soldats ont dû se soumettre à un scénario stressant de premiers soins afin d'évaluer leurs aptitudes de gestion du stress. Les analyses statistiques du rythme cardiaque et du cortisol salivaire ont révélé un stress significativement plus bas pour les soldats entraînés avec ImPACT. Également, les soldats du groupe ImPACT ont mieux performé et ont développé une plus grande confiance dans leurs TGS. Un sondage auprès des soldats a confirmé l'attrait d'ImPACT.

Importance et perspectives: Il est difficile de croire que limiter l'entraînement aux techniques de gestion de stress à des présentations théoriques suffit pour maîtriser ces techniques. La pratique en contexte stressant s'avère essentielle; elle peut néanmoins demeurer insuffisante si elle n'est pas combinée à de l'information objective sur le niveau d'excitation physiologique afin d'éclairer

l'impact immédiat de la technique. L'immersion dans un jeu vidéo stressant, combinée à un appareil de bio-rétroaction, a été démontrée comme étant plus efficace que l'entraînement théorique habituel et comporte l'avantage d'être plus attirant comme outil de régulation émotionnelle pour la population militaire. Des recherches complémentaires pourraient être effectuées pour affiner le programme, mais entre temps, les Forces Canadiennes se doivent de considérer l'implantation de cette approche à plus grande échelle.

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1 Introduction

1.1 Mental resilience

Theatres of operations expose Canadian Forces (CF) members to the physiological and psychological consequences of chronic stressors and, for some of them, to potentially traumatic events. Stressful situations could impede the operational effectiveness and potentially lead to operational stress injuries such as post-traumatic stress disorder (PTSD) (Hoge et al., 2004). A report of the Standing Committee on National Defence (Bernier, 2009) revealed that 13 percent of the 8222 CF members returning from Afghanistan responded to a survey in a manner consistent with any mental health diagnostic and 4 percent responded in a manner consistent with PTSD diagnostic. Military personnel has to be prepared to cope with combat stress.

Mental resilience (i.e., the capacity to withstand, cope or recover from stress and adversity) (Davydov, Stewart, Ritchie, & Chaudieu, 2010; Masten, 2007; Reivich, Seligman, & McBride, 2011; Rutter, 1987) is now receiving significant attention in the United States, as illustrated by an opening article for a special issue of *American Psychologist* by the U.S. Army Chief of Staff, General George W. Casey (Casey Jr, 2011). In Canada, report from the CF (Zamorski, Jetly, & Jung, 2010) on suicide prevention points out the potential of stress inoculation therapy (training) to prevent the effect of work stress, especially prior to an upcoming anxiety-provoking event. Related concepts have been discussed in the literature, such as mental readiness (Thompson & McCreary, 2006), mental toughness (Murphy & Cohn, 2008), or emotional resilience (Algoe & Fredrickson, 2011). Soldiers are frequently exposed to traumatic events and acute stressors, which is associated with considerable rates of post-traumatic stress symptoms. Research has consequently been increasingly focused on the prevention of the negative effects of trauma exposure in soldiers. It is believed that fostering better resiliency in soldiers could not only positively improve their ability to cope with stress, but also reduce psychological wounds in the end and augments their performance in theatres of operations.

Mental resilience draws on factors such as emotion regulation (i.e., the ability to regulate positive and negative emotions; Algoe & Fredrickson, 2011) and, in a broader sense, self-regulation (i.e., "the ability to regulate impulses, thinking, emotions, and behaviours to achieve goals, as well as the willingness and ability to express emotions", Reivich et al., 2011, p. 27). Building psychological strength before being deployed implies building psychological fitness and learning to manage emotions more positively, efficiently and with flexibility (Casey Jr, 2011; Cornum, Matthews, & Seligman, 2011; Kashdan & Rottenberg, 2010).

Training in the use of coping skills is important, and not only because it might reduce the risk of developing PTSD and other psychological injuries. It can also mitigate the effect of stress and anxiety on the operational effectiveness (Castro, Adler, & Britt, 2006). Anxiety, acute stress or operational stress affect information processing, including focus of attention, sensitivity to certain peripheral cues, memory recall and encoding. It also directly influences physiology (e.g., trembling, loss of fine motor skills) and emotion regulation, and thus has a strong impact on performance in situations requiring emotional, cognitive and behavioural control such as military operations (Thompson & McCreary, 2006).

Increasing resilience through the acquisition of self-regulation or, more narrowly, emotion regulation skills, are common objectives for psychological training programs aimed at military personnel. A few prevention programs have already been developed for soldiers and military personnel to build resilience and avoid psychological injuries, including Battlemind Training in the U.S. (Adler, Bliese, McGurk, Hoge, & Castro, 2011), Road to Mental Readiness (R2MR) in Canada (Guest & Bailey, 2011), and *Programme d'Entraînement à la Resilience Militaire* (PERM; Routhier, 2007).

1.2 Existing resilience programs

In Canada, the R2MR program (Guest & Bailey, 2011) aims at preventing psychological injuries related to operational stress and at improving resilience both in theatres of operations and in garrison. It is composed of different modules that target the soldiers, their superiors, spouses and life-partners, and mental health professionals. The program is based on a cognitive-behavioural / bio-psychosocial approach and includes numerous stress management training (SMT) strategies, namely goal setting, diaphragmatic and controlled breathing, mental rehearsal/visualization, and self-talk. The key learning objectives are understanding stress reactions, identifying challenges of deployment and their impact, learning and applying strategies to mitigate the impact of stress, and recognizing when and where to seek support.

In the U.S., one of the first largely implemented mental preparedness programs was Battlemind (Adler et al., 2011). Developed by the Walter Reed Army Institute of Research, it aimed at mentally preparing soldiers to the rigours of combat and other military deployments in order to foster better mental health post-deployment. This program is now being replaced by a new one that integrates some aspects of Battlemind but that focuses even more on resilience as a mean of prevention, with a stronger influence from positive psychology[1]: the Comprehensive Soldier Fitness program (Cornum et al., 2011).

The main goal of the Comprehensive Soldier Fitness program is to enhance psychological resilience in members of the Army community. This program not only focuses on the prevention of psychological disorders in soldiers but also aims at enhancing psychological strengths already present in military personnel (Casey Jr, 2011; Cornum et al., 2011). More specifically, this program is being implemented with the goal of increasing psychological growth following combat exposure for an increased number of soldiers and of decreasing the number of soldiers who develop disorders related to stress (Cornum et al., 2011). This program promotes a holistic approach that focuses on five dimensions associated with resilience: physical, social, emotional, spiritual, and familial (Casey Jr, 2011). It is delivered in four major modules: (a) online self-assessment that allows the identification of resilience strengths; (b) online self-help modules adapted to each soldier in regards to the results of the self-assessment (individualized training); (c) mandatory resilience training upon the initial entry into the U.S. Army; (d) training of master resilience trainers who will, in turn, be in charge of training in resiliency.

The module on master resilience trainers of the Comprehensive Soldier Fitness program is already being implemented (Reivich et al., 2011). It is divided into three components that take place in a 10-day program: preparation, sustainment, and enhancement. The preparation component, which

[1] Positive psychology aims at making normal life more fulfilling, instead of focussing on treating mental illness.

is the main part of this program, focuses on four modules: resilience, building mental toughness, identifying character strengths, and strengthening relationships. In every module, diverse activities are utilized to assure a better understanding of this new information. For instance, each module starts with a brief didactic presentation and continues with activities like discussions, role plays, and exercises that allow participants to put into practice newly acquired skills. Sustainment and enhancement components are added as a way to prepare for future use of the new techniques by allowing trainees to identify difficulties in their resilience skills. The entire Comprehensive Soldier Fitness program is now being empirically tested in outcome trials (Lester, McBride, Bliese, & Adler, 2011).

1.3 Limitations of current training methods

The typical (standard) training method used to acquire the emotion regulation skills in the Road to Mental Readiness, PERM, and Comprehensive Soldier Fitness programs relies essentially on didactic seminars and short demonstrations in a classroom. Although the teaching method for the Comprehensive Soldier Fitness may differ slightly from the Canadian program (Algoe & Fredrickson, 2011; Cornum et al., 2011), SMT is not practiced under stress. SMT is the application of any set of techniques aiming to improve how people cope with stress. Coping represents efforts to manage demands, conflicts, and pressures that drain or exceed a person's resources (Lazarus & Folkman, 1984).

As a set of techniques, SMT has been shown to be effective to control stress and reduce its negative impact (Bouchard, Guitard, Bernier, & Robillard, 2011). The techniques used in SMT differ greatly from one program to another, ranging from prayer (Oman, Flinders, & Thoresen, 2008) to problem solving (Timmerman, Emmelkamp, & Sanderman, 1998) and diaphragmatic breathing (referred to as tactical breathing by Grossman & Christensen, 2008). Some strategies have received very strong empirical support, especially progressive exposure or "inoculation" to stressful stimuli, relaxation, biofeedback, diaphragmatic, and other breathing techniques and cognitive restructuring (Bouchard, Guitard, et al., 2011). Like the acquisition of any new skill, SMT is difficult to master in a stressful situation, and therefore repeated practice is important, usually over several training sessions (O'Donohue & Fisher, 2009; Oman et al., 2008; Wolpe, 1990). The exact number of sessions or hours of training remains undefined, but attaining a performance-based criterion appears to be optimal (e.g., reaching a pre-defined level of stress control or perceived self-efficacy) and is usually the standard in psychotherapeutic applications (O'Donohue & Fisher, 2009). Nevertheless, in mental resilience programs delivered in the military, training as usual does not involve rigorous practice.

Restricting teaching psychological coping skills to lectures and role-plays, no matter how long it may be, can hardly be sufficient to lead to effective use of the techniques, especially in stressful situations (Bouchard, Guitard, et al., 2011). Like any behavioural skill, learning in theory how to use a skill transfers very poorly to actual behaviour change in difficult and challenging situations. How can someone become efficient to manage stress if he or she never practices in a stressful situation? First, the basic principle for effective learning of a coping skill is to teach and explain the strategy, second to practice coping skill in a simple situation, and finally to progress to more and more challenging situations (O'Donohue & Fisher, 2009; Thompson & McCreary, 2006; Wolpe, 1990). It is important to note however that practicing SMT or emotion management skills requires inducing stress, which may be difficult to recreate in didactic settings and role-plays in a classroom.

In addition to the need for practice, another important challenge in the implementation of SMT and emotion regulation skills is the soldiers' potential resistance to practice and use tools developed to deal with emotion self-regulation. In a report by the Mental Health Advisory Team 6 (2009), over half of the soldiers surveyed reported that they believed seeking psychological help would lead to their being perceived as weak. In addition, almost half of the sample felt that, had they required help for a psychological problem, their unit leader might have treated them differently and members of their unit would have had less confidence in them. Although this data focuses more on seeking treatment than using prevention tools, it fits well with current knowledge in masculine gender role (Wexler, 2009). In accordance with well described and documented male socialization processes (Good, Thomson, & Brathwaite, 2005; Good et al., 2005; Levant & Pollack, 1995) and implicit masculine standards in the military culture (Casey Jr, 2011; Green, Emslie, O'Neill, Hunt, & Walker, 2010; Rosen, Weber, & Martin, 2000), soldiers may very likely be reluctant to practice and use skills developed for the purpose of regulating emotions.

Video games (VGs) and immersive technologies such as virtual reality (VR) provide an interesting solution to the problems of soldiers not buying-in and being non-compliant with the practice of SMT (Bouchard, Guitard, et al., 2011; Stetz et al., 2007; Thompson & McCreary, 2006). Since a significant percentage of soldiers play VGs (Orvis, Moore, Belanich, Murphy, & Horn, 2010), VG technology may be well accepted in this population. In addition, the fact that VG and VR technologies have repeatedly demonstrated their effectiveness in similar contexts like the treatment of PTSD (Wiederhold & Wiederhold, 2008) and the acquisition of military skills (Hays, 2005; Langkamer Ratwani, 2010; Nullmeyer, Spiker, Golas, Logan, & Clemons, 2006; Roman & Brown, 2008) strengthens confidence in the proposed approach. It was clear at the early stage of the project that the level of stress induced by VGs would be lower than the most acute situation of stress experienced in theatre of operation. VGs reproduce fictional situations and the amount of stress induced by these situations is likely to remain under those experienced in theatre of operation. VR can compensate for the artificiality of the situation by augmenting the level of realism perceived by the soldiers. Nevertheless, learning to cope in a low to moderate level of stress may be transferable to a higher level of stress and if not, it would be useful for dealing with chronic stress. The final experiment covers some of these aspects.

1.4 Stress management training project

The VR-Based SMT project has been carried out by a team of scientists from Defence Research and Development Canada (DRDC) – Valcartier and the Université du Québec en Outaouais (UQO) from June 2008 to March 2011 under the work unit 14da01. The purpose was to investigate the potential of VR and VGs in training military personnel to cope with stress. This project was composed of four main tasks and five sub-tasks as illustrated in Figure 1.

During the first three months of the project (end of the financial year), literature reviews (Bouchard, 2009; Bouchard, Guitard, et al., 2012; Bouchard, Baus, Bernier, & McCreary, 2010) gathered the information required to set down the foundations of the project. Throughout the second financial year, two exploratory experiments (Monthuy-Blanc, Bouchard, Bernier, Boivin, & Robillard, 2011; Bouchard, Bernier, & Boivin, 2011; Bouchard, Bernier, et al., 2012) were designed and conducted to test various approaches for developing a training system. During the last year, the training system was designed, implemented, and validated experimentally.

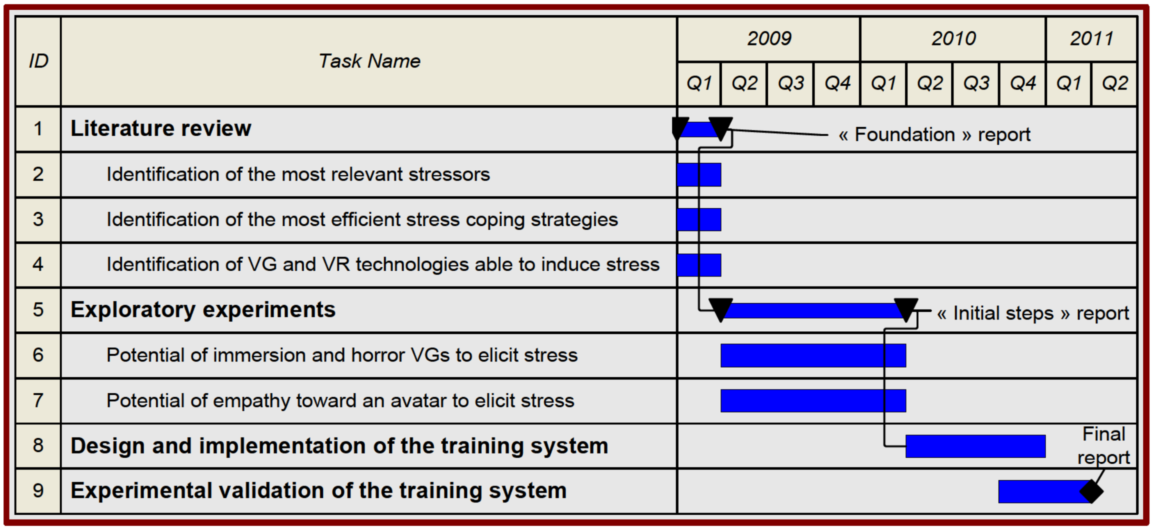

Figure 1: SMT 14da01 project Gantt chart.

This report summarises the principal findings of the 14da01 project. The reader is invited to consult previously published reports and papers for more details. These publications are cited in due course in the following chapters. The current report is organized as follows. First, Chapter 2 presents the conceptual view, the objectives of the training system, and the coping strategies. It also identifies potential solutions. Chapter 3 is devoted to the main findings of literature reviews (tasks 2, 3, & 4) and exploratory experiments (tasks 6 & 7) that were conducted for defining a virtual environment sufficiently stressful for training. Chapter 4 covers the design options and recommendations on challenging technical aspects, more precisely on biofeedback and VG modification (first part of the task 8). Chapter 5 describes the implementation architecture, implementation and training procedure of the training system (task 8). Chapter 6 presents the experimental validation of the training system (task 9). Finally, Chapter 7 concludes with a summary of the main findings and future work.

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2 Biofeedback-assisted training in VR

Biofeedback-assisted training consists in informing a trainee about his physiological response to a stressor so that he may learn to regulate his level of physiological arousal. Conducting such activity in a VG augmented with VR presents many advantages. First, the VG can provide stressful content whilst VR technology conveys it efficiently to the trainee. Second, when military personnel receive biofeedback in the virtual environment, they can be coached and practice coping strategies until they are mastered and their perceived self-efficacy is high. Other advantages of using virtual environment include increased motivation, affordability, manageable stress, and a high level of engagement.

The first section of this chapter presents the objectives of such an approach. Next, existing solutions with similar purpose are described. Since none of these solutions fulfils the required needs, a new concept called Immersion and practice of arousal control training (ImPACT) is proposed. Then, a literature review on the efficacy of coping strategies is conducted. This chapter concludes with a list of important questions to tackle before implementing ImPACT.

2.1 Training objectives

As mentioned in Chapter 1, two main limitations affect current resilience building programs: lack of practice and of interest by the military personnel. For overcoming these limitations, a training system should allow the trainees to:

- Practice techniques that allow soldier to control their arousal (stress) in different types of contexts;
  - before a stressor creates a peak in stress (i.e., in moments of apprehension);
  - while stressed and performing his or her duties (i.e., with minimal intrusion on task performance); and
  - while stepping back for a task (i.e., when becoming overwhelmed by stress the "tunnel vision" could totally disrupt performance, and stepping back becomes necessary to regain control) – less common.
- Recognize the physiological and psychological signs of stress;
- See the benefits of arousal control/stress reduction on their well-being and performance; and
- Train in a motivating context.

Achieving a high positive transfer is also of upmost importance.

2.2 Existing solutions

Biofeedback-driven VGs were first mentioned in papers on affective computing (Picard, 1995), VR-based neurofeedback research (Allanson & Mariani, 1999), VG biofeedback (Pope & Palsson, 2001), physiological computing (Allanson & Fairclough, 2004), physiological computer game and affective VGs (Sykes & Brown, 2003). All these terms describe VGs in which players' emotions modulate the game experience. The emotional state of the player is usually measured by physiological reaction[2] via electrocardiogram (heart rate; HR), galvanic skin response (GSR), respiration changes, electroencephalogram and electromyography. The computer is then an active intelligent participant in the biofeedback loop (Bersak et al., 2001); the computer is affected by the player's emotional state and vice versa. Only a few commercial VGs have exploited psychophysiology (Arroyo-Palacios & Romano, 2010), but the number of papers on the subject is appreciable and increasing. Some solutions based on biofeedback-driven VGs have the potential to meet the objectives mentioned in the last section. These were created for either 1) improving the gaming experience, the relaxing property being a by-product, or for 2) helping people to manage their stress.

Many advocate (Picard, 1995; Gilleade, Dix, & Allanson, 2005) that a gaming experience could be improved by making VGs responsive to the player's emotional state. An important proportion of *affective* VGs indirectly foster a state of relaxation for their players. The first of its kind, *Tetris 64* (1997), uses a HR sensor attached to the player's ear to control the block falling speed in the VG. This form of biofeedback encourages players to maintain their HR as low as possible in order to win. Similarly, in *Relax-to-win* (Bersak et al., 2001), players use their GSR to control the speed of a dragon in a race. A more recent VG, *Physi Rogue* (Prendinger, Becker, & Ishizuka, 2006), exploits the players' electromyography and GSR to influence the level of activation of the seekers. By making predators chase the seekers according to their proximity and level of activation, more relaxed players are more likely to win the game. *Skip-Bo* (Prendinger et al., 2006) implements an electromyography and GSR-based card VG involving a virtual agent either expressing empathy or not according to the player's emotion. To our knowledge, the most stressful VG that incorporates biofeedback is *Ravenholm* (Dekker & Champion, 2007) and derives from *Half-Life 2* (2004) VG. The gameplay of this VG is enhanced by allowing the player's HR and GSR to affect many aspects: ability to see through walls, volume of environmental sound, avatar speed, screen shaking and color, field of view, invisibility, weapon damage, volume of the heartbeat, and artificial intelligence of the zombies. The GSR and HR influence too many variables of the VG in too confusing ways to be useful for SMT. Nevertheless, anecdotal evidence provides interesting avenues worth exploring. For instance, players of *Ravenholm* commented that the sound of their own heartbeat made them feel more anxious. Many other solutions and studies (Conati, 2002; Tijs, Brokken, & Ijsselsteijn, 2008; Tijs, Brokken, & IJsselsteijn, 2009) investigated the potential of affective VGs but the focus was on emotion in general and not on stress.

[2] More information about the physiological measures sed to assess emotional reactions is provided in Section 4.1 on biofeedback.

Biofeedback-driven VGs were also employed in many stress relief products. *Critter Quest* (McDowell & Perry, 2011) encourages children to relax by linking their HR to the gathering speed of an animal character evolving in a VG. *Breathing Space* (McDarby, Condron, & Sharry, 2003) and *Brainchild* (MacLachlan & Gallagher, 2004) are sequel of *Relax-to-win*. They encourage the use of diaphragmatic breathing to achieve a deep state of relaxation. A few commercial VGs allow people to practice their arousal control techniques in a way that is mostly relaxing but sometimes exiting, without being stressful or fearful. Commercial products identified include *The Journey to Wild Divine* (2010) and *Wisdom Quest* (2011) from Wild Divine; *Dual Drive* (2011) and *Inner Tube 3* (2011) from Somatic Vision; and *Relax & Race* (2011) and *Storm Chaser* (2011) from Vyro Games. On the military side, two recent initiatives were identified. The first one, an e-learning tool called *Stress Resilience Training System* (Cohn, Weltman, Ratwani, Chartrand, & McCraty, 2010) comprises cognitive know-how, heart-rate variability, coherence training, and the above-mentioned *Dual Drive* VG for practicing and mastering the coherence breathing technique. The second one, the *Multimedia stressor environment*, allows soldiers to practice and assess their stress-reduction skills (Hubal, Kizakevich, McLean, & Hourani, 2010). Trainees do not play themselves and consequently do not receive biofeedback. Instead, they observe recorded scenes of a VG in a theatre-style setup with 5.1 surround sounds.

Table 1 shows a comparison between all systems cited previously according to the following factors: nature of change in the VG, ability to encourage relaxation (i.e., must relax to win), captivating potential of the VG genre, type of visual representation, and finally, inherent stressful nature.

None of these VGs is suitable for this project. First, little experimental evidence supports the ability of these VGs to improve stress management skills once the training sessions are completed, even less for a military population. In addition, with the exception of *Avenholm*, these VGs are based on relaxation themes. Even for the more exiting ones, they elicit a level of stress far below the one experienced by military personnel in theatre of operations. These VGs are no match—in term of graphic quality and entertainment— with most recent VGs played by the population targeted by this project. Besides, none of these VGs is immersive (in a VR sense). Finally, these products seem to comply with the New Age movement, which does not help to solve the unattractiveness of emotion regulation with a military population. A solution to these two problems would be to use a popular VG in order to ensure higher level of appreciation and acceptance.

Table 1: Biofeedback-driven VGs for practicing arousal control.

Name	Description	Control	Encourage relaxation	VG style	3D	Stressful
Tetris 64 (1997)(Stach, Graham, Yim, & Rhodes, 2009)	Player's HR controls the blocks falling speed.	Speed	Yes	Puzzle	No	No
Relax-to-Win (Bersak et al., 2001)	In a racing VG, two players control the speed of an animated 3D dragon with their GSR.	Speed	Yes	Racing	Yes	No
Breathing Space (McDarby et al., 2003)	The fate of a flying creature is controlled by the player's breathing pattern (diaphragmatic).	Altitude	Yes	Arcade	Yes	No
Brainchild (MacLachlan & Gallagher, 2004)	Children must relax to unlock a door. It is a sequel of the *Relax to win* VG.	Lock	Yes	Adventu re	?	No
Physi Rogue (Toups et al., 2006)	Predators, controlled by the computer, track live player based on the player's electromyography and GSR.	Stealth	Yes	Strategy	No	No
Skip-Bo (Prendinger et al., 2006)	An opponent in a card VG, enacted by a computer agent, displays sadness when the player is distressed (based on electromyography and GSR).	Empathy	No	Game board	Yes	No
Please Biofeed the Zombies (Dekker & Champion, 2007)	In *Avenholm* level of *Half-Life 2*, a first person shooter (FPS) with zombies, the player's HR and GSR modulate many aspects of the VG.	Speed Stealth FOV, AI Sound	No	FPS	Yes	Yes
CritterQuest (McDowell & Perry, 2011)	The food gathering speed of an animal depends on the player's HR.	Speed	Yes	Adven-ture	Yes	No
Relax & Race (2011)	In *Relax & Race*, two players control the speed of a character with their GSR.	Speed	Yes	Racing	Yes	No
Journey to Wild Divine (2011), Wisdom Quest (2011)	Meditation skills (as measured by EDA and HR variability) allow progressing in an adventure VG.	Speed	Yes	Adventu re	Yes	No
Dual Drive (2011), Inner Tube 3	In *Dual Drive*, level of difficulty (obstacles) increases with the HR.	Speed	Yes	Racing	Yes	No

Note: FOV= Field of view, AI = Artificial intelligence

2.3 Conceptual view

Since none of the existing solutions is adequate, ImPACT was then proposed to teach SMT to soldiers. It is based on seven essential components, four of which are illustrated in Figure 2. The first component consists of a list of coping strategies selected for their proven efficacy and for the possibility of applying them in a military context. The trainee would probably already have a theoretical background about these strategies and/or a few minutes would be sufficient to review them prior the training session. Section 2.4 covers these strategies. Then, a set of pre-identified stressors can, on request by the instructor or based on the mission progress, induce stress to the trainee. These stressors should be of military nature and must be able to create storyboards unfolding in virtual environments. Third, virtual environments expose the trainee to stressors. The trainee learns to control his own level of stress while, thanks to the high engaging nature of the virtual environment, being concentrated on the "mission objective". This has the advantage of recreating, to a lesser extent, the highly engaging nature of military operations where soldiers rarely focus on their arousal control. Chapter 3 covers these last two components. Since a trainee's level of stress can be inferred from HR and GSR measures, the biofeedback component returns this information in real-time to the virtual environment. Chapter 4 covers the biofeedback component in more details. The fifth and sixth components, namely the controller graphical user interface (GUI) and the physiological data display (not showed in Figure 2), allows the instructor to evaluate the trainee's progress, give recommendations, evaluate and adjust the mission and the stressors, and adjust the biofeedback parameters. Finally, the training program provides guidelines to the instructors and ensures proper and uniform training. Chapter 5 and Annex A present the last three components.

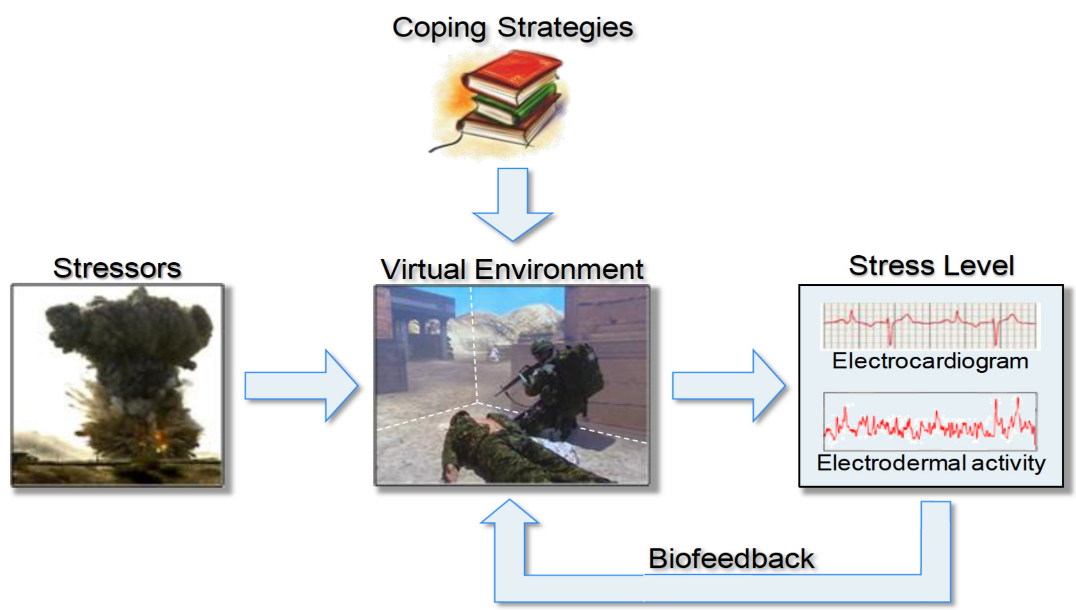

Figure 2: Using biofeedback to practice SMT while immersed in a stressful virtual environment.

2.4 Coping strategies

SMT is comprised of various tools and techniques that aim at reducing stress among a multitude of populations. Section 1.3 presented some of these strategies. In spite of the fact that SMT strategies are included in existing resilience programs, a literature review was conducted for confirming their efficacy for training military personnel to cope with potentially traumatic stressors met in theatre of operations or for more chronic stressors while being deployed. The literature search was extensive with 350 relevant papers identified in the domain of SMT, stress inoculation training and anxiety management training. More details on the methodology and the results are available in Bouchard (2009) and Bouchard et al. (2012).

As expected, the review shows that SMT is useful for numerous applications, ranging from improving physical and medical conditions to the treatment of anxiety disorders. Surprisingly, no empirical study was found on the use of SMT to cope with stressors experienced in theatre of operations. Nevertheless, several studies clearly show that SMT can be used to train people to cope with acute stressors. The current project can provide such empirical evidences; the experimental validation of ImPACT, in which SMT strategies are taught, could also be considered to a certain extend as a validation of the efficacy of strategies themselves in a context that bear some resemblance with a theatre of operation.

Based on the literature review, the PERM key individual strategies applied in pre-deployment, and the *Big Four* strategies of the R2MR program, it was decided that tactical/combat breathing would be the technique to be taught first. Its efficacy is proven, it is already included in existing resiliency programs, and is well known (but not mastered) by the military population.

2.5 Important design questions

Before engaging significant resources in its development, a few questions must be answered.

1- Which stressors could be considered for VR-based SMT?

2- How can stressful virtual environments be created?

3- How should biofeedback be implemented in a VG?

4- Could and to which extend an existing VG be adapted for SMT?

Chapter 3 addresses Questions 1 and 2 whilst Chapter 4 answers Question 3 and 4.

3 Stressful virtual environments

The practice of coping strategies in a virtual environment requires exposing the trainee to simulated stressful situations. Exposure to stressful stimuli could be repeated until the coping strategies are well mastered. How to create a stressful virtual environment is the question that Chapter 3 tries to answer. VR has shown its capacity to produce stress reaction with phobic people (Bouchard, 2009). However, inducing moderate stress to non-phobic people over many training sessions can be a more difficult task. Many simultaneous investigations were undertaken to tackle this challenge. The first section of this chapter presents a selection of key stressors found in theatres of operations that could be reproduced in a virtual environment (Bouchard et al., 2010). In the second section, a literature review identifies the elements of VGs and VR have been shown to stress their users. This chapter concludes with two experiments conducted during this project that tested the most promising approaches for creating stressful virtual environments (Bernier et al., 2009, 2011; Bouchard, Bernier, et al., 2011; Monthuy-Blanc et al., 2011). The objectives of these experiments were to 1) identify the most appropriate level of immersion and type of VGs and 2) evaluate the potential of using virtual character of a known person experiencing pain to induce stress.

3.1 Selecting key stressors

Since one of the objectives of SMT is to prevent the incidence of PTSD, stressors that are associated with psychological injuries in the military personnel are of interest. Incidentally, those stressors may be good candidates to create stressful virtual environments. Since the development of a virtual environment is a long and costly process, a cost-effective solution is then to limit to handful of carefully selected stressors. This section presents a summary of this selection process. For more information, consult previous publications (Bouchard et al., 2010; Bouchard, Bernier, et al., 2011). As a selection guideline, the list should include stressors that are:

- significantly stressful;
- specific enough to allow reducing the likelihood of developing PTSD; and
- generic enough to apply to a large number of military personnel involved in current theatres of operations like Afghanistan.

This challenge was addressed by integrating knowledge from three sources: (i) published information on subjective characteristics of stressors associated with PTSD, (ii) the objective characteristics of stressors associated with PTSD, including the frequency of occurrence of specific military stressors, and (iii) analysis of new data on combat experience among CF and potential association between some stressors and mental health problems. Only the two most important findings are presented in the current report. The first one deals with the trade-off between using the most frequent stressors experienced by Canadian military personnel versus using stressors associated with higher risks of suffering from psychological injuries. The second part presents a key stressors list based on the combination of these three sources of information.

3.1.1 New data on combat experience

Raw data was obtained from the CF Land Personnel Concept and Policies Office on the frequency of stressors and combat experiences among Canadian military personnel during deployment in Afghanistan. The data comes from the postdeployment Human Dimensions of Operation survey, an endeavour in the CF to provide information on human dimensions that can affect individual and group performance during and after missions (Brown, Villeneuve, & Lamerson, 2005). This survey contains a list of 31 situations that may cause soldiers to experience stress, usually when they go outside the base. For each of the situations, two answers are required. First, using a 5-point rating scale, respondents are directed to indicate the frequency with which they have experienced each of these situations. Second, they are asked to indicate how much trouble or concern each of these situations has caused them, on a scale from 1, *No trouble or concern,* to 5, *Very much trouble or concern*. The survey also includes the Kessler Psychological Distress Scale (Kessler et al., 2002), a 10-item self-report assessing psychological distress based on the level of anxiety and depressive symptoms experienced in the last four weeks. A cut-off score of 30 or more indicates that the respondent has three out of four chances to meet the diagnostic criteria for an anxiety or depressive disorder. Based on that cutoff score, estimates of 108 military personnel were very likely to suffer from an anxiety or depressive disorder (8.2% of the respondents) at the time of the survey (i.e., approximately 4-6 months after the end of the mission). This data (see Table 2) should be interpreted with caution because it does not represent a detailed analysis of stressors involved in the development of reliably diagnosed cases of PTSD. However, they are the closest estimation available to address which frequent stressful combat situations are associated with psychological injuries.

An examination of the rate of stressful situations shows that some stressors are more frequently experienced than others. For example, knowing someone seriously injured or killed and receiving incoming artillery, rocket or mortar fire were experienced by more than 70 % of the respondents. These events comply with the selection criterion C. As for the criteria A and B, it is interesting to see among those who were expose to a stressor, what was the percentage of people susceptible to suffer from an anxiety or depressive disorder (second column in Table 2). For example, being responsible for the death of Canadian or ally personnel is the least frequent stressor in the entire sample; it occurred to 3.1% of the respondents, or 41 times. Among these 41 cases, 20 (48.8%) are strongly probable cases of anxiety or depression. Thus, even though this stressor is infrequently experienced among those deployed to Afghanistan, when it does occur, it appears to be associated with an increased likelihood of suffering from an anxiety or depressive disorder.

Table 2: Rate of military personnel at high risk of suffering from psychological injuries like anxiety or depressive disorder among those who experienced stressful situations.

Stressful situations in the Human Dimensions of Operations Survey (number of respondents without missing data)	Rate of occurrence		Average trouble or concern felt in the entire sample (s.d.)
	of the stressor in the entire sample	of strongly probable cases of anxiety/depression among those who experienced the stressor (n=108)	
Had a close call; was shot or hit but saved by protective equipment (N=1306)	4.9%	53.1%	1.08 (0.41)
Being responsible for the death of Canadian or ally personnel (N=1305)	3.1%	48.8%	1.05 (0.31)
Engaging in hand-to-hand combat (N=1307)	3.3%	48.8%	1.06 (0.38)
Witnessing brutality/mistreatment toward non-combatants (N=1311)	7.9%	31.1%	1.14 (0.50)
Disarming civilians (N=1307)	9.0%	26.5%	1.17 (0.63)
Being wounded/injured (N=1302)	6.4%	25.3%	1.09 (0.37)
Had a close call; a bullet or shrapnel hit a piece of personal equipment (N=1306)	11.3%	23.1%	1.17 (0.54)
Clearing/searching caves or bunkers (N=1308)	12.2%	19.4%	1.26 (0.79)
Calling in fire on the enemy (N=1306)	15.2%	19.2%	1.35 (0.94)
Witnessing violence with the local population or between ethnic groups (N=1304)	20.7%	18.9%	1.36 (0.81)
Being directly responsible for the death of an enemy (N=1303)	16.4%	18.2%	1.38 (0.97)
Being in threatening situations and being unable to respond because of rules of engagement (N=1310)	20.9%	15.7%	1.42 (0.94)
Handling or uncovering human remains (N=1305)	15.7%	15.7%	1.37 (0.91)
Participating in demining operations (N=1305)	19.9%	15.4%	1.51 (1.16)
Witnessing an accident which resulted in serious injury or death (N=1305)	30.4%	13.9%	1.54 (0.95)
Clearing/searching homes or buildings (N=1310)	22.8%	13.7%	1.59 (1.22)
Improvised explosive device (IED) / booby trap exploded near you (N=1308)	38.3%	13.2%	1.76 (1.13)
Shooting or directing fire at the enemy (N=1308)	27.6%	12.5%	1.68 (1.26)
Receiving small arm fire (N=1309)	39.3%	12.4%	1.93 (1.36)
Seeing ill/injured people and being unable to help (N=1305)	30.0%	12.3%	1.64 (1.13)
Seeing dead or seriously injured Canadians (N=1307)	40.0%	11.9%	1.79 (1.13)
Having a close call: dud landing near (N=1304)	31.7%	11.9%	1.50 (0.87)
Having hostile reactions from local civilians (N=1307)	42.0%	11.1%	1.92 (1.29)
Being attacked or ambushed (N=1306)	49.9%	10.6%	2.28 (1.50)
Seeing dead bodies or human remains (N=1302)	43.8%	10.4%	1.92 (1.13)
Working in areas that were mined or had IED (N=1306)	51.8%	10.0%	2.43 (1.62)
Having members of your own unit become a casualty (N=1302)	41.2%	9.9%	1.81 (1.11)
Seeing destroyed homes or villages (N=1308)	57.7%	9.7%	2.62 (1.65)
Knowing someone seriously injured or killed (N=1307)	72.2%	8.2%	2.97 (1.13)
Receiving incoming artillery, rocket or mortar fire (N=1304)	77.5%	7.3%	3.46 (1.62)

3.1.1 Selection of key stressors

Our approach was to find converging information from various sources, including the Human Dimensions of Operation survey, in order to find the most appropriate stressors. Since the current objective focuses on developing coping strategies as opposed to treatment using virtual exposure, developing stressful virtual environment from the seven stressors most frequent (i.e., more than 20%) associated with psychological injuries (except for hand-to-hand combat) may be questionable. It is doubtful that one wants to desensitize people to inhumane situations and the long-term consequences of such expose would probably be disastrous. Thus, less traumatic and more frequent stressful situations have been retained in our analysis, as it would probably be more productive to develop them into virtual scenarios. The final choice of which virtual environment to develop should be based on a decision to create either situations that are experienced by most military personnel and are not strongly associated with psychological injuries like receiving incoming fire, or situations that are experienced by fewer military personnel yet are more strongly associated with psychological injuries like clearing/searching houses, caves or bunkers.

Stressor selection was based on a few criteria, such as: (a) frequency of occurrence of at least 50% among those military personnel who were involved in active combat; (b) frequency of occurrence of at least 10% among Canadian military personnel deployed in Afghanistan; (c) low rate (<20%) of strongly probable cases of suffering from anxiety or depression among those who experienced the stressor, (d) the feasibility of recreating the stressor in VR, (e) sharing objective characteristics associated with traumatic stressors, and (f) sharing subjective characteristics associated with traumatic stressors. After submitting stressors in combat experience to the above criteria, eight stressful situations stand out (see Table 3). These stressors are frequent and present strong psychological challenges that last long enough to be used in storyboards unfolding in virtual environments and involving either unpredictability or lack of control. They are also among the most troubling reported by the respondents. Finally, they possess important subjective characteristic that were identified as significant in traumatic stressors.

Despite our efforts to operationalize the selection process of key stressors, the final selection was still based on subjective criteria. Judging which stressors were unpredictable and involved lack or loss of control, a feeling of helplessness or horror and novelty was not based on empirical grounds. All the same, this process follows a formal and explicit approach that is rarely documented in the development of virtual environments. Another unknown is how the effect of these stressors translates into virtual environments. The following section tackles this question.

Table 3: Checklist of traumatic events selected for virtual environments to be developed for SMT.

Stressful combat experiences and situations	**Frequent**	**Prevalent in the psy. injured**	**Perceived challenge/threat**	**Duration (long)**	**Unpredictable**	**Lack / loss of control**	**Helplessness**	**Life Threatening**	**Challenge to beliefs systems**	**Horrible**	**High in stimulations**	**Voluntarily caused harm**	**Novelty**
Seeing dead bodies / uncovering human remains	☑	☑	☑	☑	☑	☑	☑		☑	☑	☑		☑
Knowing someone seriously injured or killed	☑	☑	☑	☑	☑	☑	☑		☑	☑			☑
Receiving artillery fire	☑	☑	☑	☑	☑	☑	☑	☑			☑		
Being unable to help because of rules of engag.	☑	☑	☑	☑		☑	☑		☑	☑			
Seeing destroyed homes and villages	☑	☑	☑	☑		☑	☑		☑	☑			
Clearing / searching (house, cave, bunker)	☑	☑	☑	☑	☑			☑			☑	☑	
Receiving small arms fire	☑	☑	☑	☑	☑			☑			☑		
De-mining operations	☑	☑	☑	☑	☑			☑					

3.2 VGs and VR for inducing stress

3.2.1 VG techniques

The most stressful genres of VGs, i.e., the horror and to a lesser extend action genres, aim mainly to entertain and to frighten, but incidentally they are also a means for inducing stress. The interest is not in the brutal or bloody scenes these VGs depict but in their ability to subtly create suspense and elicit important emotional responses from their players. They try to implement the "art of frightening", often with suggestive staging and appropriate mood setting. This approach works only if their players accept involvement in the artificiality of situation. The Entertainment Software Rating Board (ESRB, www.esrb.org) confirms the harmlessness and respect for social values of these VGs. The use of ESRB-approved 3D VGs is thus a promising alternative to creating stressful virtual environments because they induce stress without having recourse to stimuli that might be traumatic for certain persons. Consequently, a survey was conducted to evaluate the potential of this technology.

Horror movies preceded the VG genre, and the literature about them is rich. However, this domain was not reviewed because VGs differ in too many aspects like the level of interactivity and the narrative approach. Instead, the survey reviewed mostly theoretical papers discussing the art of horror VGs and the techniques for developing them (Ivory & Kalyanaraman, 2007; Perron & Barker, 2009; Perron, 2004, 2005a; Taylor, 2006; Toet, van Welie, & Houtkamp, 2009). Many stressful VGs were also analyzed in order to identify commonalities among them. Table 4 presents the most frequent stressors/techniques for inducing stress found by the survey and the analysis.

These stressors can be categorised in three groups: the elements populating the VG, the staging of these elements in a scenario, and the specific player-game interaction.

Table 4: Categories of stressors/stressing techniques exploited by VGs.

Elements populating the VG	Static characters and objects: human bodies and faces, monsters, corpses, injuries, human remains, blood, etc.
	Animations: pain, fear, screaming, flight, bleeding, vomiting, mutilating, fighting, shooting, injuries, etc.
	Sounds: cries, moans, environmental sounds, bombs, music
	Scene: dark, unfriendly, creepy, etc.
Staging in a scenario	Forewarning, surprise, sudden burst, horrific premise, unexpected event, helplessness, revolting moment, altered reality, weird things
Player-game interactions	Lack of control of the character Real world effects Limited fighting abilities Limited FOV

First, most stressful VGs, like the horror genre VGs, often comprise realistic and horrific 3D models, animations, and sounds often located in dark, creepy, and unfriendly environments. Second, these elements are staged so that they create suspense and fear, with the goal of entertaining the player. They exploit innate fear mechanisms. For instance, forewarning (Perron, 2004), which consists in announcing an oncoming threat, puts the player in an emotional alert. Finally, the interaction between the player and the VG itself can be exploited as a stressor. For instance, the VG can "hurt" the player in the real world by threatening its progress or by threatening a character in whom the player has invested a lot of time. More details about how horror VG may contribute to create stressful virtual environment are available in Bouchard, Bernier et al. (2011).

3.2.2 Empirical studies

Preliminary investigations revealed the potential of VGs to produce stressors and of VR to convey them to the player. A more extensive literature review was conducted in the domains of VGs and VR to identify 1) the extent of which there are experimental studies confirming this potential 2) which specific attributes have shown (experimentally) a potential to induce stress.

Many experiments have identified a correlation or a causation relation between VGs and stress. A recent meta-analysis on the effect of violent VGs on aggression (Anderson et al., 2010) found a positive correlation (r=0.184) between playing violent VGs and an increase in the players' arousal in studies that comply with "best practices" for a total of 15 studies and 969 participants. This meta-analysis is consistent with previous meta-analyses (Anderson & Bushman, 2001; Anderson, Carnagey, Flanagan, Benjamin, & others, 2004) and most papers referred in this section. In the VR research field, no such meta-analysis has been found. Nevertheless, an extensive review (Youngblut, 2006) of the factors contributing to the sense of presence identified many studies involving a measure of arousal. Also, several studies listed below suggest that many VR-related attributes like immersion and stereoscopy are responsible for an increase in physiological arousal. In summary, there is plenty of evidence showing that VR and VGs can be used to develop the training system.

The experimental confirmation that VGs and VR may increase the level of arousal of their users is a necessary but an insufficient step. Also important is the identification of the specific attributes that cause more stress in the players/users. Youngblut (2006) provides some answers in the domain of VR. As for the domain of VGs, an extensive review (Barlett, Anderson, & Swing, 2009) classified a significant number of studies under eight moderator variables. The physiological arousal was not the focus of this review though. On the other hand, Kivikangas et al. (2010) identified many studies that investigated the effect of VGs on the arousal. Although these reviews provide a good starting point, further investigation was required since other studies, not cited previously in any reviews, were found.

The main findings of our own investigation are summarized in Table 5. Most of these papers suggest a causation relation between the attribute and arousal but, for a limited amount of them, only a correlation relation was found. Studies that did not observe any effect of the attribute on the arousal are underlined. This review includes almost exclusively experimental papers based on quantitative or qualitative approaches for measuring the arousal. The quantitative approaches were based on physiological measures like GSR, blood pressure, heat flux, and many electrocardiogram-derived measures like the HR. As for the qualitative measures, they were self-reported (SR) from ad-hoc or standardized questionnaires like game experience questionnaire (GEQ) or self-assessment manikin (SAM) that were found be correlated with physiological measures of arousal. Three theoretical papers were also included, since empirical data may be still lacking or difficult to find for some important attributes.

The literature review was limited to a few relevant research domains: effect of VGs on aggressive behaviours, gameplay experience evaluation, psychophysiology of VGs and VR, and affective gaming. For VR-related attributes, although presence has been extensively studied, a majority of papers neither measured nor reported any measures of stress or physiological data. The few papers that failed to demonstrate an effect were omitted because there were no additional studies that confirmed the findings. An example of omission: reducing illumination in a virtual environment does not increase stress (Toet et al., 2009). Papers in the domain of cinematography and on phobic patients were ignored because they may not be applicable in the current context. For two attributes, immersion and violent VGs, the list is non-exhaustive since significant evidences were found (in term of papers that observed a positive effect). Finally, although many attributes have been extensively studied, further scientific investigations should be conducted for some attributes like stereoscopy, specific VG events, and cinematographic/narrative approaches. The finding column reports the direction of the effect that an attribute has on arousal. For instance, VGs played on stereoscopic-based displays were found more stressful than monoscopics or VGs played on a larger screen, which were considered more stressful than if there were played on a smaller screen.

Many observations may be drawn out from this review. First, some attributes are more tangible than others. It is simpler to add a stereoscopic or a multi-player mode than to rewrite the storyline to make a VG more stressful. Second, interactions between attributes were not considered for most studies, and combining them could produce the opposite desired effect. For instance, increasing the field of view may interfere with the partial vision exploited to give the illusion that the enemy is everywhere (Perron, 2005a). Another example is the social setting: the suspense created by being alone in a dangerous place may be broken by adding a multiplayer cooperative mode since co-located friendly character may help to face the danger. Conversely, knowing that the threat is controlled by a human adversary could amplify the intensity of the situation. Also, even if studies have shown an increase of arousal, it does not necessarily imply all the increase of physiological arousal was due to other reasons such as pleasure or frustration (Arriaga, Esteves, Carneiro, & Monteiro, 2008). There is a lack of scientific evidence that prevents this list of attributes from being ranked. Nevertheless, the fact that some narrative and staging techniques are extensively used in stressful VGs and movies implies these techniques are the basic ingredients of stressful virtual environment.

Finally, an important finding of this review is the decrease in arousal over an extended period of play (Sherry, 2001; Weber, Behr, Tamborini, Ritterfeld, & Mathiak, 2009). This result is consistent with the theory that repeated exposure to an emotional stimulus could lead to a desensitization of emotional response (Bradley, Cuthbert, & Lang, 1996). From a quantitative perspective, a meta-analysis (Sherry, 2001) revealed that the effect size of level of arousal induced by violent VGs was negatively correlated to playing time. Most experiments exposed the participants for a limited period of time, usually 10 (Ballard & Wiest, 1996; Ivory & Kalyanaraman, 2007), 15 (Barlett, Harris, & Baldassaro, 2007) or 20 minutes (Anderson et al., 2004). Consequently, training in a stressful virtual environment should be limited to 20 minutes per session.

Table 5: List of attributes shown to increase the arousal.

Attribute	Findings	Measure	Supporting studies
Field of view (FOV)	Larger screens (or larger FOV) vs. smaller screens (or narrower FOV)	GSR HR	(Ivory & Magee, 2009) (Lin, Hu, Imamiya, & Omata, 2006) (Lin, Imamiya, Hu, & Omata, 2007) (Reeves, Lang, Kim, & Tatar, 1999)
Stereoscopy	Stereoscopic vs. monoscopic - displayed VGs	GSR Not HR	(Rajae-Joordens, 2008)
	Stereo. vs. monos. still images	SR	(Häkkinen et al., 2008)
Visual fidelity	Visually advanced vs. visually simple VGs	GSR SR	(Ivory & Kalyanaraman, 2007) (Sherry, 2001) (Slater, Khanna, Mortensen, & Yu, 2009) (Zimmons & Panter, 2003)
Immersion/ Presence	Immersive vs. non-immersive systems (not an exhaustive list)	HR SR	(Arriaga, Esteves, Carneiro, & Monteiro, 2006; Arriaga et al., 2008) (Persky & Blascovich, 2006) (Slater et al., 2006) (Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2004) (Wiederhold, Davis, & Wiederhold, 1998)
Haptic/ Feedback	Rumbling vs. static controllers	SR	(Immersion, 2010) – Theoretical (Perron & Barker, 2009) – Theoretical (Salminen et al., 2008)
	Explicit biofeedback vs. implicit or no biofeedback	GSR	(Kuikkaniemi et al., 2010)
	Passive haptic (ledge)	GSR, HR	(Meehan, Insko, Whitton, & Brooks, 2001)
Interactivity	Active playing vs. observing violent VGs	HR SR-SAM	(Calvert & Tan, 1994) (den Broek, 2008) (De Waal, 1995)
	Interactive light gun vs. mouse and keyboard	HR SR	(Barlett et al., 2007)
Sound/ Music	Music x sound	Cortisol SR-GEQ GSR(+/-) Not HR	(Hébert, Béland, Dionne-Fournelle, Cręte, & Lupien, 2005) (Sanders Jr & Scorgie, 2002) (Nacke, Drachen, & Göbel, 2010) (Grimshaw, Lindley, & Nacke, 2008)
	Immersive vs. non-imm. audio Subwoofers vs. headsets	GSR Body T	(Shilling, Zyda, & Wardynski, 2002)
	Surround vs. stereo sound	GSR	(Manalili, Hirsch, Roginska, & Rowe, 2009)
Social setting	Play against human vs. compu. Playing against friend vs. stranger Players being collocated vs. distant	HR SR SR-GEQ	(Anderson & Morrow, 1995) (Gajadhar, de Kort, & IJsselsteijn, 2008) (Mandryk & Inkpen, 2004) (Mandryk, Inkpen, & Calvert, 2006) (Ravaja, Saari, Turpeinen, et al., 2006)

Attribute	Findings	Measure	Supporting studies
Virtual humans	Emotion exhibited by virtual agents	GSR	(Prendinger et al., 2006) (James, Lin, Steed, Swapp, & Slater, 2003)
Game experience	More vs. less interesting game experience	GSR SR-GEQ	(Jeong, Biocca, & Bohil, 2008) (Mandryk et al., 2006) (Nacke & Lindley, 2008)
	Winning vs. losing	HR Blood pressure	(Ricarte, Salvador, Costa, Torres, & Subirats, 2001)
	Character identification - point of view	GSR	(Kuikkaniemi et al., 2010) (Lim & Reeves, 2010)
Violence	Many experiments have investigated the effects of violent VGs on the children's aggressiveness. Incidentally, the level of physiological or self-reposted arousing during VG play has been reported. This is a non-exhaustive list.	HR GSR SR	(Anderson & Bushman, 2001), (Anderson & Dill, 2000), (Anderson & Ford, 1986), (Anderson et al., 2004), (Anderson et al., 2010) (Arriaga et al., 2006, 2008) (Ballard & Wiest, 1996) (Baldaro et al., 2004) (De Waal, 1995) (Fleming & Rick Wood, 2001) (Griffiths & Dancaster, 1995) (Lynch, 1994) (Merkx, Truong, & Neerincx, 2007) (Panee & Ballard, 2002) (Persky & Blascovich, 2007)
Specific events and situations	Reward vs. no-reward	HR, GSR	(Ravaja, Saari, Salminen, Laarni, & Kallinen, 2006)
	Hockey goal or fight	GSR	(Mandryk et al., 2006)
	Wounding and killing	GSR	(Ravaja, Turpeinen, Saari, Puttonen, & Keltikangas-Järvinen, 2008)
	Started round, running out of ammunition, etc.	HR	(Weber et al., 2009)
	Phobogenic stimuli (heights, spiders, enclosed spaces)	SR	(Robillard, Bouchard, Fournier, & Renaud, 2003)
	Danger of falling	GSR, HR	(Meehan et al., 2001)
Narrative/ Staging	Contrast, affinity of color, saturation	GSR, Heat Flux Body T	(El-Nasr, Morie, & Drachen, 2010) (Block, 2001) - Theoretical
	Narrative in a VG	SR-SAM	(Schneider, 2004)
	Uncertainty, forewarning, surprise	GSR SR	(Perron, 2004, 2005a, 2005b) - theoretical (Sparks, 1989)
	Level of violence realism (e.g. blood and screams)	SR-SAM	(Jeong et al., 2008)
	Horror sequences (movies)	HR Blood pressure	(Mian, Shelton-Rayner, Harkin, & Williams, 2003) (Palmer, 2008) (one measure only)

3.3 Study 1: level of immersion and type of VGs

Although previous reviews identified many possible solutions to creating stressful virtual environments, none of these studies have evaluated new low-cost 3D display systems, like stereoscopic televisions (TVs) and stereoscopic liquid crystal display monitors. Besides, many studies investigated the effect of VGs on arousal but none of them exposed participants to recent stressful VGs, even less with military personnel. This section summarises a study (Bernier et al., 2009; Bouchard, Bernier, et al., 2011) that assessed the potential of some VGs and VR technologies to induce stress in military personnel.

3.3.1 Objective

A new study was conducted to investigate three research questions:

– Could 3D VGs induce stress in a population of military personnel (in order to apply SMT later)?

– Does a VG considered as more stressful, based on the quality of its graphics and differences in gameplay, has a higher anxiety-inducing potential?

– Would a more immersive system like the CAVE automatic virtual environment (CAVE) be significantly more stressful than recent low-cost stereoscopic displays?

3.3.2 Set-up

A screening procedure with four objectives was designed to identify the VGs with the highest potential for SMT. In order to avoid any important subjectivity bias, the subjective *Stressful* criterion was based on the ranking of seven “top-10 scariest VGs” done in the last two years according to websites and gaming magazines (About.com, Askmen.com, BrightHub.com, GossipGamers.com, JoystickDivision.com, PopCrunch.com, and Telegraph.co.uk). Table 6 lists 11 titles initially identified as most promising for the experiment. Each criterion was rated on a scale ranging from 0 (least) to 5 (most). A group of three VGs clearly stands out above the others: *F.E.A.R.* (www.whatisfear.com), *Killing Floor* (KF, www.killingfloorthegame.com), and *Left 4 Dead* (L4D, www.valvesoftware.com). It should be noted that, with the exception of the “experimentally friendly” criterion, this screening procedure could also be exploited to determine the more promising VGs for ImPACT.

Table 6: Review of a selection of VGs titles.

Titles	Criterion					
	Stressful	**Ethical**	**Exp. Friendly**	**VR Compatible**	**Adaptable**	**Total**
Call of Cthulhu: Dark Corners of the Earth (2005)	2	1	1	0	0	4
Condemned: Criminal Origins (2006)	3	2	3	0	0	8
Dead Space (2009)	5	3	3	2	0	13
F.E.A.R. (2005)	5	2	4	4	5	20
F.E.A.R. 2 (2009)	2	1	4	2	0	9
Fatal Frame II : Crimson Butterfly (2003)	4	5	1	0	0	10
Killing Floor (2009)	*1*	*3*	*4*	*5*	*5*	*18*
Left 4 Dead 1 (2008)	*3*	*3*	*5*	*4*	*5*	*20*
Penumbra: Black Plague (2008)	2	4	0	0	1	7
Resident Evil 4 (2005)	2	2	3	0	1	8
Silent Hill 2 (2003)	4	2	2	0	0	8

Two similar FPS/ horror VGs obtained the higher score (20 for both) and were therefore selected: KF – Archives and L4D – No Mercy (see Figure 3). The major difference between the two VGs lies in the "stressful factors", more present in L4D and further increased by the modifications such as those described in Section 3.2. The hypothesis was that participants playing L4D would be more stressed than those playing KF.

Figure 3: Two VGs evaluated by the experiment (from left to right): KF and L4D.

Three immersive technologies were also compared (see Figure 4): (a) a Samsung model 2233RZ 22-inch stereoscopic monitor (www.samsung.com), (b) a Mitsubishi model 73735 rear-projection 73-inch stereoscopic TV (www.mitsubishi-tv.com), and (c) a Mechdyne 10'8" x 8' Flex CAVE (www.mechdyne.com), with 8000 Lumens digital light processing digital projection Highlight 8000 Dsx+ projectors (www.digitalprojection.com) on three adjacent walls and a floor. Immersive (5.1) digital theatre sound, with headsets for the first two systems and speakers for the CAVE, was also included. The participant's position in the CAVE was tracked by a wireless Intersense IS-900 virtual environment tracker system (www.intersense.com) to correct the perspective in real-time.

Figure 4: Three immersive systems evaluated by the experiment (from left to right): a 22-inch stereoscopic monitor, a 73-inch stereoscopic TV, and a "4-wall" CAVE.

Despite the researchers' strong motivation to use L4D in the CAVE, adapting the engine for the CAVE setup was not possible within the available timeframe. Consequently, participants were assigned to one of the five following conditions: L4D-22 inch, L4D-73 inch, KF-22 inch, KF-73 inch, and KF- CAVE. As a control and reference comparison of induced stress, participants were exposed to a standardized stressful procedure, the Trier Social Stress Test (TSST) (Kirschbaum, Pirke, & Hellhammer, 1993). The task consisted of: 1) simulating a job interview in front of a panel of three people with neutral reactions; 2) counting backwards from 2083 in increments of 13 as fast as possible. The hypothesis was that the CAVE would be more stressful than the two low-cost VR environments. In summary, an equal or a higher measure of stress for the 3D VGs for any immersive system when compared to the TSST would be considered a success.

3.3.3 Participants

The sample comprised 47 soldiers from Valcartier military base of the CF, in Québec City, Canada. Subjects were divided into five conditions as illustrated in Table 7.

Table 7: Experimental groups.

	22" stereoscopic screen	**73" stereoscopic screen**	**CAVE**
L4D	Group 1 n=8	Group 2 n=11	Non-applicable
KF	Group 3 n=10	Group 4 n=9	Group 5 n=9

3.3.4 Procedures

After a 25-minute screening and baseline session, all participants underwent a TSST for 15 minutes. They were afterward randomly assigned to one of the five conditions during which they played either the KF or L4D on one of the three immersive technologies as depicted in Figure 5.

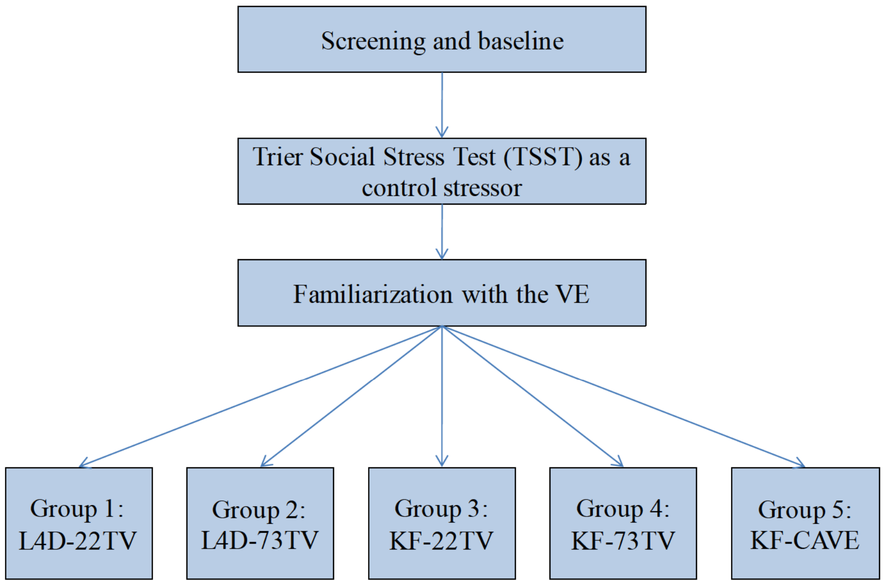

Figure 5: Experimental protocol.

Heart and respiratory rates were assessed before the TSST for control, during the TSST for reference, and during the 20-minute VG playing session in order to measure of the effect of each condition. The participants' stress was also measured from the *State-Trait Anxiety Inventory-Y1* questionnaire (Gauthier & Bouchard, 1993) before and after the TSST and after the playing session.

3.3.5 Results

Repeated measures of analyses of variance (ANOVAs) revealed statistically significant increases in HR and respiration rate while playing the 3D VG and during the TSST when compared to baseline (see Table 8). Results suggest that 3D VGs are stress-inducing, both physiological measures confirming the hypothesis. No significant differences were found between the VGs or between the three immersive systems used in this study. Although two out of three hypothesises were not valid, this finding is encouraging since it allows flexibility in the choice of stressor and of the immersion technology.

Table 8: HR (N = 36) and respiration rate (Resp; N = 42) – means and standard deviations (SD) for each condition.

Condition	Type of measure	Baseline mean (SD)	TSST mean (SD)	VG Play mean (SD)
L4D – 22 inch	*HR (n = 4)*	85.3 (13.3)	109.0 (25.7)	98.6 (27.6)
	Resp (n = 7)	2.3 (5.9)	15.4 (3.5)	20.1 (3.6)
L4D – 73 inch	*HR (n = 10)*	88.3 (8.4)	93.4 (14.0)	95.0 (23.1)
	Resp (n = 10)	8.5 (16.6)	12.9 (3.5)	17.3 (7.2)
KF – 22 inch	*HR (n = 7)*	85.1 (15.6)	94.7 (22.6)	93.6 (31.6)
	Resp (n = 8)	5.6 (7.8)	15.7 (2.7)	17.0 (3.7)
KF – 73 inch	*HR (n = 8)*	83.4 (10.3)	89.0 (14.3)	87.8 (18.7)
	Resp (n = 9)	10.4 (13.2)	14.5 (3.5)	18.7 (4.5)
KF – CAVE	*HR (n = 7)*	80.1 (16.4)	97.0 (9.8)	103.2 (21.3)
	Resp (n = 8)	5.7 (7.2)	12.8 (4.5)	18.1 (2.9)

The fact that both physiological measures were as high for the 3D VGs as for the TSST is an indicator of the high potential of VGs considering that 1) tasks to be performed during the TSST was potentially frustrating for soldiers whereas the gameplay was quite similar to what they are regularly trained to do, like house clearing and 2) participants performed a physical effort since they were standing up and in some cases walking during the TSST while they were seated during the VG play.

A survey at the end of the study (see Table 9) revealed that participants playing L4D on the 73-inch TV appreciated the approach more and found it more useful to practise stress control than those playing KF on a 22-inch monitor. The CAVE condition was considered the least useful. Data collected with people immersed in the CAVE were not supporting the use of this technology as much as expected. The stronger immersive properties of this technology set hopes for more presence, more stress, and better acceptance from participants. A possible explanation is the possible interaction between factors that individually tend to increase the stress but when combined can have the opposite effect.

Table 9: Assessment of the immersion by participants – means and standard deviations (SD) for each condition (N=46).

Personal impressions (0-10)	L4D-22 inch (n=7) Mean (SD)	L4D-73 inch (n=10) Mean (SD)	KF-22 inch (n=11) Mean (SD)	KF-73 inch (n=9) Mean (SD)	KF-CAVE (n=9) Mean (SD)	F
Stress during immersion	6.00 (2.52)	4.20 (2.86)	3.55 (2.21)	3.56 (2.79)	3.44 (2.30)	1.36
Appreciation of immersion	7.67 (2.25)	9.50 (0.71)	6.27 (3.04)	7.33 (2.78)	6.78 (2.39)	2.67*
Usefulness to practice stress control	6.20 (3.56)	7.30 (2.83)	4.90 (3.64)	6.44 (2.51)	3.11 (2.76)	2.63*

Note. *$p < 0.05$.

Analysis of the performance during VG play revealed that participants playing L4D on the 73-in TV were "killed" less often than those playing KF in the CAVE. This finding confirms that playing L4D on a 73-inch TV was likely more engaging and appreciated by the participants.

Figure 6 illustrates a typical HR response of a soldier to stressful events in L4D during tests conducted after Study 1 but in similar conditions. Red zones correspond to most intense moment of stressful events while green zones correspond to the less stressful moments. This test clearly reveals a series of 2-minute periods where the trainee could practice coping strategies. Studies cited in 3.2.2 confirm this anecdotal evidence.

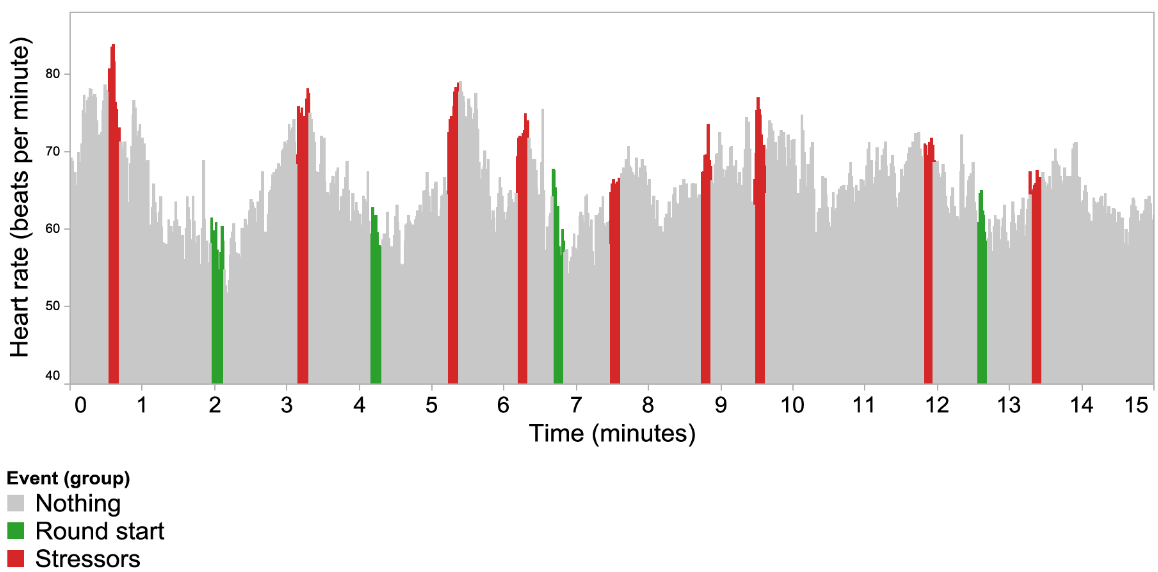

Figure 6: Typical participant's HR response to stressors in L4D.

3.3.6 Discussion

In summary, the use of 3D horror VGs definitively represents an interesting means for teaching and practicing SMT. Yet, a task that differs more from the regular training imposed on soldiers might be even more fruitful. An important finding is the facility to induce stress with relatively low-cost immersive technology and widespread VGs. Also noteworthy is the possible interaction between the stress inducing potential of the content (i.e. VG) and the medium that conveys it (i.e. VR). One of the lessons learned during the TSST was that bringing soldiers outside their zone of comfort was very stressful. To avoid situations where soldiers' responses have been overlearned (i.e., house clearing), the stressor could be based on a scenario where the participant is not in service but gets caught in an ambush and must help someone severely wounded and in acute pain. Such a scenario could even be included within an already existing stressful VG. For example, the software-controlled VG could include a team of virtual characters comprised of a child, a young female representative of the United Nations, and a male wearing the uniform of a member of the CF. One of the three characters, randomly selected each time the VG is played, could survive the ambush and become a burden for the participant due to the wounds and extreme pain reactions. If a scenario were developed along those lines, an important question would be whether being familiar with the wounded person significantly increases stress levels. Finally, according to Table 6, L4D and KF are not considered by the gaming community as being very stressful compared to some other VGs. There is room for choosing a more stressful VG but other important factors should be considered as well, like the possibility of a military population having been over exposed (overlearn) to a very popular VGs, which could negatively influence the practice of SMT. Analysis does not support the hypothesis that L4D is more stressful than KF neither that the more immersive system is more stressful. However, the greater level of appreciation and higher level of performance observed with L4D on a 73-inch TV makes this condition as the most suited for VR-based SMT.

3.4 Study 2: realistic suffering avatar of a known person

The combined genre FPS and horror VG is somewhat stressful for soldiers. However, the intensity of the stress was not as high as expected, probably because soldiers are trained to react efficiently to situations involving close combat or search and rescue missions in hostile areas. Other stressful situations reported in Section 3.1 may represent more appropriate stressors, especially if they involve being alone and disarmed. Knowing someone seriously injured, receiving artillery and small-arms fire, and being unable to help are stressors frequently encountered by Canadian soldiers. Based on lessons learned from the previous experiment and other studies, a better stressor to practice SMT while stressed might be a scenario where: (a) the user is on leave, walking unarmed with a few other people in an area surrounded with destroyed homes, (b) they are ambushed and suddenly attacked from artillery and small-arms fire, (c) most of the other people are killed, except the user and one other person who is severely wounded and in pain, (d) the user cannot return enemy fire and must provide basic medical help to the wounded. This scenario would include several stressors that are typical of what is experienced in a theatre of operations (Bouchard et al., 2010), and yet remain different from the L4D map used in Study 1 where the gameplay shares similarities with house clearing, a task for which soldiers are heavily trained. Before designing and testing such a stressor, it is important to know if being familiar with the wounded compatriot is important. This section summarises a study (Bouchard, Bernier, et al., 2011; Monthuy-Blanc et al., 2011) that assess the potential of a suffering avatar, which is a graphical representation of a person, in inducing stress.

3.4.1 Objective

The aim of this study was to assess how a real human in an immersive and compelling environment reacts to an avatar expressing pain, for possible use in a scenario close to what was described in the previous paragraph. Scientific inquiry was needed to know whether stress could be induced simply by the fact of seeing an avatar in pain or whether the avatar needs to represent a known individual. The current study investigated three research questions:

- Can pain experienced by an avatar induce reactions in a user immersed in VR?
- Is the emotion induced by observing the avatars of a known individual stronger than by observing the avatar of an unknown person?
- Would familiarity with the individual used to create the avatar have an impact on the user's reactions?

3.4.2 Set-up

All immersions were performed in Psyche, the CAVE-like system of the Laboratoire de Cyberpsychologie of the UQO (see Figure 7). Psyche is driven by a cluster of six slave computers and one master computer, all running a *Virtools VPPublisher Unlimited* 5.0 (www.3ds.com). Participant's position was tracked by a wireless Intersense IS-900 Virtual Environment Tracker system to correct the perspective in real-time. In addition, participant wears Nu Vision 3D glasses (www.nuvision3d.com), Sennheiser RS146 wireless stereo headphones (www.sennheiser.com) and a Shure L3 (www.shure.com) wireless lapel microphone.

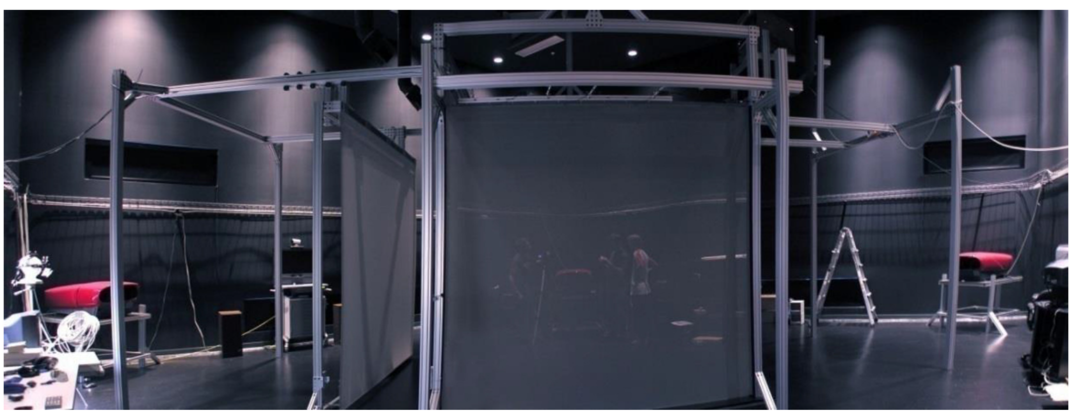

Figure 7: Side view of Psyche, with the door almost closed.

Figure 8: Screenshots of the three avatars (cat, known/Stephane Bouchard, and unknown) in idle position waiting for the participant to interact with them.

Two home-made virtual environments were used: a training used as a baseline and an experimental environment. The training environment consisted of an empty room with three windows, a glass door and a cat waiting on a table behind the glass door (see Figure 8). This environment allowed participants to familiarise with being immersed in a CAVE-like system to record a baseline of physiological data. The experimental environment was a sports barroom measuring 8.5 metres in width by 13.5 metres in depth. A standing human avatar was in a waiting position near a pool table and was looking vaguely at the participant.

The three avatars used were a cat, Stéphane Bouchard (being a university professor, it was easier to find people familiar with his physiognomy), and a virtual human created without reference to a real person. Stéphane Bouchard's avatar, referred in this report as the known avatar, was developed using pictures, videos, and voice recordings of himself enacting the various behaviours and facial expressions needed for the study. Attention was paid to animate the avatar as realistically possible, although the avatar's gaze patterns were not synchronised with the participant's head position in Psyche. The unknown avatar was designed to have the same dimensions as the known avatar, in order to use the same animations. The audio recordings were modified so the voice of the unknown avatar could carry the same emotions yet sound different from the known avatar. Slight differences still remained between the two avatars: the textures of the known avatar were more refined and nuanced, and the facial animations of the known avatar were performed using blendshapes while the facial animations of the unknown avatar were created using morph targets.

3.4.3 Participants

The sample was composed of 42 civilian, 16 males and 26 females, between 18 and 60 years old, in good mental and physical health, as verified through telephone pre-screening. To be eligible for the study, participants had to have directly talked at least once with the person that was used as a model to create the known avatar (Stéphane Bouchard) but had to have never seen the avatars used for the project nor been aware that the avatars would express pain. Participants were randomly assigned to two avatar conditions: (a) Known Avatar First (KAF; i.e., the immersion with the known avatar preceded the immersion with the unknown avatar, n = 22) or (b) Unknown Avatar First (UAF; i.e., the immersion with the unknown avatar preceded the immersion with the known avatar, n = 20).

3.4.4 Procedures

The first immersion, which served as the baseline and control, was with a virtual animal. Then, after random assignment, it was followed by another immersion involving discussing with a known avatar and with an unknown avatar, the order of appearance of the known/unknown avatars being assigned randomly. During the verbal exchanges, the human avatars experienced acute and very strong pain as illustrated in Figure 9. The participants' stress was measured from the *State-Trait Anxiety Inventory-Y1* questionnaire (Gauthier & Bouchard, 1993), the respiratory rate, HR, and GSR.

Figure 9: Screenshots of the known and unknown avatars expressing acute and sustained pain.

The GSR was measured before exposure to the training environment and throughout the whole experiment. The relative position from the avatar was also measured but not before the exposure.

3.4.5 Results

Physiological data illustrated in Figure 10 and Figure 11 show that the GSR and the distance from the avatars increased during the 12 seconds preceding the expression of acute pain by the avatars. The stressful impact of observing pain was documented for the GSR by a significant Time effect during the first immersion [$F_{(1,40)} = 7.26, p < .01$] and the second immersion [$F_{(1,40)} = 5.58, p < .05$], as well as for distance from the avatar in the first [$F_{(1,40)} = 8.87, p < .01$] immersion. Change in distance from the avatars during the second immersion was much smaller and non-significant [$F_{(1,40)}$ = 2.25, *ns,* partial eta-squared = .05]. These results confirmed that avatars experiencing pain can induce reactions in the observers.

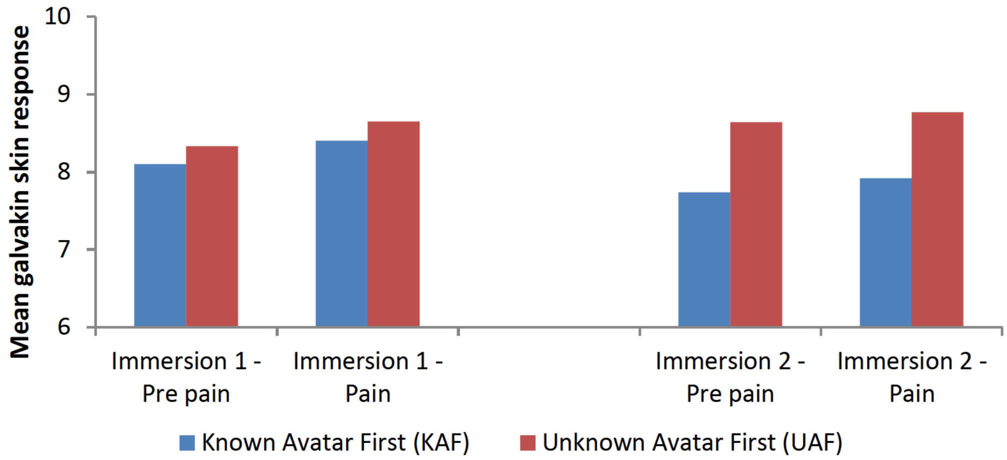

Figure 10: Immediate physiological and behavioural reactions to the pain stressor (N=42).

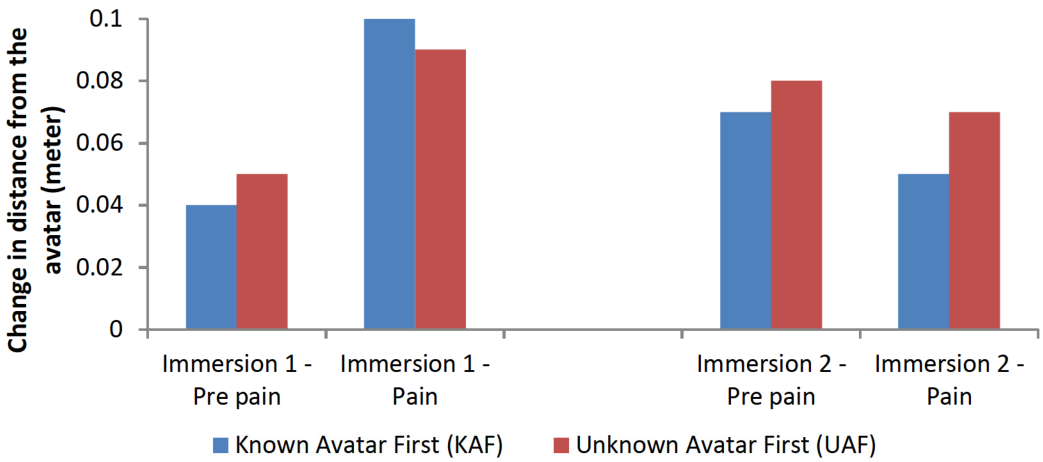

Figure 11: Movement relative to the avatar: recording 12 second segments before and during the acute pain (N=42).

The Time×Condition interactions were not significant for each of the four 2×2 repeated measures ANOVAs. No Conditions main effects were significant either.

3.4.6 Discussion

Results of these analyses suggest that the participant's reactions were the same when observing a known or an unknown avatar. Participants nevertheless found the known avatar more likable and were more empathic toward his pain (based on post-exposure questionnaires). The explanation comes from the "uncanny valley" caused by sensitivity and revulsion to perceived imperfections in near-humanlike forms. As avatars become more realistic, anthropomorphic and behavioural realism set up higher expectations, which in turn could lead to more disenchantment when small imperfections are perceived, either because of behavioural (Garau et al., 2003) or physical discrepancies (Seyama & Nagayama, 2007). Considering the cost and the time of developing a familiar avatar for a large number of trainees, the results do not support the added value of adapting avatars to someone familiar to the military personnel being trained in SMT. Using a suffering avatar proved to be an efficient way to induce stress and, considering that an unknown person is sufficient to induce stress, it was also a cost-effective approach. However, developing stress management skills requires repeated exposure to stressors, something a suffering avatar cannot do more than one or two times. Consequently, this approach would be one among many to be exploited in a stressful virtual environment.

3.5 Summary

Creating a stressful virtual environment was a more challenging task than it seemed at first. This task was all the more difficult, because no one knows how stressful a virtual environment should be in order to train coping strategies. Creating more stressful virtual environments has the advantage of providing room for fine-tuning, including reduction in stress. Thus, more stressful virtual environments were favored.

Another challenge lies in finding the most appropriate trade-off between all these approaches. A few similarities stand out when comparing the checklist of traumatic events selected for virtual environments (see Table 3), the list of VG and VR attributes that are related to an increased level of arousal (see Table 5), and the categories of stressors found in horror VGs (see Table 4). Common elements include seeing dead bodies/uncovering human remains, knowing or seeing someone seriously injured or killed, being unable to help, seeing destroyed homes and villages, and clearing /searching houses. One must be careful not to consider the origin of these elements, for the meaning of military-related stressors is stronger since these elements refer to real situations and to known people, while VGs stressors reproduce fictional situations. As a final point, receiving artillery or demining operations are military specific events not really exploited in VGs.

Could stressful VGs be exploited to create a stressful virtual environment for ImPACT? Many studies listed in Section 3.2 support this idea and Study 1 confirmed the potential of VGs in inducing stress to a military population. Could the stressfulness of VG be further augmented in a safe manner in order to provide a level of stress in a training context closer to what is experienced in theatre of operations? One approach could be to modify an existing VG but the potential of improvement is limited since too many changes could break the fragile conditions that make them stressful. A simpler solution could exploit VR to amplify the stressfulness of the VG. For instance, immersion may amplify the stressful effect provided by violent content. Yet, there are no guarantees that the effects are additive and some combinations may produce the inverse desired effect like when combining a display providing a wide FOV with a VG exploit narrow FOV to create uncertainty.

In summary, two solutions stand out to create ImPACT. A first one would be based on a military scenario that could include traumatic events of the previous list (Table 3) and stressful elements and attributes identified throughout this chapter. This solution would be incorporated in existing military training software like Virtual Battle Space 2 (2007), which is well-known and readily available to military personnel. However, the development of such a scenario could be costly, and expertise required for this task is scarce. A far less risky and costly solution would exploit a VG that has already proved to be effective for inducing stress. This VG would then be slightly modified to satisfy the needs of SMT. Since Study 1 has already shown the efficacy of two existing VGs and since further investigations have not allowed identifying a better solution, it was decided that ImPACT would be based on L4D. The choice was justified on the experimental findings, namely that L4D was more appreciated by our sampling of the military population, is modifiable to some extent and was tested as stressful as a TSST. On the VR side, our study demonstrated that a large stereoscopic TV is the best fit for the current needs: it is cheap, readily available, and appreciated by military personnel.

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4 Design options

How stressful virtual environments can be created has been addressed in Chapter 3. Two questions remain: how biofeedback should be implemented and to what extent can an existing VG be adapted for SMT. Instead of presenting the final choices made for this project, Chapter 4 presents and compares the many possible designs. The objective is twofold. First, it provides a rational behind decisions taken for ImPACT. Second, it would facilitate the development of an alternative SMT system, assuming that more efficient technology has appeared, more funding were available, or important flaws were revealed by ImPACT experimental validation.

4.1 Biofeedback

Developing a biofeedback-assisted training system using VG and VR implies solving many technical challenges and choosing among many design options. Section 2.4 introduced the concept of biofeedback-driven VGs. This section details this topic with the purpose of guiding in the design of ImPACT. First, it justifies why biofeedback-driven VG should be used for SMT and provides a theoretical background on the psychophysiology on arousal/stress. Then, it establishes a list of design parameters and makes recommendations.

4.1.1 Functional requirements

In the context of SMT, a VG incorporate biofeedback in order to achieve many functions:

- Inform the trainee about his level of stress;
- Show to the trainee the efficacy of SMT;
- Inform the instructor about the trainee's level of stress;
- Force the trainee to relax in order to achieve the mission;
- Induce stress to the trainee (i.e. the more aroused the trainee is, the more stressful the virtual environment would be); and
- Adjust the level of difficulty of the VG.

Each of these functions was included in this list for a particular purpose. First, in a stressful situation, a person's attention is rarely focused on the physiological and psychological effects of stress (objective 2 of Section 2.1). Trainees would benefit from being continuously informed of their level of arousal while playing a highly captivating video game so they could learn to stay aware of their stress, better assess it, and take action if necessary. Second, biofeedback does not only convince trainees of the SMT efficiency (objective 3 of Section 2.1) but also reinforces the learning process with a positive reward when good stress management practices are used. Next, instructors could manually adjust the biofeedback parameters and tailor the training session to individual needs. In addition, biofeedback could force the trainees to relax in order to win, similarly to most VGs listed in Section 2.4. Biofeedback-controlled modifications in a VG could also increase the player's stress. For instance, a player's modulated heartbeat sound is considered stressful in itself in a VG (Dekker & Champion, 2007). Finally, trainees' gaming experience could be maintained in optimal ranges, neither boring nor frustrating, by adjusting the game difficulty in real-time (Yun, Shastri, Pavlidis, & Deng, 2009).

4.1.2 Measures of arousal

Human emotions cause physiological changes in the body. Emotions are mediated by the central nervous system, the somatic nervous system and the autonomic nervous system. Together, these systems control the major organs and glands of the body, like the heart muscle and exocrine gland. A direct consequence of this mediation is the ability to estimate a person's emotion from many physiological measures (Bouchard, 2009; Haag et al., 2004) like electroencephalography, electro-oculogram, electromyography, GSR, cortisol, blood volume pulse, electrocardiogram, and respiration.

The measure of human emotions depends on the theory of emotions (Gauducheau, 2009). The two-dimensional space (Russell, 1980) is the most commonly used theory in the domain of biofeedback-driven VGs and measure of user experience in VGs. Figure 12 shows the mapping of a few emotions in the arousal-valence dimensions developed according to this theory. The arousal is the axis of interest to measure the stress. Two measures stand out for the arousal: HR and GSR.

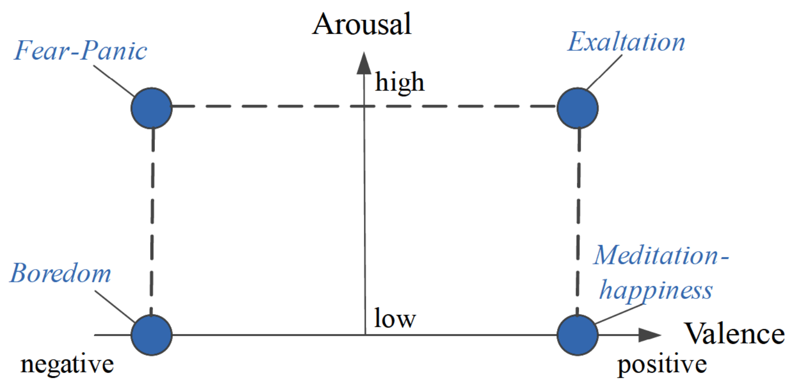

Figure 12: Multi-dimensional representation of human emotions in the arousal-valence plane - from Russel (1980).

Many physiological responses, enumerated in Section 2.2, may be exploited to measure emotional reactions: HR, GSR, electroencephalogram and electromyography. Simpler measures like HR and GSR were exploited first followed by more complex or technologically advanced ones like electroencephalogram and electromyography. For instance, facial electromyography uses two major muscle groups in the face, the corrugator supercilli and zygomaticus major muscle groups, for measuring emotional reactions during VG play. It has been shown to correlate negatively with valence emotions (Nakasone, Prendinger, & Ishizuka, 2005). Another measure, electroencephalography, can also be exploited for assessing complex emotions and has even achieved a commercial stage (e.g. Emotiv Systems, www.emotiv.com). The body also responds to stress by producing cortisol, which can be measured from saliva samples. However, the delay in the body response (many minutes) and the difficulty of measuring it in real-time prevents its use for feedback. It can nevertheless be used for assessing level of stress during the entire experiment.

Since the purpose here is to evaluate the arousal dimension of emotions using mature approaches, only HR and GSR will be considered for feedback.

The most common objective measure of stress is HR response, controlled by the autonomous nervous system. Stress increases HR frequency and stability of the inter-beat intervals. HR is monitored with an electrocardiogram, which records the electrical activity of the heart. Blood pressure could be used to measure HR but it is less precise. Since HR is influenced by breathing patterns, an increasingly popular index is the respiratory sinus arrhythmia amplitude. HR has the advantage of being simple to measure but it is influenced by the subject's physical activity during the assessment. When comparing results between subjects, researchers must compensate for individual differences by adjusting the HR measure in the experiment with resting / baseline HR. This correction is called the law of initial values (Wilder, 1958). Many biofeedback-modified VGs address the individual differences with various solutions: baseline measure, scaled HR (Stach et al., 2009), etc.

Also controlled by the autonomous nervous system, the GSR, also called skin conductance or electrodermal activity, is another measure of stress because GSR linearly correlates with the arousal (Lang, 1995). Changes in the hydration of the sweat glands increase the skin conductivity. This phenomenon is related to sympathetic activity in the nervous system caused by emotional arousal. Many emotions elicit this response (e.g., anxiety, sexual feelings, guilt).

Any arousal changes should be reflected in the VGs immediately, so that the trainee receives immediate feedback. Otherwise, with long latencies, the trainee could wrongly associate his current level of arousal influenced by a recent stressful VG event with a feedback resulting from an older level of arousal influenced by a previous event. Such a high resolution and timely feedback relies on phasic psychophysiological measures, which are interested in the immediate player's response to specific VG events, as opposed to tonic which averages physiological measures across a long time period (Ravaja et al., 2005). The ability of phasic measures to determine players' emotional reaction to precise VG events is supported by a growing body of evidence (Ravaja, Saari, Salminen, et al., 2006; Ravaja et al., 2005, 2008; Weber et al., 2009). Among these approaches, GSR presents an interesting phasic response measure because it peaks rapidly after introduction of emotional stressors and progressively fades out afterward.

Ad-hoc methods for calculating players' emotions from physiological measures have been exploited with some success. More formal and robust methods, based on many physiological measures and complex mathematics and algorithms, have been also proposed (Arroyo-Palacios & Romano, 2010) including fuzzy network (Mandryk, 2007), neural networks (Haag et al., 2004), linear discriminant analysis (Kim & André, 2009), and Bayesian network (Nakasone et al., 2005). However, none of these formal methods has been judged suitable since they 1) aim at distinguishing several emotions, not just measuring arousal in a reliable way and 2) cannot deal in a satisfactory manner with the individual differences. Consequently, based on previous comments and other literature (Benoit et al., 2005; Katertsidis, Katsis, & Fotiadis, 2009; Schwartz, 2003; Shi et al., 2010) on biofeedback, combining both HR and GSR in an ad-hoc manner was identified as the most suitable solution. In this context, attention should be paid to hard problems (Nakasone et al., 2005) like the baseline, timing of data assessment, and intensity of emotion.

4.1.3 Design principles

Many design decisions must be taken before implementing biofeedback into a VG. Table 10 lists a few of the design parameters found in the literature and for which previous empirical studies provide some guidance.

Table 10: Design parameter for a biofeedback-driven VG.

Design parameter	Description	Examples/Comments
Noticeability of the effect	An implicit feedback is not easily identifiable but still influences the gameplay. An explicit feedback is obvious to the trainee (Dekker & Champion, 2007; Fairclough, 2008; Kuikkaniemi et al., 2010).	In an implicit biofeedback, the ability to aim in FPS VGs, or to drive in racing car VGs, can be slightly reduced. An explicit one would be changing the type of weapon.
Amplitude of the effect	Feedback effects can be more or less important in the VG. The amplitude could influence the noticeability.	The amplitude is related to the calibration/baseline of physiological measures (Stach et al., 2009).
Time window for measurement	Physiological measures, even the phasic ones, are usually averaged over a period of time to match the duration of an emotion and to filter out incorrect physiological readings.	Two (Dekker & Champion, 2007; Haag et al., 2004), four (Levenson, 1988), five (Nakasone et al., 2005), or seven seconds (Nasoz, Alvarez, Lisetti, & Finkelstein, 2004)
Delays	Immediate feedback is usually preferred but sometimes a delay can prevent incongruent situations. Data filtering also cause delays. Another reason for delays is the physiological “inertia” to emotion (Dekker & Champion, 2007; Kuikkaniemi et al., 2010; Nakasone et al., 2005).	The running speed could be changed in real-time but increasing the number of enemies would require to spawn them outside the player’s field of view, assuming that nothing justifies they can appear suddenly from nowhere.
Loop sign	A positive or negative feedback loop amplifies or reduces respectively the emotion caused by an event, leading to a divergence until a ceiling or a floor is reached. A negative feedback loop is more stable if no delays exist (otherwise it causes oscillations).	In a positive feedback loop, a VG would become more stressful as the trainee feel more under stress when hearing his earth beat, resulting in an additional increase of the trainee’s level of stress. The inverse loop sign is also possible.
Reinforcement	A feedback can be implemented as a reward or a penalty. This is independent of the loop sign of the feedback (Allanson & Mariani, 1999).	A reward can be an unusually fast moving speed for a game character while a penalty can be a slow /at rest character.
Game flow	A feedback can be well integrated with the storyline (Csikszentmihalyi, 1991), i.e. being appropriate and enjoyable. By contrast, an inappropriate feedback can break the game flow or change the VG balance. (Kuikkaniemi et al., 2010).	Flashing the lights in dark areas is likely to be considered as well integrated but the same feedback in daylight areas is unnoticeable and then useless.
Automation	Feedback parameters can be calculated automatically or be controlled by a human operator (Mandryk, 2007).	Baseline, timing, intensity of emotion are hard problems difficult to solve with automatic approaches.
Modality	Many modes can be used to transmit feedback to the trainee.	Sound, visual effect, character and object control and behaviour, artificial intelligence, etc.

Based on the previous literature review, the implementation of a training system should comply with the design principles enumerated in Table 11.

Table 11: Selection of the decision parameters values for SMT.

Design parameter	**Value**
Noticeability	Perceptible by the participant, i.e. explicit
Amplitude	Adjustable by the instructor
Time window	5 seconds
Delays	0-5 seconds
Loop sign	Positive
Reinforcement	To be determined
Game flow	Aligned with the storyline / ensured the game flow Little effect on the game balance
Automation	Manual control, by the instructor of the amplitude and baseline. Initial baseline recording.
Modality	One visual and one auditory

4.2 Potential of VGs modifications

The last few years have seen the arrival of many military game-based training systems. Some of the first systems suffered of a lack of realism and high development costs (*Full Spectrum Warrior*, 2004). Nevertheless, game-based training systems matured, became widespread, and demonstrated their capability to meet learning objectives (Korteling, Helsdingen, Sluimer, van Emmerik, & Kappé, 2011; Woodman, 2006).

Modern armies integrate into their training programs various game-based training systems. For instance, *Virtual Battle Space 2 (2007)* (VBS2) (www.vbs2.com) offers realistic battlefield simulations and the ability to operate land, sea, and air vehicles. *UrbanSim* (2012) allows practising battle command in complex counterinsurgency and stability operations. Finally, in *Bilateral Negotiation Trainer* (www.peostri.army.mil/), soldiers can practise their skills in conducting meetings and negotiating in a specific cultural context.

The development of these training systems requires substantial resources. Unfortunately, few projects have a sufficient budget to develop from scratch a complex training system that can meet a specific set of training objectives such as those targeted by this project. In order to develop an effective VG-based training system able to support the practice of arousal control in a sufficiently stressful context, the training system must integrate specific functionalities such as scenario authoring, real-time monitoring, control of gameplay, and after-action review of the performance (Freeman et al., 2006). Modifying an existing VG based on large development budget is a more frugal option, especially if the objective is to validate a proof of concept. Several titles, like *Unreal*

Tournament (2000) or *Half-Life 2* (2004) sequels provide enough modification capabilities to hopefully meeting ImPACT design requirements.

VG modifications require specialized knowledge such as object-oriented programming, engine architectures, custom scripting languages, and so on, especially when the documentation provided by the VG developer is insufficient or simply inexistent. A skilled workforce supported by proper "modding" guidelines can overcome programming challenges or limitations. This section provides such guidelines by identifying the options for creating serious games from existing VGs. It first enumerates and classifies the possible forms of modification (modding forms) and then identifies the means for implementing these modifications in VGs (modding techniques). Not only is this analysis is relevant to ImPACT but also to any serious gaming projects with limited budget or for prototyping.

4.2.1 Modding forms

A large underground community called "Modder" is interested in VG modifications, called "Modding". The purposes of modding are various (Scacchi, 2010), namely entertaining, R&D, engineering, etc. *ModDB* website (www.moddb.com/) provides an extensive list of modding projects created by this community. For ImPACT, four modding forms are required in order to achieve training goals defined previously: GUI customization, VG content customization, I/O customization, and immersive customization.

GUI customization

The GUI customization, a widespread form of modding, consists in adapting the GUI in order to optimize player efficiency during the game experience. Some training solutions, such as VBS2, allow the GUI to be customized by means of software development kits or scripting capacities. The three most common GUI changes are (1) the development of better information representations (see Figure 13), (2) the addition of a head-up/overlay display (see Figure 14) over the scene to support the realism of environmental constrains, and (3) the reorganization of widget distribution and the creation of shortcuts able to trigger a sequence of scripted events.

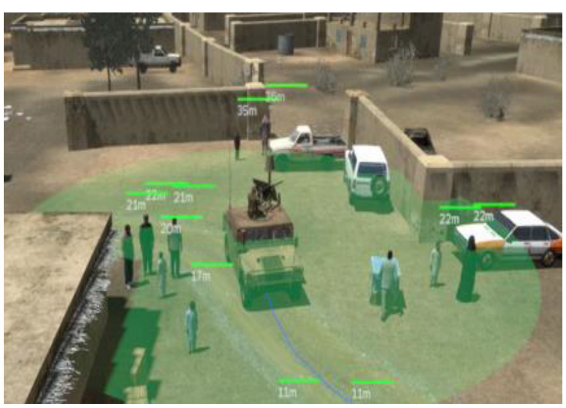

Figure 13: Highlighted information into VBS2.

Figure 14: Head-up display of VBS2 Fires.

ImPACT requires that the trainee/player be informed of his level of stress based on physiological measurements. GUI customization offers the capability to display this data on the player's head-up display. In addition, GUI customization can help to standardize and constraints training and experimental sessions. The idea is to restrict player's actions by disabling specific keyboard keys and widgets, like limiting action to *Move* and *Attack Opponents* with a unique weapon.

VG content customization

Content customization, another prevailing form of modding, consists in modifying one or many aspects of the VG such as in-game objects, terrains, textures, animations, lighting, sound, music, camera settings, artificial intelligence rules, scripted actions, gameplay rules, levels, maps, shaders, etc. VG community (e.g. ModDB) provides numerous examples of modified VGs. The potential of content customization inspired the *Canadian Forces Army Learning Support Centre* (www.armyelearning.ca/) in the development of the virtual tactical simulator *Canadian Forces: Direct Action* (2008) (see Figure 16), a mod of *S.W.A.T.4* (2005) released by Irrational Games (see Figure 15), where police officer textures were replaced by military ones.

Figure 15: S.W.A.T. 4.

Figure 16: Canadian Forces: Direct Action.

Many VG companies, such as Valve (www.valvesoftware.com/), Crytek (www.crytek.com/) and Epic Games (www.epicgames.com/), provide editors to assist mod makers in their content customizations. A SMT application could benefit from these modifying capabilities in order to tune the scenario for the purpose of conducting experiment or correcting potential ethical issues related to gore or sexual themes aspects.

I/O customization

I/O customization exploits external data to enhance game experience. Many research projects (see section 2.2) have applied this customization form in order to study the concept of biofeedback-driven VGs. Once again, VG architecture must provide the required functionalities for type of modding. Second, *I/O customization* could also help to analyse players' game experience by exporting game variables such as the number of shots fired. The VG *Half-Life 2 Episode 2* (2004) includes a tracking mechanism that reports players' actions. Data are collected to detect emergent problems and create better experience. Figure 17 (steampowered.com/) shows graphs that summarize length of typical VG sessions to assess the level of difficulty of the map. Figure 18 shows hot action spots where enemies are killed on a map of the VG.

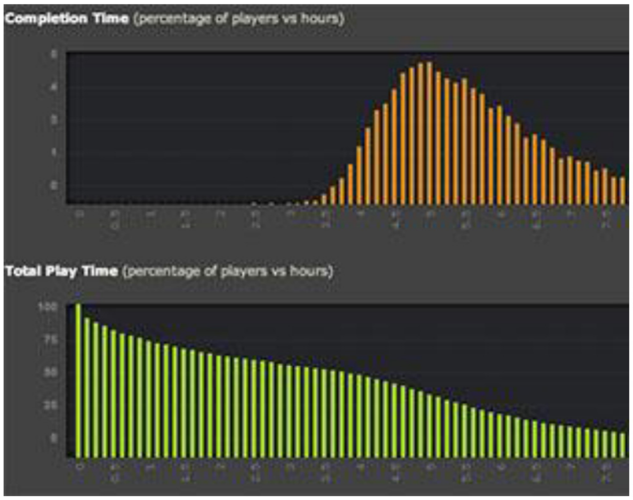

Figure 17: Completion time and total play time in Half-Life Episode 2: VG analysis.

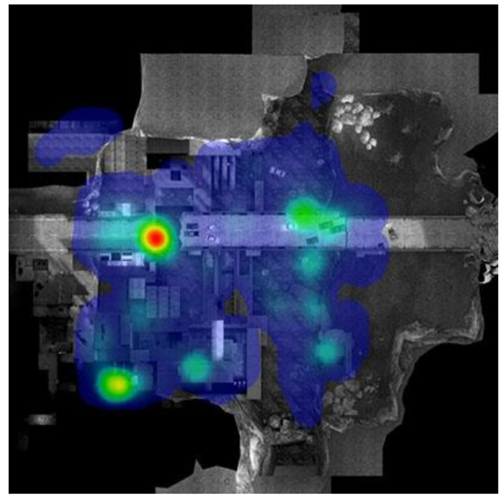

Figure 18: Dead map in Half-Life Episode 2.

I/O customization is an essential feature for importing a VG external data stream coming from biometrics sensors and for exporting data used in experimental analysis and after-action reviews of training sessions.

Immersive customization

The last modding form focuses on the capacity to integrate immersive technologies into the software architecture to enhance the feeling of presence during the game experience. Stereoscopic visualization, multiple displays, gesture recognition devices, 3D surrounds sound are some examples of such technologies.

Existing solutions can adapt VGs to some VR display. For instance, 3D Vision (www.nvidia.com) enables stereoscopic visualization for up to three displays. This technology does not support most advanced immersive systems though. For instance, a CAVE facility (see Figure 19 and Figure 20) like the one available in DRDC Valcartier requires major VG software modifications, a feature currently not supported by any existing solutions. Missing functionalities include multi-displays rendering, off-axis real-time stereoscopy, VR device control, etc. External libraries like CaveUT (Jacobson & Lewis, 2005) for Unreal and getReal3D (www.mechdyne.com) for Unity facilitate the adaptation of some VGs to the CAVE. Immersive customization would allow implementing many VR attributes that influence the users' arousal/stress and maximizing their involvement into the game.

Figure 19: CAVE Facility at DRDC Valcartier.

Figure 20: Experiment at DRDC Valcartier.

Figure 21 summarizes modding forms by representing them in a generic VG architecture. The allocation of some elements to customization form groups may be debatable. Head-up display is one of them. It can be seen as a way to customize the GUI or enhance immersion.

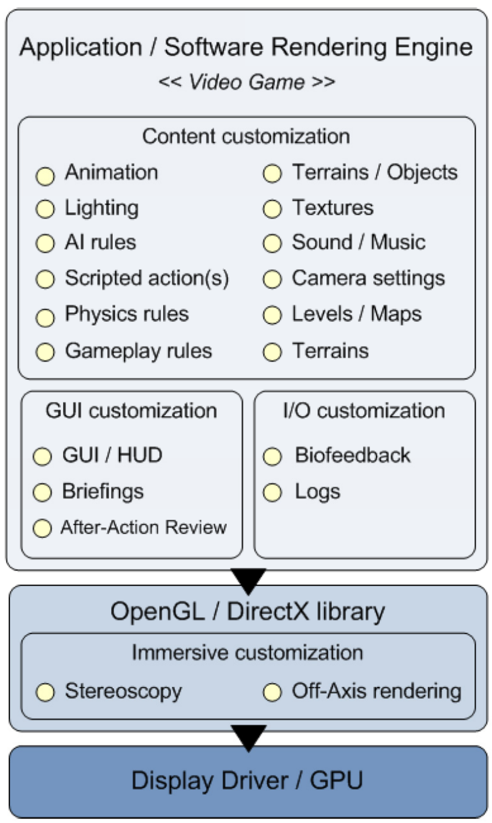

Figure 21: Distribution of modding forms into a generic VG architecture.

4.2.2 Modding techniques

Modding techniques depend on the type of VG software architecture. For instance, the GUI could be customized by modifying scripts or configuration files on a first architecture, and programming an external component on the second architecture. Although the result is the same for the player, the first approach may be more limiting in the long term if more modifications are required. This aspect must be assessed early in the project in order to identify required human resource expertise.

Level editor

A level editor is a GUI software application able to design or modify levels, maps, and campaigns of VGs (see Figure 22). Level editors assemble 3D objects together in order to create complex scenes to which apply behaviours and events. When available, the level editor is included within the VG distribution or developed by a game community. In general, level editors are easy to use but mainly devoted to the graphical aspect of game content customization modding form. To make more complex changes, software development kits or scripting approaches are more suitable.

Software Development Kits and scripting

Software development kits, such as *Source SDK* (source.valvesoftware.com) and *CryENGINE* (mycryengine.com/), and scripting languages, such as *Unreal Script, (*www.unrealengine.com), offer the best customization possibilities. Depending on the openness of the VG architecture, these techniques allow modders to change or enhance the entire spectrum of VG customizations. Since these approaches require programming and sometimes compilation, they offer more modding capabilities when third party software can be linked with them. Overall, scripting is slightly less restrictive than software development kits, even though there are scripting approaches offering high level of customization. Both approaches are suitable to solve I/O and immersion customization challenges for ImPACT.

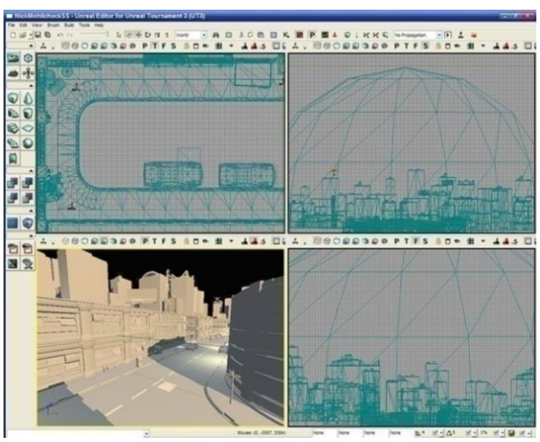

Figure 22: Modding technique exemplified with a level editor (UnrealEd).

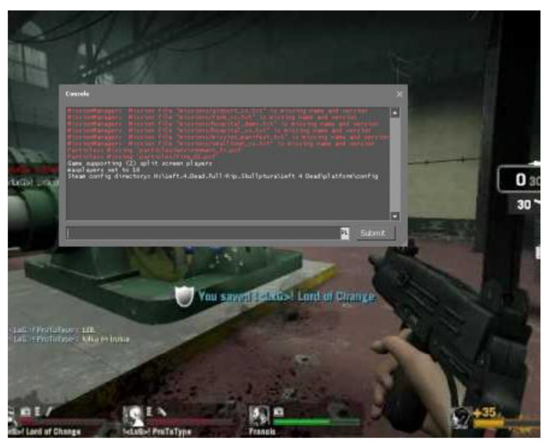

Figure 23: Modding technique exemplified with in-game command line console (L4D).

In-game command line console and configuration files

These techniques, available in L4D for instance, allow modders to parameterize existing variables made available by the VG architecture. In general, these variables are closely related to GUI and VG content. Examples of parameterization include:

- VG avatars: speed, attack capabilities, stamina, artificial intelligence, etc.;
- VG environment: lighting, seasons, physics behaviours, etc.;
- player experience: heads-up display, VG rules, etc.; and
- computer system: video resolutions, sound levels, network settings, log system, etc.

An in-game command line console permits changes during the VG play (Figure 23) whereas the configuration files allows changes prior the VG is launch.

File replacement

File replacement technique consists in modifying or replacing files provided in the VG distribution, including the sound files, the 3D model files and the textures files. This modding technique requires known and editable file formats, usually achieved via dedicated editors. This technique cannot modify the VG in real-time.

Wrapper

The last technique consists in intercepting any function calls to a specific software dynamic library by redefining the original version. When the application starts, the wrapper library is loaded instead of the original one. This modding approach can extend existing functionalities, including those related to sound and rendering. For instance, it could be used to add a post-rendering HUD to display debugging information, modify projection matrices in real-time to apply stereoscopic effect or manage multi-display rendering for CAVE projection.

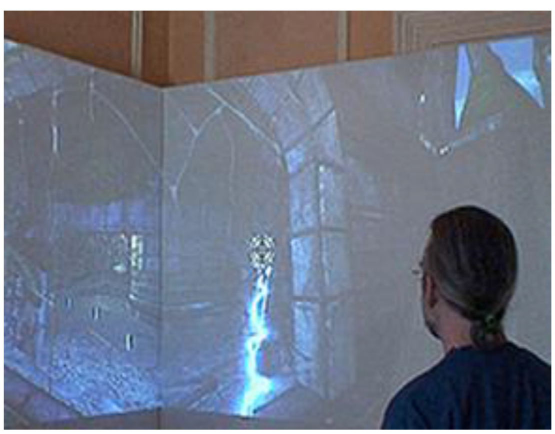

Figure 24: Modding technique exemplified with wrapper (CaveUT).

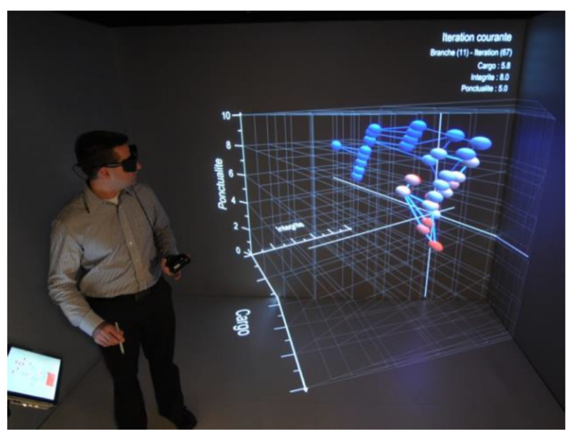

Figure 25: DRDC project using wrapper into the CAVE Facility (IMAGE).

The wrapper approach is inspired from the Virtual Reality Graphics Library (VRGL) and CaveUT libraries which intercept the application's OpenGL calls, introduces needed changes, and passes the requests to the true OpenGL library (www.publicvr.org/) (see Figure 24). The wrapper approach is also exploited at DRDC Valcartier in the IMAGE project (Lizotte et al., 2008) deployed in a CAVE facility (see Figure 25). Table 12 summarizes the seven modding techniques described above.

Table 12: Modding techniques.

<table>
<tr><th>Modding techniques</th><th>Description</th><th>Associated customization forms</th><th>Examples</th></tr>
<tr><td>Level editor</td><td>GUI-based development.</td><td>VG content customization (especially for graphics aspects).</td><td>Animation, Levels / Maps, etc.</td></tr>
<tr><td>Software development kit</td><td rowspan="2">Various object-oriented programming forms (C++, C# ...) scripting forms (Phyton, LUA ...) or custom languages.</td><td rowspan="2">All customization forms.</td><td rowspan="4">GUI, Gameplay rules, Logs, etc.</td></tr>
<tr><td>Scripting</td></tr>
<tr><td>In-game command line console</td><td>Functions called through a command shell interface embedded into the VG.</td><td rowspan="2">All customization forms (exclusively for existing VG settings and variables).</td></tr>
<tr><td>Configuration files</td><td>Linear programming forms embedded in files.</td></tr>
<tr><td>File replacement</td><td>Modification or replacement of original file contents.</td><td>GUI & VG content customization forms (done offline).</td><td>Terrains / Objects, Sound / Music, Textures, etc.</td></tr>
<tr><td>Wrapper</td><td>Interception of function calls by creating software component minic of the original one.</td><td>Immersive & I/O customization forms.</td><td>Stereoscopy, Off-Axis rendering, Heads-up displays, etc.</td></tr>
</table>

4.2.3 Modding forms and modding techniques

Since there are neither clear boundaries between the modding techniques nor a clear definition of what a level editor should do or not, it is difficult to identify the most adequate technique to achieve a customization form. A deep understanding of the VG architecture capabilities is essential before committing time and resources to any modding techniques. Table 13 summarizes the potential modding form achievable by each modding technique. It is based on a review of VG architectures (Sheldon et al., 2009).

Table 13: Matrix of modding forms vs. modding techniques.

	Modding forms			
Modding techniques	**GUI customization**	**VG content customization**	**Data flow customization**	**Immersion customization**
Level editor		**G** - b		
Software development kit	**X**	g - **B**	**X**	**X**
Scripting	x	g - **B**	x	x
In-game command line console	x	g - b	x	x
Configuration files	x	g - b	x	
File replacement	x	g		
Wrapper	x		x	**X**

Legend:
Bold upper case: strong modding potential
Normal lower case: limited modding potential
G/g: graphics aspects
B/b: behaviours aspect
X/x: whole aspects

4.2.4 Modding for ImPACT

This section presents an overview of the modding options for L4D, the VG retained for designing ImPACT. First, L4D SDK possesses the mechanisms to implement the incoming data streams required for the biofeedback. These data streams, such as calculated arousal or commands, would be linked with specific VG variables having the capability to modify the player's gameplay experience in real-time. Second, L4D possesses a scripting capability and a level editor that could be used to remove any unethical aspects and improve the realism of the training context. Scripting capability could address minor VG content changes (ex.: disable enemies, highlight objects) while level editor could address major ones (ex.: add obstacles, modify mission pathway). The player's sense of belonging could be supported by using the file replacement technique to replace textures of avatar clothes by others imitating those used by CF soldiers. Finally, L4D was tested compatible with the wrapper modding technique so that a HUD could be added to simulate variation in the field of view of the player. In summary, L4D is sufficiently customizable to implement missing training functionalities. Section 5.2 will present details of ImPACT implementation.

4.3 Summary

Implementing biofeedback and modifying a VG for training presents many technological challenges. Chapters 3 and 4 showed the large variety of possible implementations. The reader should keep in mind that the technologies were retained commensurate with available funding and in line with project objectives. Nevertheless, documenting the process itself provides may benefit future developments or improvements.

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5 ImPACT

The technologies and methods that could produce the training system aimed in Section 2.1 have been identified in the previous chapters. Current chapter presents the architecture, the implementation and the training program of ImPACT. The description is at high level and many technical details were omitted since they have little effect on ImPACT performance.

5.1 Architecture

A system architecture is a high level representation that describes the structure, the behaviours and more views of a system. In a world of constant evolution, cost reductions, and unanticipated needs, an architecture must be generic and extensible. Software framework and middleware are examples of generic approaches to create software. Few middleware and frameworks have been developed in the domain of biofeedback-driven VGs. For instance, some middleware (Saari, Laarni, Ravaja, & Turpeinen, 2005; Saari, Turpeinen, Kuikkaniemi, Kosunen, & Ravaja, 2009) and a psychophysiology logging framework (Stellmach, 2007; Sasse, 2008) provide basic functionalities from which biofeedback-driven VGs can be developed. However, none of these solutions were retained for ImPACT, for they focus on more complex emotions. Instead, a simple and custom but still generic and extensible solution was proposed.

The ImPACT architecture was developed using the Unified Modelling Language (Booch, Rumbaugh, & Jacobson, 2005), a standardized modeling language designed for object-oriented software engineering. The following sections present the three kinds of diagrams (views) that were used to create and document the ImPACT architecture: use case, class, and deployment diagrams. The ImPACT architecture complies with a handful of design principles, including ensuring independence of modules, minimizing the complexity, and a providing a user-friendly approach in its use (automatic parameter settings, macros).

5.1.1 Use case

The use case diagram, showed in Figure 26, describes the interaction between ImPACT and its users. Only the most important use cases are presented here. Three kinds of users were identified: the trainee, who plays the VG and receives visual and audio feedback based on his physiology; the instructor, who accomplishes fine-tuning and control over the VG; and the system operator, who sets up the training session and ensures everything works normally.

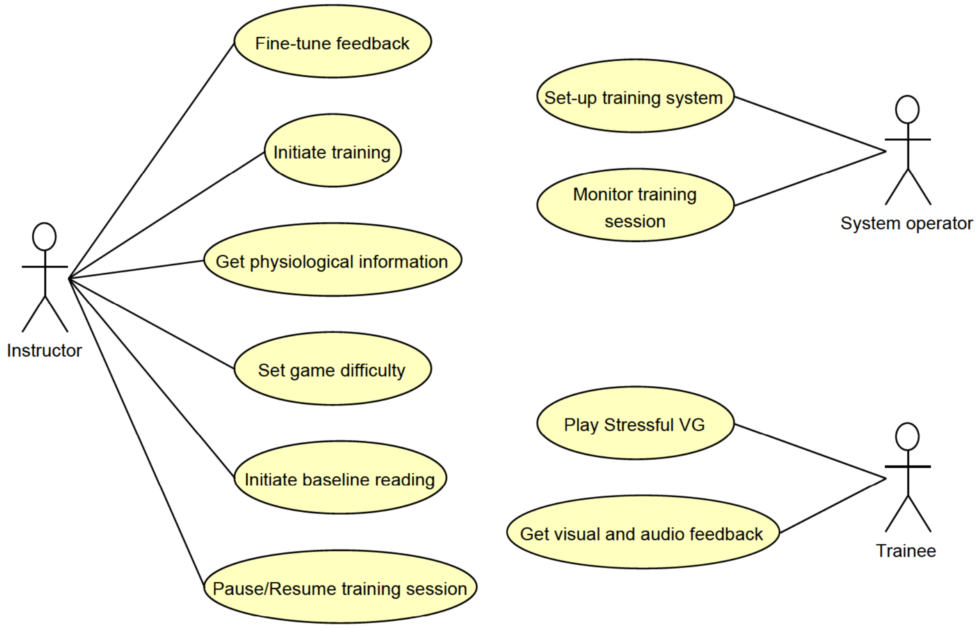

Figure 26: ImPACT use case diagram.

5.1.2 Structure

The structure of a system can be described with a class diagram, which shows the main modules and their relationship. Figure 27 shows the five main packages of ImPACT.

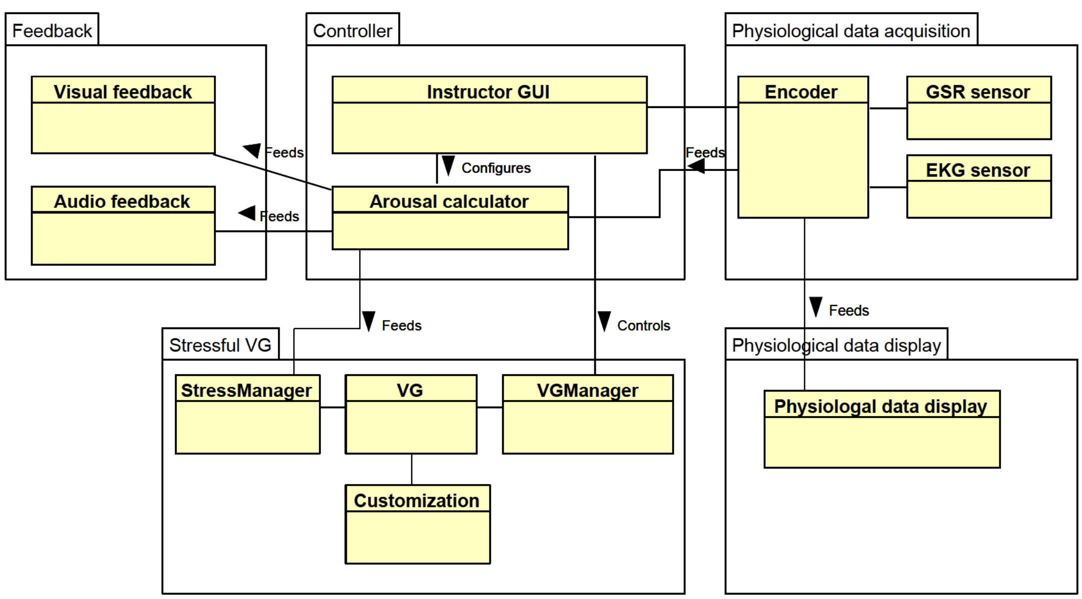

Figure 27: ImPACT class diagram.

First, the *Stressful VG* package comprises four elements that achieve the following functions: a) the *StressManager* class adjusts the level of difficulty of the VG according to the trainee's level of arousal (Relax-to-win); b) the *VGManager* class executes the commands (start, pause, set difficulty level) received from the instructor GUI; c) the *VG* class stresses, "entertain", captivates and provides a "mission" objective to the trainee; d) the *Customization* class adapts the VG to the training needs. The *Controller* package includes two classes: the *Instructor GUI* class, which provides the instructor with all functionalities corresponding to its use case, and the *Arousal calculator* class, which determines the level of arousal according to the sensitivity and HR/GSR balance provided by the instructor and to the baseline recording. Another package, the *Physiological data acquisition*, captures biometric information from the trainee and encodes it for its use by other packages. The *Physiological data display* package shows the instructor the current and past physiological data in a temporal graph. This module is tailored for the instructor by pre-setting the visual arrangement and the kind of sensors to be displayed. Finally, the *Feedback* package uses auditory and visual medium to inform the trainee about his level of arousal. This package complies with the design recommendations given in Section 4.1.

5.1.3 Deployment

In Unified Modelling Language, a deployment diagram depicts the hardware components used for deploying the system and the software installed on this hardware. Although such a diagram may comprise many implementation details, one must avoid committing too much in terms of technology in order to keep the architecture as generic as possible. Figure 28 shows both the generic—technology agnostic—and technology specific deployment diagrams of ImPACT. Selected technologies are identified in parenthesis. Devices, including the hardware for visual and auditory immersion and for the biofeedback, are also indicated. In addition, the deployment in computers, applications, files, and other "components" (driver, library, software component, scripts) is showed.

The most computationally and graphically intensive elements are located on the VG computer. The original VG required a few adaptations to make it suitable for training, including some configuration files and plug-ins (*Mutators* and *Executors*), and a C++ extension. The extension, named *TCPInterface*, provides communication functionalities with the controller. For simplicity's sake, many details were excluded from the stressful VG component of the deployment diagram. For instance, the *Executors* component contains the *StressManager* and *VGManager* classes while the *Mutators* component contains other game modifications that were impossible to implement via a configuration file. The instructor computer contains the controller and the physiological data display. Both components require small processing capacities and therefore can be located on a less powerful laptop.

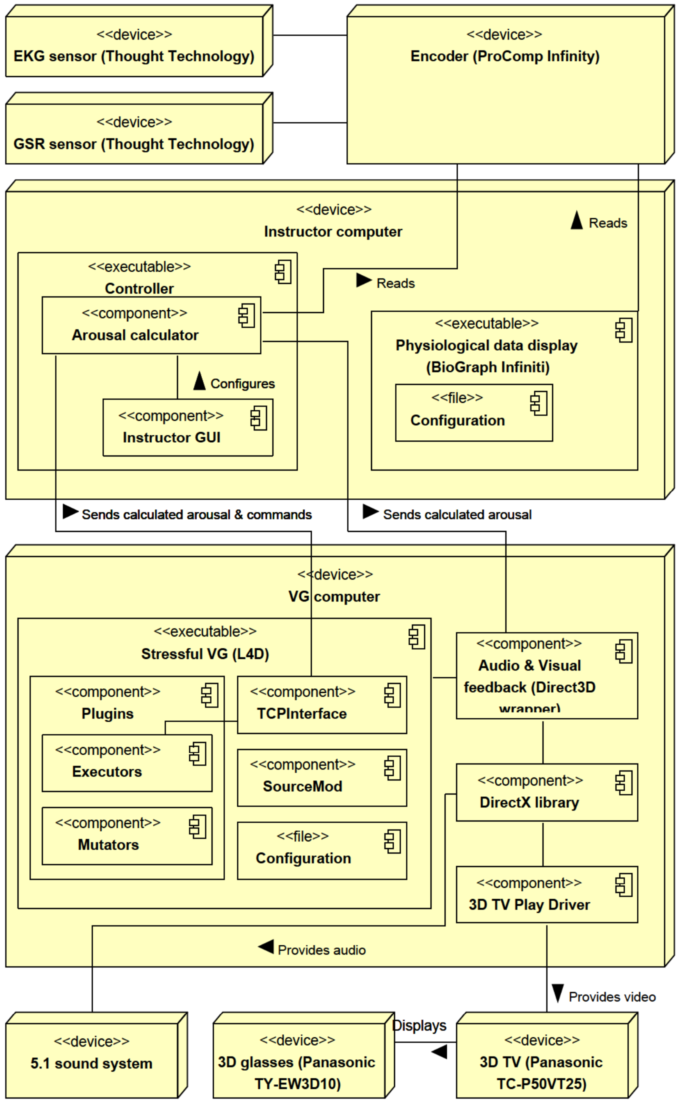

Figure 28: ImPACT deployment diagram.

The feedback package is located on the VG computer. It exploits the adapter pattern, also called the wrapper pattern or simply wrapper, to achieve its functions. First, the DirectX wrapper intercepts graphic instructions usually received by the Direct3D library and adds an overlay when the application ends the scene so that the user perceives visual feedback as if it was part of the VG. Second, the wrapper produces audio feedback by generating sounds of heartbeats and forwards it to the DirectSound library. This library then combines this sound with audio data coming from the VG, giving the illusion that the sound comes from the VG itself. This approach, depicted in Figure 29, has the advantage of not requiring any modifications to the VG. Consequently, the feedback can be applied to any DirectX applications.

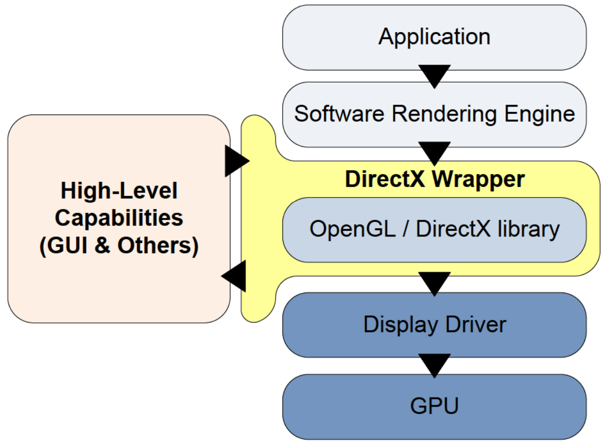

Figure 29: DirectX wrapper used for implementing visual and auditory feedbacks.

5.2 Implementation

This section presents the implementation of the five main ImPACT packages, namely *Stressful VG*, *Feedback*, *Physiological data display, Controller/Instructor GUI,* and *Physiological Sensors*. A description of VR technologies selected for immersing trainees and an example of deployment are also provided.

5.2.1 Stressful VG

The stressful VG is a modified version of L4D (© 2008 Valve, United States; ESRB rated as "Mature"). This horror / FPS VG was found in a previous study (Bernier et al., 2009; Bouchard, Bernier, et al., 2012, 2011) to be sufficiently stressful and yet appreciated by soldiers as a training stressor. The VG was further modified to increase stress level and trainees must play in team (multi-player mode) against the computer.

The mission objective is defined as follow: two trainees are part of a team of three, two soldiers and one civilian female, who are survivors of an apocalypse that created zombies. They have to exit a hideout and reach a rallying point on a farm while hordes of infected zombies (see Figure 30; maps farm04 and farm 05) try to kill them, and without having the defenceless civilian being killed. To increase stress, the following modifications (from the default difficulty level) of the VG were performed with *SourceMod*: (a) the number of zombies was increased by 66%, their artificial intelligence by 50%, their resistance by 50% and their rapidity by 80%; (b) the special infected zombies were increased in number (33% more boomers, hunters smokers, 2% more tanks, no witches), in resistance to damages (50% for boomers, 40% for hunters, 40% for smokers and 25% for tanks), and in rapidity (58% for boomers, 66% for hunters, 48% for smokers and 48% for tanks), (c) the delay for spawning new hordes of zombies varied between zero to 60 seconds, (d) the damages caused by friendly fire was increased by 3000%, and (e) the civilian medic's behaviour was erratic so she could walk in the line of fire at any time and killed. These modifications were based on trial and error by personnel developing ImPACT.

Figure 30: Screenshots of the VG L4D as played during the ImPACT program.

5.2.2 Visual and audio feedback for the trainee

The design of the biofeedback complies with the values provided in Table 10. Feedback on arousal is provided in part with visual feedback. As the trainee's arousal increases, the display of the VG on the TV is reduced with a red texture that partially obstructs its field of view, up to a point where only a small oval portion of the centre remains visible (see Figure 31). The field of view is not totally obstructed in order to avoid masking the action and stirring a sense of loss of control, but still it interferes sufficiently with the game to require corrective actions from the user. It also illustrates the concept of tunnel vision that is associated with extreme stress (Grossman & Christensen, 2008). The sound of a pumping heart audio feedback complements the visual feedback by progressively increasing in rate and loudness. Pre-recorded heartbeats start to provide biofeedback before the red texture becomes visible and continue to increase in pace and volume after the red texture reaches its full opacity. This allows trainees to pay attention to heartbeat, which is a natural indicator of stress level, and keeps providing useful feedback after the visual display reaches its maximum level. Both forms of biofeedback are clearly noticeable. Hearing heartbeats is a positive reinforcing feedback—the more stressed a trainees feels, the more stressful the heartbeat becomes. Both feedbacks are implemented as penalty form of reinforcement. In addition, the feedbacks do not disrupt the game flow. Other design parameters, including how the arousal is calculated from the HR and GSR measures, will be covered in the following section.

Figure 31: Illustration of the visual feedback (progressively more opaque red texture) overlaying the game as arousal increases.

5.2.3 Physiological data display

The biofeedback recording system allows instructors to visualize on a graph the evolution of a trainee's HR and GSR in real-time. It uses two channels / screens provided by the Biograph Infinity software from Thought Technology (see Figure 32). This information is displayed on the instructor's laptop computer and can be used to detect problems with the biofeedback device and, at the end of the training session, to show to trainees change in their physiology. The Biograph Infinity software is tailored for ImPACT by selecting the sensor data to display and the visual layout.

Figure 32: Screenshot from the instructor's laptop during the immersion, with the physiological response (left) and the GUI (right) (Published with the permission of www.thoughttechnology.com)

5.2.4 Instructor GUI and controller

The GUI provided on the instructor's laptop, next to the physiology level window (see Figure 33), allows fine tuning of the biofeedback delivered to the trainee. By referring to a two-minute baseline recorded while loading the VG, both physiological parameters are integrated to provide feedback on arousal. The instructor can adjust in real-time: (a) the sensitivity of the feedback, (b) the relative weight of the HR versus the GSR, (c) revise the baseline level in order to maximise the chance of trainees benefitting from the biofeedback (e.g., if trainees reduce their stress level below baseline they can still get useful feedback on their reaction to stressful events occurring in the game), and (d) increase the difficulty level of the VG (e.g., significantly increasing the number, health and rapidity of the enemies). At the end of the immersion, the weight and sensitivity settings are saved to be available for subsequent immersions.

The controller, which includes the instructor's GUI and arousal calculator, is developed in C#. The controller communicates with Biograph Infinity through a component object model interface and with L4D and the Direct X wrapper through a TCP connection. By establishing the connection from the host to the client running L4D, the data is sent over the network to the computer(s) running L4D.

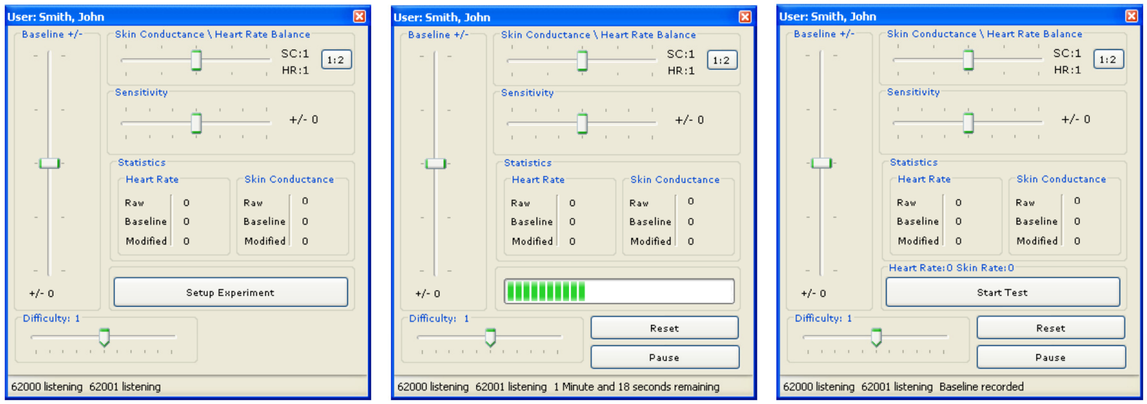

Figure 33: GUI for the instructor as it was displayed before starting the experiment (left), during the baseline (middle) and when ready to begin the immersion (right).

Based on the previous literature review on biofeedback, values in Table 11, and trial and error iterations, arousal level is estimated according to Eq. (1).

$$Arousal = c\left[W\left(\frac{Mean\ during\ 5\ sec._{HR} - Mean\ baseline_{HR}}{Std\ dev\ of\ baseline_{HR}}\right) + W\left(\frac{Mean\ during\ 5\ sec._{GSR} - Mean\ baseline_{GSR}}{Std\ dev\ of\ baseline_{GSR}}\right)\right] \quad (1)$$

By default, the HR and the GSR were given equal importance, or equal relative weight “W”. The sum of both physiological parameters was multiplied by a constant “c” to allow an increase in the sensitivity of the feedback. The physiological data are sampled at 5 Hz. Every 200 milliseconds, data averaged in the last five seconds are transmitted to the feedback and physiological data display modules.

5.2.5 Physiological sensors

HR and GSR are captured with a ProComp Infinity, wireless-enabled with TeleInfiniti Compact Flash T9600 from Thought Technology. A Polar T31 wireless transmitter belt from Polar captures the trainee’s HR and transmits it to a wireless electrocardiogram receiver, from Thought Technology, connected to a ProComp Infinity. A wired skin conductance sensor from Thought Technology, installed on the right hand fingers of the trainee, transmits the GSR to the ProComp Infinity (see Figure 34).

Figure 34: ProComp multi-modality encoder (left), GSR sensor (middle), and HR sensor—Polar belt and receiver—from Thought Technology Ltd.

5.2.6 Immersion

A previous study (Bernier et al., 2009; Bouchard, Bernier, et al., 2012, 2011) favoured common-off-the-shelf hardware over exotic and more immersive system like the CAVE; the large 73-inch stereoscopic Mitsubishi TV was the preferred configuration. At the time of the study, only 3D-Ready TVs were available. Since that time, the market of 3D exploded. Manufacturers reduced the cost and improved the quality of their products. Consequently, it was decided that ImPACT would be based on a more recent 3D TV, a Panasonic Viera TC-P50VT25 3D Plasma TV provided with TY-EW3D10 3D glasses.

Most VGs created before 2011 were not designed to work in stereoscopy, a feature made popular after their release on the market. To solve this problem, NVIDIA developed a special driver called 3D Vision that enables the stereoscopy on most VGs. 3D Vision was used in Study 1 (Bernier et al., 2009; Bouchard, Bernier, et al., 2012, 2011). However, this driver does not work with more recent 3D TV. A new driver, called 3D TV Play, solves this issue and was included in ImPACT.

Hardware for 3D rendering used to be an expensive component of VR systems. The mass production due to the explosion of popularity of VGs and the improvement in performance due to Moore's law reduced considerably the cost of this component.

Audio immersion is also required to 1) play L4D and 2) produce a realistic and stressful heartbeat. Headsets were rejected since the instructor must be able to give instructions verbally to the trainee. After a few tests with various speaking systems, the Logitech Z-5100 was selected since it contains a sufficiently powerful subwoofer so that the trainee could feel the low-frequency vibrations of the heartbeat sound.

5.2.7 Deployment

ImPACT requires a small footprint for its deployment. Figure 35 shows an example of ImPACT deployed during the experimentation described in Chapter 6.

Figure 35: ImPACT deployment showing the trainee, instructor and sensors (left) and the instructor laptop, TV, and speakers (right).

5.3 Training program

The training program was documented so that it could be administered uniformly and tested experimentally. First, the program ensures that tactical breathing is presented to the participant as a tool that can be used in at least three types of contexts: (a) before a stressor creates a peak in stress (i.e., in moments of apprehension), (b) while stressed and performing his duties (i.e., with minimal intrusion on task performance), or (c) while stepping back from the task (i.e., when becoming overwhelmed by stress and stepping back becomes necessary to regain control). All three types of contexts must be practised during the training program. The instructor should insist on first recognizing stress as it increases (discrimination training; Fergusson & Sgambati, 2009) and then on progressively developing confidence and proficiency in the use of tactical breathing (self-control). Tactical breathing (Grossman & Christensen, 2008) is a stress management technique where the user: (a) takes a deep abdominal breath through his nose for a count of four, (b) holds that breath for a count of four, (c) breathes out through his mouth for a count of four, and (d) holds again for a count of four without breathing at all. The program is broader than a narrow training in tactical breathing. Participants were trained in tactical breathing but also other relevant SMT techniques, such as the recognition of signs of stress, increase in perceived self-efficacy to control stress and biofeedback.

The program comprises three 30-minute sessions. A first session includes a brief recap of the technique, a guided discovery and familiarization with one's own stress response, a period for getting acquainted with biofeedback while playing with the goal of mastering the skill instead of winning, a playing sequence at a slow to moderate pace, and a summary of what is learned in the session. A second session allows practising the technique while playing the VG at a moderate pace and increasing the pace progressively. It would end with a summary of key learning points. A last session requires only one instructor who would supervise both players while they apply SMT and play the VG at a more natural pace while being guided by biofeedback for autonomously applying tactical breathing. The last session would end with a revision of what was learned during the program.

This training program does not pretend to be optimal. For instance, the ideal number of sessions is not known. Nevertheless, it provides guidance that draws from best practice in the domain. For more details on the training program, see Annex A.

5.4 Summary

ImPACT was designed to achieve the objectives defined in Section 2.1. For that purpose, Chapter 3 and 4 identified and selected the most promising approaches and technologies for ImPACT. Available funding constrained further the design. As a result, there is certainly some room for improvement; some alternatives may exist but it was not possible to test them all, so choices had to be made. Yet ImPACT efficacy has to be validated experimentally.

6 Experimental assessment of ImPACT

6.1 Goal of study

A study was designed to test whether practicing SMT with ImPACT would increase the efficiency of "training as usual" (TAU) offered to military personnel. Based on previous publications documenting the efficacy of SMT (Bouchard, Guitard, et al., 2012) and arguing for the need to practice these skills in order to become efficient (Bouchard, Guitard, et al., 2011), we hypothesized that when facing an objective stressor, participants who receive the ImPACT program would experience less stress and perform their task better than those who only received usual training.

6.2 Method

6.2.1 Participants

Soldiers were recruited from a list of volunteers provided by the Valcartier military base of the CF. A total of 60 participants were initially recruited, but one was excluded (see selection criteria below) and some others dropped-out or their data were lost during the experiment due to technical problems (see Figure 36 for a flow chart and the Measure section for details). The final sample was composed of 41 male soldiers corresponding to inclusion and exclusion criteria established before the start of the study.

The study was open to male and female between 18-60 years old with stereoscopic vision and who had received both the basic stress management program provided by the CF (either the PERM or its latest version, the Road to Mental Readiness) and training with "First Aid Training – Basic". They also had to be physically and mentally fit for duty and, to reduce the risks of cybersickness, not suffering from vestibular problems, recurrent migraines, epilepsy, postural balance problems, cardiac or ocular problems, frequent and intense motion sickness in transports.

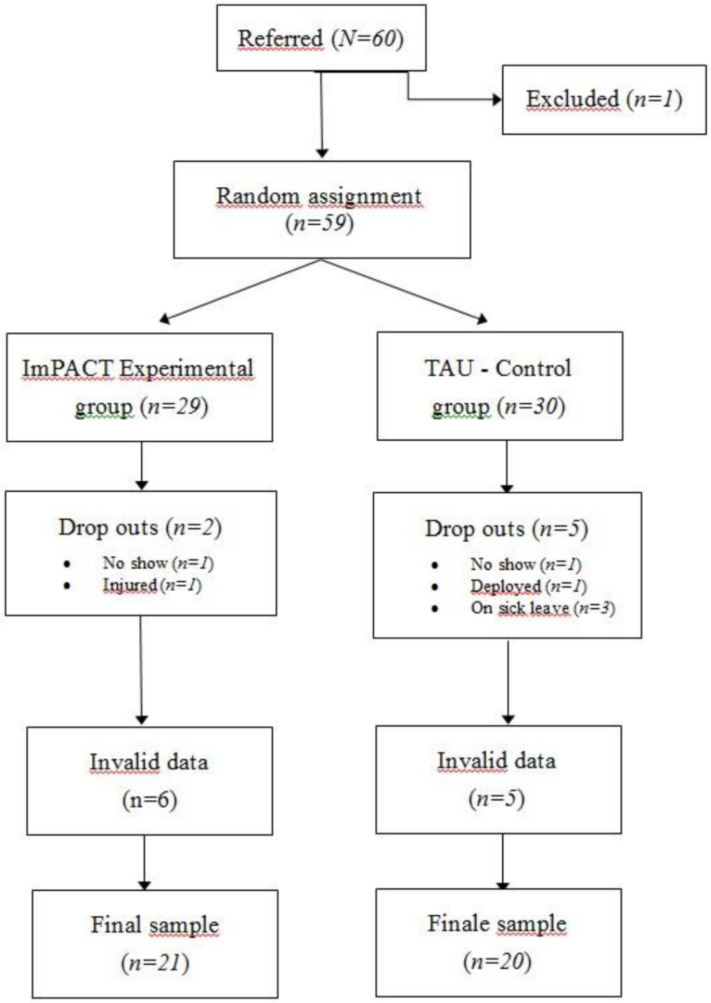

Figure 36: Participants' flowchart.

Selected participants were randomly assigned to one of the two conditions: (a) a TAU - Control condition where no session of supervised practice was offered to participants, or (b) a practice condition (ImPACT) where three daily sessions were offered to practice SMT while immersed in a 3D VG to induce stress and using biofeedback to inform the participant on current level of arousal.

Table 14 and Table 15 provide descriptive information about the sample. Comparisons between both conditions with Student t tests (for data in Table 14) and chi-square (for data in Table 15) did not reveal any statistically significant differences between both groups.

Table 14: Average age and past experience in participants assigned to the ImPACT program or to TAU-Control.

	Mean (standard deviation)	
	ImPACT	**TAU-Control**
Age	25.00 (6.64)	24.80 (4.29)
Years of service	5.24 (3.52)	4.35 (3.28)
Sessions of training with PERM or R2MR	1.67 (2.13)	1.22 (1.22)
Sessions of training with First Aid Training – General	2.9 (2.34)	2.35 (2.16)
Sessions of training with First Aid Training - in Combat	1.48 (1.08)	1.00 (0.80)

Note : PERM = Programme d'Entraînement à la Resilience Militaire. R2MR = Road to Mental Readiness SMT program.

Table 15: Descriptive statistics in participants assigned to the ImPACT program or to TAU-Control.

	Frequency (in percent)	
	ImPACT	**TAU-Control**
Marital status		
Single	66.7 %	70.0 %
Married / with a spouse	28.6 %	30.0 %
Divorced/separated	4.8 %	0 %
Socio-economic status		
Low (Under 20K)	4.8 %	0 %
Moderate (20-50K)	47.6 %	70.0 %
High (50k or more)	47.6 %	30.0 %
Education		
High school grade 1-4	28.6 %	25.0 %
High school diploma	52.4 %	45.0 %
College or professional	9.5 %	25.0 %
University	9.5 %	5.0 %
Rank		
Private	33 %	55.0 %
Corporal	57 %	40.0 %
Master Corporal	9.5 %	5 %
Been in combat before	75 %	47 %
Took "Tactical Combat Casualty Care" training	14 %	15 %
Played the VG L4D before	37 %	55 %

6.2.2 Procedures

Upon arrival at the CF Medical Simulation Centre of the Valcartier garrison for pre-screening (Day 1), participants were informed about the study and their right to refuse to participate. They completed an interview with an experimenter who administered the pre-screening survey, performed the Randot stereotest, filed-in the State-Anxiety scale and the perceived self-efficacy scale, and were told how to collect cortisol samples. All participants were gathered into groups to receive a 15-minute refresher briefing on SMT. The briefing focused on tactical breathing, a technique they had already learned in their training as usual through either the PERM or the R2MR training. Participants in the TAU-Control condition were told they would come back only on Day 5 for the final part of the study. Participants in the ImPACT condition remained on site and played the VG on a 50-inch monoscopic TV until they learned how to navigate in L4D.

For participants in the experimental condition, the ImPACT program was delivered on Day 2, 3, and 4 and cortisol samples were taken every day. The training program required participants to wear a system that monitored their HR and GSR while playing for 30 minutes a modified version of a stressful 3D VG. The immersive and biofeedback training was delivered inside two military ambulances located in the simulation centre (see Figure 37 and Figure 38). Ambulances were chosen because they allowed the immersion to be conducted in a dark and loud environment. Two such ambulance-modified rooms were located about 10 meters from one another (see Figure 37) and were linked to a cluster of computers allowing participants to work in team (multi-player mode) and a research assistant to supervise all events occurring on the gaming computers and instructor's computers. An experimenter, referred to as an instructor, sat beside the participant (see Figure 39), closed the ambulance door, and launched the software. Instructors were experienced retired members of the CF. While the VG was loading, baseline physiology was recorded during two minutes. During each session, the participant was receiving continuous visual and audio feedback on his stress level. The three training sessions were given according to the ImPACT procedures described in section 5.3 and the instructor followed the techniques described in the ImPACT trainer's manual. Post-immersion, the participant completed the State-Anxiety scale and rated his self-efficacy to control his stress. Instructors completed a checklist of tasks performed during the session and reported the usability of the system.

Figure 37: Set-up where the ImPACT program was implemented with particiants (left) and with close-up view of a modified-ambulance training room (right).

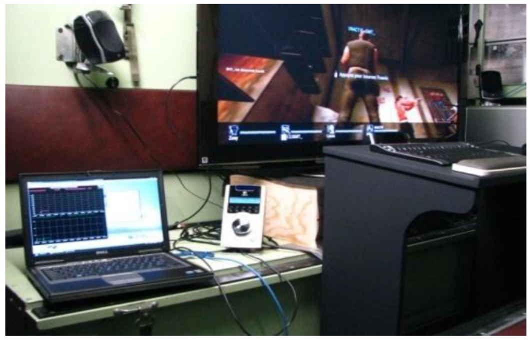

Figure 38: Interior set-up of a training room illustrating the stereoscopic TV, the user's station, loudspeakers and volume control, and instructor's lap-top computer with physiology being recorded.

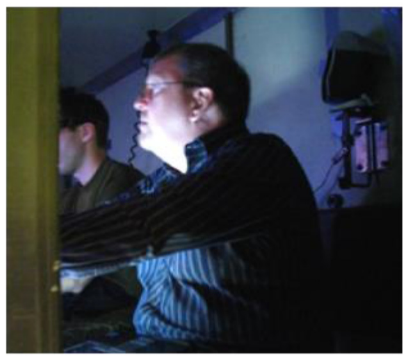

Figure 39: Instructor coaching a participant during an immersion in the ImPACT program.

On Day 5, participants came back to the CF Medical Simulation Centre for a live first aid simulation. The simulation was intended as a significant stressor that would allow measuring the impact of the program in a situation that is relevant to the work of soldiers in theatres of operations. Participants were tested in pairs at the same time of the day in the simulation, one from each condition, to limit the influence of the chronobiology of cortisol. They could not see each other during the simulation as both simulations were separated by a curtain wall. The soldiers strapped on their chest a Polar belt (see Material section), dressed on with their combat gear, took the pre simulation cortisol sample, entered the darkened simulation area, and sat for two minutes to record the baseline HR. They received their mission (See Figure 40), which described a situation in Afghanistan, after sunset, with only a full moon providing limited lighting and an Islamic call for prayer being heard loudly in the background. A fellow soldier was caught in an ambush and they had to help him. After reading the mission, participants stood up in front of a curtain wall hiding the scene until they got the order to proceed. At the exact moment the curtain opened, a very loud explosion occurred from an improvised explosive device hidden in a garbage can and the fellow soldier was severely wounded at the head (blood), chest (open wound with blood), arm (blood) and leg (severely wounded and dismembered prosthetics) (see Figure 41 for an actor being prepared). Eight medic actors were recruited to perform, one at a time, the wounded fellow soldier. They were randomized across conditions so for each pair of participants, one actor was randomly assigned to the participant in the ImPACT or the TAU-Control condition. The wounded soldier was lying on the floor (see Figure 42), covered with blood while begging for help and suffering from severe pain. The room was filled with real smoke and a second improvised explosive device exploded while the participants were providing first aid medical assistance. After 10 minutes, the simulation ended and participants took the post-simulation cortisol sample and completed the state anxiety scale and the self-efficacy scale.

Figure 40: Participants reading their mission.

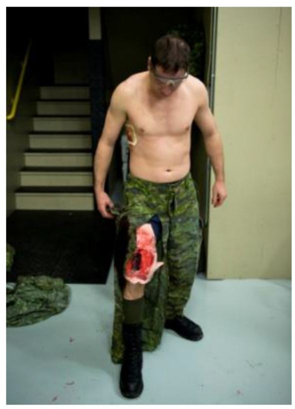

Figure 41: An actor's wounds being prepared.

Figure 42: A participant providing first aid during the simulation, with paramedic instructor rating the performance (in the right corner of the picture).

Figure 43 illustrates an overview of the procedures. It should be noted that the main difference between the two groups is the training sessions from Tuesday to Thursday. The training sessions exposed the ImPACT group to many elements (playing a VG, having physiological feedback, and practicing tactical breathing) for which the TAU-control group was not exposed. With this design, it is not possible to discriminate the contribution of each factor. This design was nevertheless retained because the number of participants was limited and having sufficient statistical power (i.e., having only two groups) was more important than being able to discriminate the contribution of each factor (which would have required more groups). A possible design with two groups was to provide an equivalent SMT training session to the control group but in a more traditional way: each participant of the control group would have sit with an instructor and practice its tactical breathing for about 15 minutes from Tuesday to Thursday (without ImPACT). However, if such experiment showed that both groups performed the same (same stress coping ability), it would not have been possible to claim that one of them has any stress reducing potential (because there is no reference that is higher or lower). In this situation, the experiment would have been useless. Thus, it was decided that TAU-control should undergo the usual training method. This way, if ImPACT has a stress reducing potential, it could be due either to the specificity of ImPACT (biofeedback-driven SMT in a VG), to the practice of tactical breathing or to both.

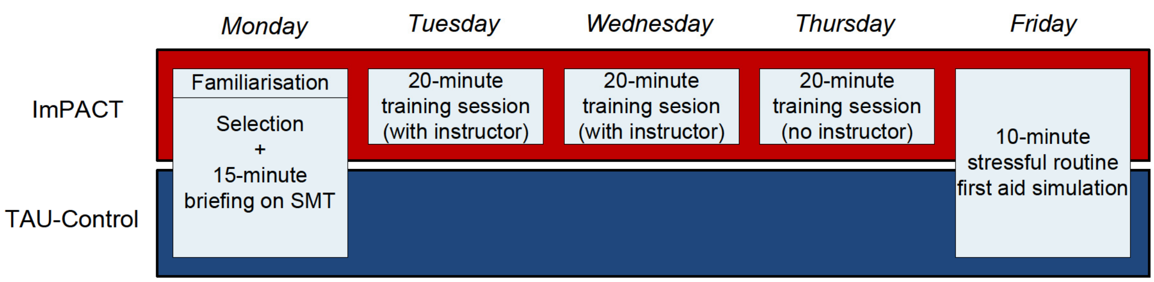

Figure 43: Overview of the procedures.

Figure 44 details the sequence of steps for the training and the first aid simulation sessions.

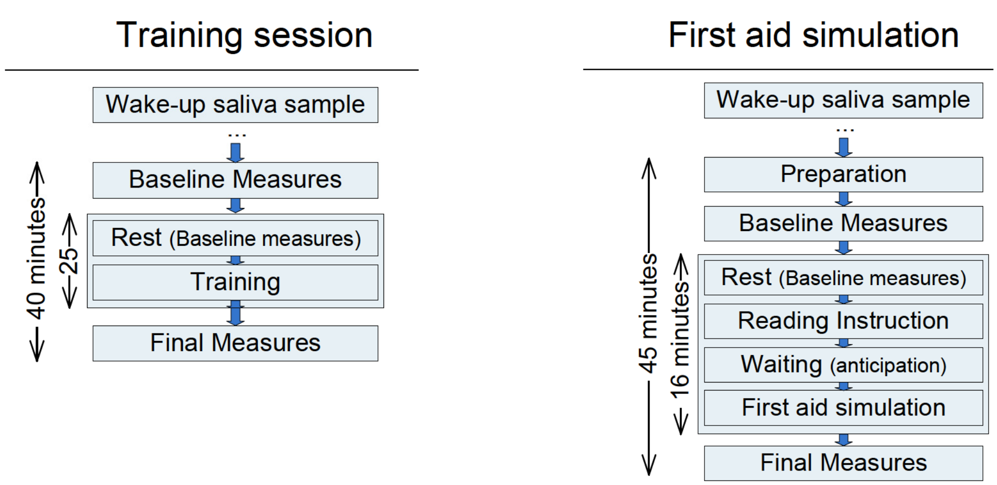

Figure 44: Sequence of steps of the training and first aid simulation sessions.

6.2.3 Material

The version of ImPACT tested experimentally corresponds to the deployment diagram depicted in Figure 28 with the differences that two training stations were set up during the experiment and that the VGs were interconnected. Each participant was immersed using a 50-inch stereoscopic Panasonic Viera TC-P50VT25 3D Plasma TV (www.panasonic.com) with a pair of TY-EW3D10 3D glasses and the VG laptop was a Dell laptop computer (XPS L501x, Intel i7 Q740 @ 1.73 gigahertz, 8 gigabytes of memory, NVIDIA GeForce GT 435M graphics card, 5.1 Surround Realtek High Definition Audio sound card and running on Windows 7 Ultimate 64-bit, 3D TV Play driver). The instructor's laptop were more modest computers (one DELL Latitude D630 Intel Core2 Duo T7800 @ 2.60 gigahertz with 2 gigabytes of memory, a NVIDIA Quadro NVS 135M graphics card, and one Gateway MA6 Intel Centrino Duo T2300 @ 1.66 gigahertz with 1 gigabytes of memory and a standard on-board graphics card). Each VG laptop provided surround sound through a 5.1 Logitech Z-5500 Digital 5.1 speakers (www.logitech.com). The instructors could communicate with each other and with the system operators using portable radios.

Although participants had to collaborate to achieve their mission, they could not communicate verbally with each other during the game. A sheet describing the mission and game controls was positioned near the participant's keyboard. Navigation was performed with keyboard keys and looking / firing with a mouse. To reduce the impact of learning how to use the controls, participants were allowed on Day 1 to play briefly, on average for 5 minutes, at an unmodified version of L4D on a 50-inch TV. The map selected was airport-greenhouse and no biofeedback was available. The notion of cooperative play was fostered during the active training with participants having to cover each other and protect the civilian (played by the computer) who was the only one with the power to restore their health. The difficulty level of the VG, available in the instructor's GUI, was used during the last day of the experiment to make sure participants would not get caught in the fun of playing and forget to practise SMT.

In order to test the ability to perceive binocular disparity in distance from static stimuli (stereoscopic vision for depth perception), the participant performed a stereopsis test (Randot® SO-002, Stereo Optical Company Inc., www.stereooptical.com) that consisted in observing various geometric shapes (between 400 and 20 seconds of arc in apparent size) and animals (between 400 and 100 seconds of arc) in front of random dot backgrounds while wearing polarising glasses. The task consisted in recognizing the 3D stimuli (i.e., specific patterns floating above the test board) from a variety of images.

6.2.4 Measures

The main measure of stress in this study was the concentration of salivary cortisol. Free cortisol response collected in the saliva is a reliable measure of stress. Although physical exercise can increase concentration of cortisol in the saliva (O'Connor & Corrigan, 1987), people regularly trained in physical exercises, such as soldiers, show an adrenocortical stress response that is significantly more moderate than non physically trained people (Rimmele et al., 2007). and more moderate than HR (Davis, Galassetti, Wasserman, & Tate, 2000; Leal-Cerro et al., 2003; Stuempfle, Nindl, & Kamimori, 2010). HR was used as a secondary objective measure of stress. Given the physical efforts inherent to the provision of first aid in combat situations, it was expected that the HR would peak significantly during the simulation. The maximum HR was therefore used as a covariable in the analysis of the cortisol response and the mean HR was used as an outcome measure and analysed independently for periods of apprehension and simulation. GSR was only used during training session and not captured during the first aid simulation because it would have interfered with the tasks to be accomplished (e.g., manipulation of the injured person). Additional measures of the impact of the training program were also collected, although the reliability of self-reported anxiety must be questioned in this sample. These additional measures include assessment of anxiety and perceived self-efficacy, and the military medical technician (paramedic) instructor's3 "blind" evaluation of participant's performance during the simulation.

Additional measures were also collected to document information relevant to the use of the program, such as physiological response, self-report and checklists from the paramedic instructors. Results on these variables are described to examine how the program was implemented. Socio-demographic information was collected to describe the sample with information on age, gender, socio-economic status, etc.

To assess free cortisol levels, salivary samples were obtained with Salivette© collection devices (Sarstedt: www.sarstedt.com/). Participants put the cotton sponge swab (without citric acid infusion) directly in their mouth, chewed and rolled the sponge around in their mouth for two minutes and spat the sponge back into the tube without ever touching the tube. The tube was wrapped in Parafilm® M self-sealing laboratory film and identified by with participant's ID, date and time. Saliver samples were taken at awakening, and before and after stressors (i.e., when practicing the ImPACT program and the simulation). The samples were stored and frozen before assaying. The biochemical analysis of free cortisol in saliva was performed with a competitive immunosorbent assay (Salimetrics™ cortisol kit, LLC, www.salimetrics.com) using a Sorvall Legend X1R centrifuge from Thermo Scientific (www.thermoscientific.com) and BioTek ELx800 microplate reader with GEN 5 software (www.biotek.com).

HR was monitored and recorded using a ProComp Infinity™, a wireless-enabling Tele-Infiniti™ Compact Flash T9600, and a wireless electrocardiogram receiver from Thought Technology (www.thoughttechnology.com). The electrocardiograph sensor for heart electrical activity was a Polar T31 wireless transmitter belt from Polar (www.polar.ca). GSR was also monitored; not as an outcome measure but for biofeedback in the ImPACT program. GSR electrodes were put on the participant's annular and auricular fingers of the hand manipulating the mouse. The Procom Infinity sampled the data at 256 Hz. While data were acquired and recorded during the simulation on Day 5, a research assistant (see Figure 45) double checked that the wireless signal remained good. In addition, he manually put markers in the series of physiological data at the instant events were starting and ending in order to define four separate blocks of HR data: (a) Baseline (2 minutes), (b) Apprehension 1 (when reading the mission and waiting, 3 minutes), (c) Apprehension 2 (facing the curtain wall waiting to waiting to enter the ambush simulation, 20 seconds), and (d) Simulation per se (10 minutes).

[3] To avoid confusion with instructors giving the SMT training program, *paramedic instructor* will refer to military medical technician instructors from the CF Medical Simulation Centre of the Valcartier garrison whilst *instructor* will refer to the former military personnel who taught SMT to the participants.

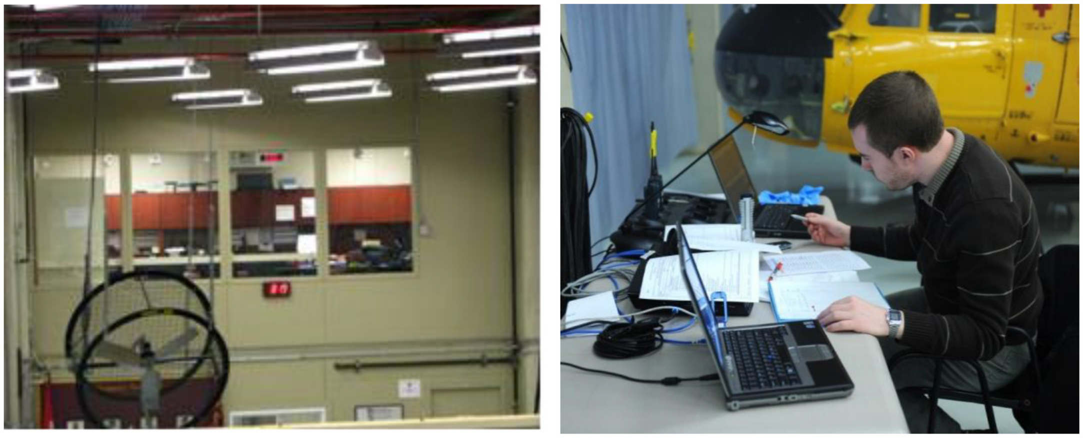

Figure 45: Research assistant getting prepared to record physiology during the simulation. Note the curtain wall on the left (facing the helicopter) and the controller's station providing an overview of the simulations (right).

HR data were analysed with the Biograph Infinity software version 5.1.0 and the Physiology Suite (www.thoughttechnology.com). The HR data of 16 participants were highly erratic during the baseline or the simulation and, to compensate, the built-in algorithm of the Biograph Infinity software automatically generated a fixed HR (e.g., a flat HR response of 170 beats per minutes as in Figure 46). In five cases, the original data recorded by the ProComp could be salvaged with an, at the time, unreleased version of the Cardio Pro Infinity (www.thoughttechnology.com) software and guidance from staff at Thought Technology. However, data from 11 participants (see Figure 36) could not be reliably extracted because the data signal was too erratic and noisy.

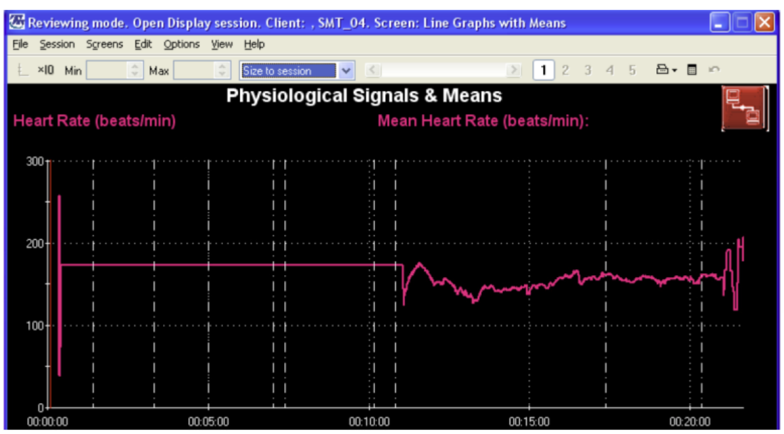

Figure 46: Example of physiological data that could not be reliably analysed as shown in the Biograph Infinity software (Published with the permission of www.thoughttechnology.com).

Figure 47 provides an example of physiological data captured during the four phases of the experiment. Increase in HR is visible during the apprehension and the two simulation phases.

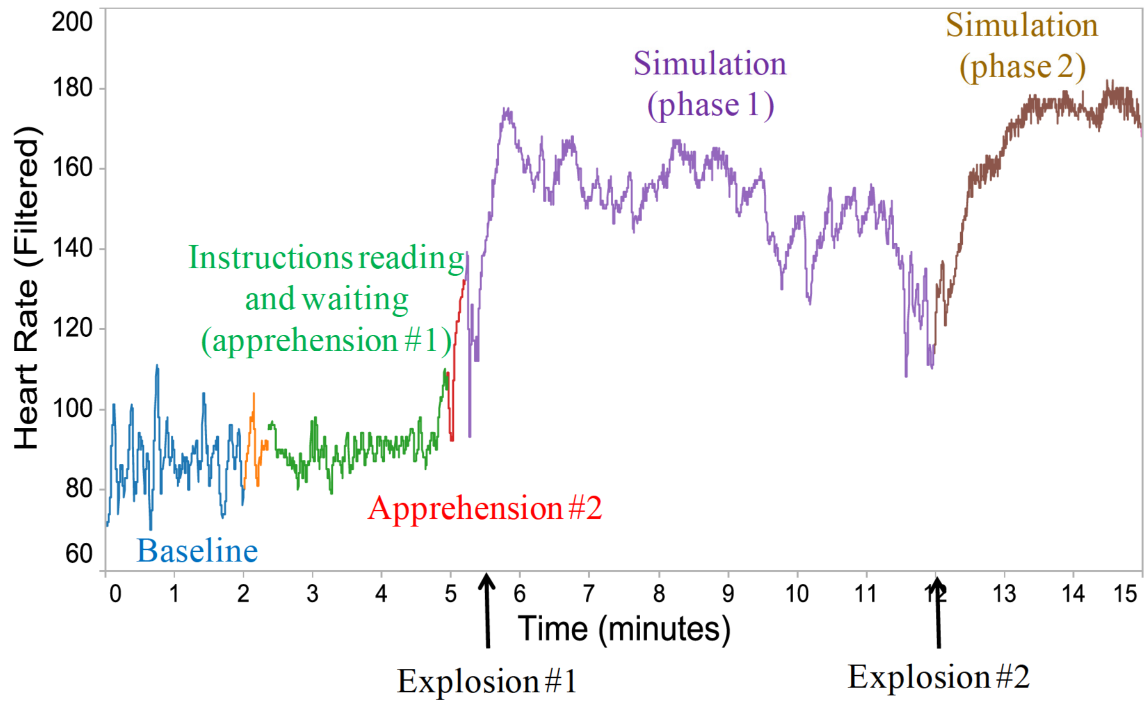

Figure 47: Example of physiological data throughout all the four experimental phases: rest/baseline, apprehension1, apprehension2 and simulation.

The State anxiety subscale of the State -Trait Anxiety Inventory (Gauthier & Bouchard, 1993; Spielberger & Gorsuch, 1983) was used as a subjective measure of stress. It was made of 20 items about how the participant currently feels. Scores on the State Anxiety scale will be reported here but, as found in Bouchard et al. (2011), self-report of state anxiety may be underestimated by soldiers. The scores on that scale can range from 20 to 80, with an average in the general population of 40. In the current study, the mean score after the simulation was 36 (i.e., rather calm) although the mean HR during the simulation was at 131.89 beat/min. The correlation was not significant with HR ($r = .05$, $p = .77$) and cortisol level levels ($r = -.02$, $p = .94$).

Perceived self-efficacy (Bandura, 1986) to control stress was assessed with a 4-item scale developed for this study. It addressed the participant's confidence, on a zero to 100 scale, they could control their stress when experienced at four different intensities. The Cronbach's alpha was .91 when analysed with 60 soldiers.

The Trainees Evaluation Sheet was completed by the paramedic instructors while soldiers were delivering first aid during the simulation. It consisted in a list of six essential tasks that had to be performed according to standard training protocol for delivering first aid in combat, otherwise the wounded patient would most likely not survive. It included: (a) assess the scene for safety, (b) assess breathing and correct if needed, (c) assess blood circulation and correct if needed, (d) identify appropriate treatment for the chest wound, (e) apply appropriate treatment for the chest wound, (f) assess patient's evolution and adapt if necessary. During the simulation, the paramedic instructor from the simulation centre (blind to the participant's condition) remained close and continuously assessed the participant's performance in the application of the medical protocol with the wounded soldier. The simulations were video recorded with 16 cameras to allow reviewing the performance so that the paramedic instructors could revise their assessment if needed. Paramedic instructor's assessment were reviewed in a meeting after the experiment to cross-check the ratings. The Trainees Evaluation Sheet was expected to provide behavioural indices of stress. The percentage of participants who performed each behaviour adequately was calculated, as well as the number of participants whose performance was perfect (i.e., zero failure).

The Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993) was used after each session of the ImPACT program to document that side effects induced by the immersion were not a source of worry for the dissemination of the program. It used 16 different items related to symptoms like headache, eyestrains, and nausea. Not weighted total scores were analysed.

The four items of UQO Presence Questionnaire (Bouchard, Robillard, Renaud, & Bernier, 2012) were administered after the immersion to document the subjective illusion of being "there", transported in the game during the ImPACT program.

The ImPACT instructor checklist was completed by the instructors immediately after each participant's session. It included nine items concerning elements of the program that had to be addressed with the participant (e.g., reviewed the three contexts where tactical breathing could be applied, helped detect signs of stress, helped apply tactical breathing technique, and reinforced the user when he did good) and three items documenting the use of the controls in the GUI (adjust sensitivity, respective weight, and value of the baseline).

A 13-item survey investigated how much participants in the ImPACT program appreciated the experience and how useful they consider the program. Only descriptive results were analysed with this survey.

6.2.5 Statistical analysis

Parametric inferential statistical analyses (ANOVA) were performed, except when variables were categorical (e.g., gender, chi-square was then used). Normality of distribution, as measured with the Kolmogorov-Smirnov (values higher than .21, $p < .025$) and the Shapiro-Wilk (.77, $p < .001$) statistics, was a problem for the cortisol data only. A log transformation corrected the problem and was therefore used for the analyses. Data on the Social Support Questionnaire (SSQ) were skewed and not normally distributed. Since a Wilcoxon non-parametric test essentially confirmed the results of the repeated ANOVAs and this measure is reported only for descriptive purposes, the parametric analyses are reported.

Cortisol was defined as the principal dependent variable. For controlling the error rate, a familywise approach was taken (Kirk, 1982). Significance levels were reduced within families of set of variables, which included one set for the physiological variable (cortisol and two analyses for HR; $\alpha = .05 / 3 = .017$), one set for the subjective self-report variables (perceived self-efficacy; $\alpha = .05$), and one set of performance variables (paramedic instructors' observation of 6 behaviours during the simulation and the number of cases with no errors, $\alpha = .05 / 7 = .007$). No corrections were applied for exploratory variables used to document how the program was used. Effect sizes were also calculated (reported in the results as partial eta squared and qualitative interpretations of

Cohen's f; Cohen, 1988) for the interaction effects in order to provide a clear impression of the impact of the program, free of cumbersome statistical considerations.

To control the effect of experience in the military, all parametrical inferential comparisons for the efficacy of the program included the number of years in the military as covariable. It allowed the impact of the program to be generalized independently from the number of years of duty and experience in combat, in applying first aid and in receiving SMT training seminars. To control for the impact on cortisol of some physical activity generated like having to drag the wounded in a safe location, the maximum HR experienced during the simulation was used as a covariable in the analysis of cortisol response.

6.3 Ethics

The present study had been approved by the Defence Research and Development Canada Ethic Committee and the Ethics committee of the UQO. All individual participants in this study gave written informed consent prior to their participation.

6.4 Results

When comparing efficacy of the ImPACT program on the main measure of stress, there was a significant difference in cortisol response (see Table 16) documenting that the program was effective in better controlling stress than training as usual (see Figure 48) [$F_{(1,35)} = 7.31$, $p < .017$, $\eta^2 = .17$, Effect size = very large]. Both the Time [$F_{(1,35)} = .28$, $p = .60$, $\eta^2 = .008$, Effect size =small] and Condition main effects [$F_{(1,35)} = .0$, $p = .98$, $\eta^2 = .00$, Effect size = trivial] were not significant.

Table 16: Cortisol (ug/dL) for participants who received the ImPACT program and TAU-Control before and after a live and stressful simulation.

	Free cortisol levels in ug/dL (standard deviation)	
	ImPACT	**TAU-Control**
Waking-up	7.79 (4.6)	9.04 (4.36)
Pre simulation	5.93 (2.39)	5.82 (4.47)
Post simulation	7.22 (3.85)	8.8 (4.94)

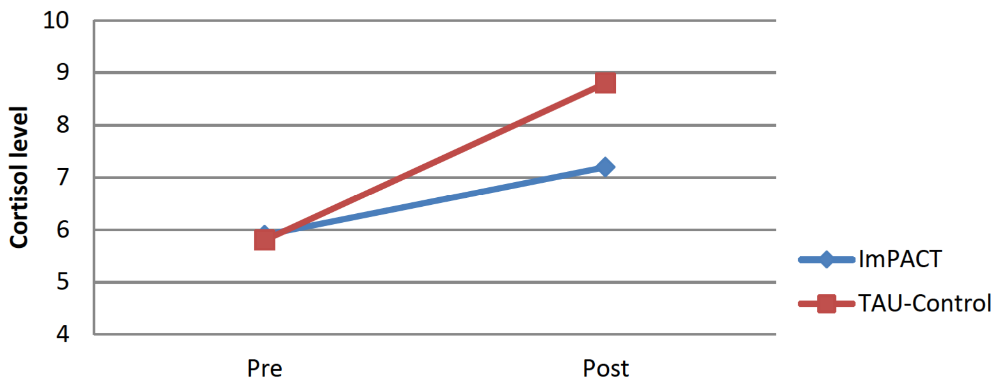

Figure 48: Illustration of a significant difference in stress response as measured with free salivary cortisol (in ug/dL) for participants who received the ImPACT program or TAU-Control before and after a live and stressful simulation.

HR was used to corroborate cortisol findings, although the physical efforts inherent to providing first aid in combat situation could blur the results with HR. The analyses were performed independently for HR during the apprehension phases and the actual simulation phases. As shown in Table 17 and Figure 49, the ImPACT program had a significant positive impact on stress levels [$F_{(2,76)} = 4.81$, $p < .017$, $\eta^2 = .11$, Effect size = almost large] during the apprehension phases. The Time main affect was significant [$F_{(2,76)} = 23.64$, $p < .017$, $\eta^2 = .38$, Effect size = very large] and the Condition main effect was not [$F_{(1,38)} = .38$, $p = .54$, $\eta^2 = .01$, Effect size = small]. The contrasts confirmed the superiority of dealing with stress following the ImPACT program compared to TAU-Control when comparing the baseline to the first apprehension phase [$F_{(1,38)} = 7.52$, $p < .017$, $\eta^2 = .17$, Effect size = very large] as well as the second apprehension phase [$F_{(1,38)} = 7.71$, $p < .017$, $\eta^2 = .12$, Effect size = more than large]. Results were not significant when comparing stress levels during the simulation (see Table 17 and Figure 50), as shown by the interaction of the repeated measure ANOVA [$F_{(1,38)} = .65$, $p = .43$, ns, $\eta^2 = .02$, Effect size = small]. The Time main effect was significant [$F_{(1,38)} = 58.73$, $p < .025$, $\eta^2 = .61$, Effect size = very large], but not the Condition main effect [$F_{(1,38)} = .87$, $p = .36$, $\eta^2 = .02$, Effect size = small].

Table 17: Average HR before and during all phases of the live simulation (Day 5).

	Mean HR (standard deviation)	
	ImPACT	**TAU-Control**
Baseline	93.32 (13.57)	86.26 (9.62)
Apprehension 1	94.08 (11.68)	91.27 (12.80)
Apprehension 2	110.92 (14.12)	112.41 (16.77)
Simulation	132.88 (24.72)	130.86 (21.58)

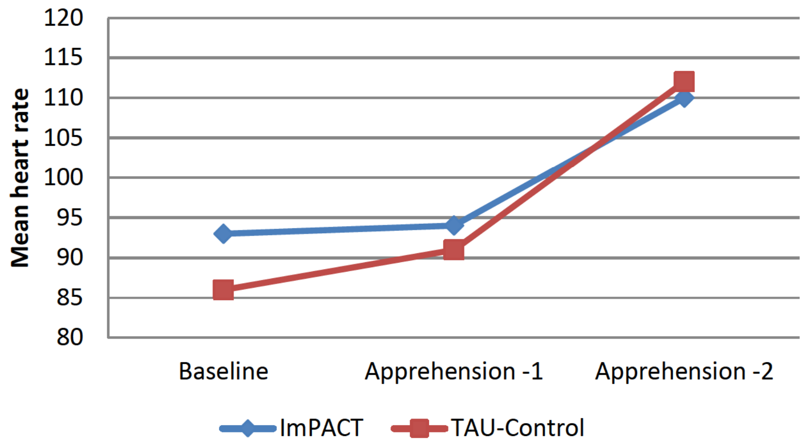

Figure 49: Illustration of the differential increase in HR from the baseline to the first apprehension period (when reading the mission) and the second apprehension period (when waiting in front of the curtain wall) phases of a live first aid simulation.

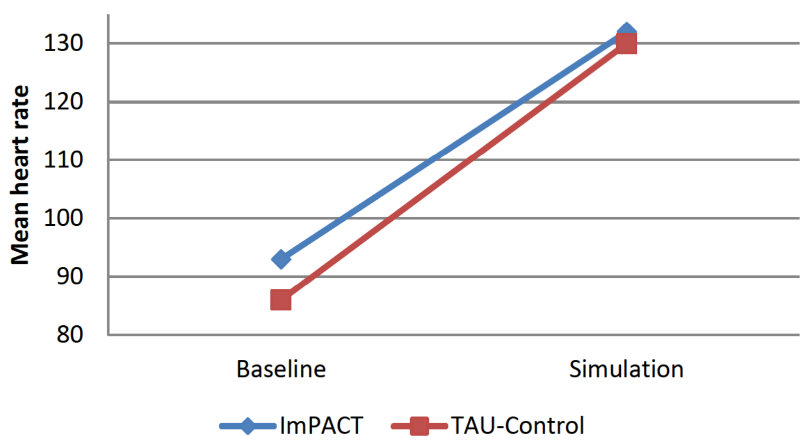

Figure 50: Illustration of the HR during the baseline and the live first aid simulation.

Results on self-report measures of state anxiety and perceived self-efficacy (see Table 18) revealed a significant interaction for perceived self-efficacy [$F_{(1,35)} = 15.8$, $p < .025$, $\eta^2 = .31$, Effect size = very large] (see Figure 51), but not for state anxiety [$F_{(1,37)} = .02$, $p = .89$, $\eta^2 = .0$, Effect size = trivial]. The Time and Condition main effects were not significant.

Table 18: Perceived self-efficacy to apply tactical breathing technique before and after the experiment, and state anxiety before and after the simulation.

	Mean (standard deviation)	
	ImPACT	**TAU-Control**
Self-efficacy pre experiment (Day 1)	69.2 (17.52)	67.21 (23.57)
Self-efficacy post simulation (Day 5)	82.69 (6.88)	59.71 (25.0)
State anxiety pre simulation (Day 5)	29.85 (7.97)	36.00 (10.05)
State anxiety post simulation (Day 5)	33.2 (9.1)	39.4 (10.91)

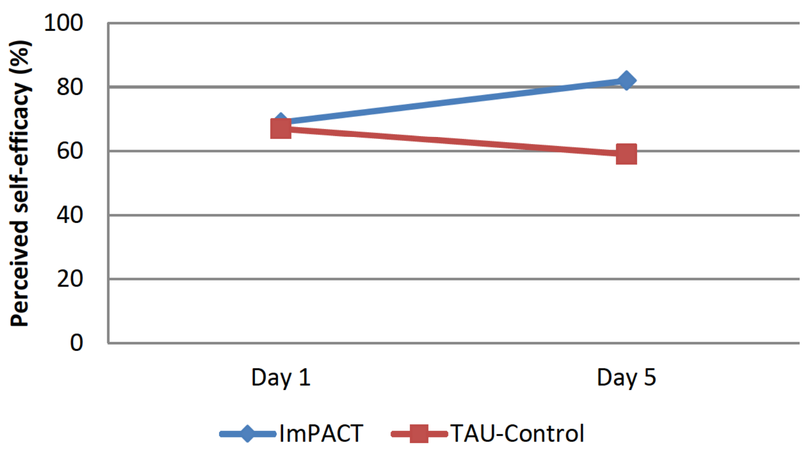

Figure 51: Perceived self-efficacy to apply tactical breathing technique before and after the experiment.

Performance during the medical simulation was assessed by the paramedic instructors using the Trainee Evaluation Sheet (see Table 19). Chi-square analyses revealed a significant difference between the conditions on the performance of one critical behaviour (identifying the appropriate treatment to a severe chest wound) and two marginal differences (i.e., they would have been significant if a Bonferroni correction had not been applied) on adapting to the changes in the patient's status and perfect success on the medical test.

Table 19: Trainees Evaluation Sheet rated by "blind" paramedic instructors during the simulation describing the percentage of participants who followed adequately the official first aid protocol.

	Rated as successfully performed		Chi-Square value (df = 1)
	ImPACT	**TAU-Control**	
Asses the scene for safety	95 %	95 %	2.03
Assess respiration and correct if needed	65 %	60 %	.11
Assess blood circulation and correct if needed	90.0 %	89.5 %	.003
Identify appropriate treatment - chest wound	58.0 %	55.0 %	.03
Apply treatment efficiently – chest wound	42.0 %	5.0 %	7.56*
Adapt to changes in patient's status if needed	68.4 %	35.0 %	4.36§
Performing without any mistakes	45.0 %	10.0 %	6.14§

Note. * Values of chi-square p < .007. § Values of chi-square p < .05, ns.

Further statistical analyses were conducted to document the use of the ImPACT program. Table 20 presents cortisol response during each training day. Repeated measures analysis of covariance (ANCOVA) with morning level as covariable did not reveal any significant change after the first [$F_{(1,11)} = 0$, $p = .99$, ns], second [$F_{(1,13)} = .52$, $p = .46$, ns] and third [$F_{(1,19)} = .11$, $p = .75$, ns] training session.

Table 20: Cortisol response associated with each training session of the ImPACT program.

	Free cortisol levels in ug/dL (standard deviation)		
	Session 1	**Session 2**	**Session 3**
Waking-up	7.61 (2.58)	4.83 (1.74)	5.14 (2.2)
Pre training	6.95 (3.47)	4.08 (2.28)	4.91 (2.74)
Post training	7.59 (3.12)	4.92 (1.99)	3.99 (1.34)

Mean HR data (see Table 21) were also collected during the sessions and compared. Repeated measure ANOVA did not find any significant changes in HR over the three sessions when looking at the average HR [$F_{(2,38)} = 0.0$, $p = .99$, ns], the maximum HR [$F_{(2,38)} = 2.18$, $p = .13$, ns] and the minimum HR [$F_{(2,38)} = .71$, $p = .5$, ns]. However, the variability (maximum value – minimum value) of the HR during the session diminished significantly [$F_{(2,38)} = 5.26$, $p < .001$, $\eta^2 = .22$, Effect size = very large]. Contrasts showed that the reduction in variability occurred when comparing within session variations during the first and the second training session [$F_{(1,19)} = 7.63$, $p < .025$, $\eta^2 = .29$, Effect size = very large], and remained stable when comparing variations within the second and the third training session [$F_{(1,19)} = .17$, $p =.68$, ns, $\eta^2 = .01$, Effect size = small].

Table 21: HR data averaged over the entire practice session (baseline excluded) during each training session of the ImPACT program.

	HR (standard deviation)		
	Session 1	**Session 2**	**Session 3**
Mean HR	82.42 (11.43)	82.44 (11.49)	82.42 (11.59)
Maximum HR	110.88 (17.31)	105.21 (15.63)	105.75 (12.91)
Minimum HR	57.91 (9.84)	59.48 (9.1)	57.5 (6.48)
Variations in HR	.12 (.04)	.1 (.02)	.1 (.02)

The self-report questionnaire completed by participants suggested no pre to post session changes in state anxiety (see Table 22) during the first session [$F_{(1,20)} = 2.45$, $p = .13$, ns, $\eta^2 = .11$, Effect size = medium] but significant increases within the second [$F_{(1,20)} = 5.16$, $p < .05$, $\eta^2 = .21$, Effect size = large] and the third sessions [$F_{(1,20)} = 6.54$, $p < .025$, ns, $\eta^2 = .25$, Effect size = large]. There was also a significant increase in perceived self-efficacy [$F_{(1,20)} = 16.91$, $p < .001$, $\eta^2 = .46$, Effect size = very large]. Contrasts revealed that the increase in perceived self-efficacy occurred from the first to the second training session [$F_{(1,20)} = 22.39$, $p < .001$, $\eta^2 = .53$, Effect size = very large], and remain stable when comparing the second and the third training session [$F_{(1,20)} = 1.56$, $p =.23$, ns, $\eta^2 = .07$, Effect size = medium].

Table 22: Self-report data on state anxiety before and after each training session and perceived self-efficacy after each session of the ImPACT program.

	Self-report for psychological variables (standard deviation)		
	Session 1	**Session 2**	**Session 3**
State anxiety pre session	29.29 (5.24)	25.76 (6.16)	26.29 (7.86)
State anxiety post session	31.29 (7.37)	28.38 (7.95)	29.33 (8.0)
Perceived self-efficacy post session	70.45 (14.09)	80.44 (10.81)	82.29 (11.53)

The side effects induced by the immersions were small (see Table 23) and did not represent a significant increase from discomfort experienced before the immersion, for session 1 [$F_{(1,20)} = 3.07$, $p = .1$, ns, $\eta^2 = .13$, Effect size = almost large], session 2 [$F_{(1,20)} = 3.94$, $p = .06$, ns, $\eta^2 = .16$, Effect size = large] and session 3 [$F_{(1,20)} = 2.45$, $p = .13$, ns, $\eta^2 = .11$, Effect size = medium]. Scores on the UQO Presence Questionnaire (see Table 23) decreased significantly [$F_{(2,40)} = 13.17$, $p < .001$, $\eta^2 = .40$, Effect size = very large], essentially from the first to the second session [$F_{(1,20)} = 13.86$, $p < .001$, $\eta^2 = .41$, Effect size = very large] and not from the second to the third session [$F_{(1,20)} = .41$, $p = .53$, ns, $\eta^2 = .02$, Effect size = small].

Table 23: Self-report data from side effects and presence during each session of the ImPACT program.

	Self-report for cyberpsychology variables		
	Session 1	**Session 2**	**Session 3**
Simulator Sickness Questionnaire pre session	2.38 (2.75)	2.14 (3.31)	2.48 (5.21)
Simulator sickness Questionnaire post session	3.71 (4.78)	3.33 (4.53)	3.67 (4.6)
Presence during the session	37.76 (16.46)	26.88 (19.04)	27.5 (19.49)

When systematically reviewing whether each component of the program was implemented as intended in the manual, results confirmed the integrity of program delivery. In general, 100% of the content was delivered to each participant at each session, except on two occasions. Only once, during session 1, where an instructor forgot to mention the contexts where tactical breathing could be applied and that SMT should be practiced with real stressors. Table 24 describes how often the different options of the GUI were used. Among the stressful events occurring in the game, the hordes of zombies were the most frequent (occurring on average 138 times per playing session) and caused significant increase in heart rate [$F(1,27)=11.01$, $p < .01$] and skin conductance [$F(1,27)=10.83$, $p < .01$] when comparing participants' physiology 10 seconds before and after the beginning of the stressor.

Table 24: Use of the available controls at least once during a session by the instructors.

	The option was used at least once		
	Session 1	**Session 2**	**Session 3**
Adjust sensitivity	86%	100%	90%
Adjust respective weight	43%	62%	84%
Adjust baseline	43%	53%	70%

After the last day of training, participants completed a survey describing how much they appreciated the program and its components. The descriptive statistics are reported in Table 25: Descriptive statistics from the survey assessing participant's impression of the ImPACT program on scales ranging from 0 to 10.Table 25. At the end of the survey, participants were invited to express comments about the ImPACT program. Sixty two percent of the participants wrote some comments and all stated they appreciated the program. Two participants suggested allowing communications between the team members would make the game more interesting.

Table 25: Descriptive statistics from the survey assessing participant's impression of the ImPACT program on scales ranging from 0 to 10.

	Mean	St. Dev.	Minimum	Maximum
Felt stress during the immersions	6.14	2.02	2	10
Like the immersions	9.05	1.05	7	10
Immersions would be useful to practice SMT	8.38	1.78	5	10
Visual feedback was useful	8.14	1.78	5	10
Presence of the instructor was useful to master SMT	8.95	1.61	7	10
How stressful was:				
Sounds in the game	7.6	2.16	2	10
Quality of the images	7.3	2.34	2	10
Visual feedback of HR	8.35	1.81	4	10
Darkness	6.55	2.84	0	10
Playing the game	7.4	2.04	3	10
Playing with a colleague	6.45	3.46	0	10
Effects of surprise	7.8	2.24	3	10
Forewarning effects	7.4	1.85	3	10

6.5 Discussion

SMT encompasses a broad range of techniques that are used either very specifically to regulate emotions or as part of broader mental fitness and resilience programs. Acquiring the psychological skills to cope with stress requires practicing under stressful conditions and coaching. The innovation in the current study is not the demonstration that SMT is effective to reduce stress. This has been demonstrated in hundreds of studies (for a review, see (Bouchard, 2009; Bouchard, Guitard, et al., 2012), although only a handful of studies have look specifically at coping with acute stress. The originality lies in the demonstration that practice is more effective than training as usual, which rests on formal descriptions of techniques and very brief practice in classroom. To practice SMT, we developed the ImPACT program, which essentially consists of three immersions in an interactive 3D environment in order to stress the trainees, provide continuous biofeedback on arousal level, and practice tactical breathing with the help of an instructor. It was our contention that was these ingredients were lacking in mental resilience packages provided to military personnel in the CF, including the Road to Mental Readiness program (Guest & Bailey, 2011) and the PERM (Routhier, 2009). Until proven otherwise, it also seems to be the lacking in the new U.S. Comprehensive Soldier Fitness program (Cornum et al., 2011). Another issue that deserved to be addressed in current programs was the low motivation, or poor "buy-in" factor, toward emotion regulations. Practicing these techniques that may be considered by soldiers as "too feminine for a real man" (Wexler, 2009) or a sign of weakness (Casey Jr, 2011).

During a stressful live simulation providing first aid to a fellow soldier wounded by an improvised explosive device, participants who had been trained with the ImPACT program were significantly less stressed than those who only received the training as usual. This is strongly supported with a statistically significant and fairly large difference in cortisol response corresponding to more than a two-fold increase in those who did not receive the ImPACT training. Average scores of salivary cortisol concentration are hard to interpret in reference to standard values because of chronobiology and the very wide range of normal values. The current data can be tentatively compared to the cortisol response of physically trained adults undergoing a standardized stressor task called the TSST (Rimmele et al., 2007) and the program reduced the stress level by more than a half.

In order to corroborate the cortisol findings and try to tease out whether the program was effective both in terms of apprehension and action, HR was examined during the simulation. HR of participants who received only the default training increased significantly more while being briefed on their mission than the trained soldiers, as well as while waiting for the action knowing that a crisis was about to happen in a few moments. Examination of HR with results found in other studies suggest that, compared to physically trained men undergoing the TSST, our participants' HR was higher in both conditions during the apprehension phase and the simulation phase. HR was also higher than in previous study (Bouchard, Bernier, et al., 2012) conducted on a similar sample during a TSST.

The program also had a clear positive impact on perceived self-efficacy to cope with stress. After the simulation, participants trained with the program showed an increase in self-efficacy while those in the control condition showed a decrease. Since self-efficacy is a very strong predictor of behaviour change (Bandura, 1986), this result suggests that soldiers who received the program are more likely to apply tactical breathing in the future. The program also had a statistically significant impact on one medical action performed by the participant during the simulation. Significantly more participants treated the patient's chest wound adequately after having received the ImPACT program. The overall quality of the trainee's performance was also much better, with perfect application of the medical protocol in 45 % of the participants in the ImPACT condition compared to 10% in those in the TAU condition. This difference was not statistically significant when applying our stringent correction for the number of statistical analyses performed, although the probability was lower than .05. A slightly larger sample would have made this difference significant. Interestingly, it appears that differences were more important in behaviours that required more cognitive attention. A survey administered to the participants also revealed that those who received the ImPACT program clearly liked it (with a mean score of 9 out of 10, and with 7 as the lowest value). After using it, they considered the program, and the role of the instructor, as useful to practice SMT.

Data gathered during the application of the program per se documented that the immersions had an impact on participants' arousal levels, as shown by variations in HR and high maximum HRs reached during each session. But overall, participants were able to control their stress level, as documented by the stability of the mean HRs and the cortisol levels over each session. Self-efficacy also increased with practice, and subjective comments expressed after the program were very positives. The immersions did not induce significant negative side effects. All important components of the program were addressed by the instructors, as demonstrated by checklists showing a 95% to 100% fidelity to what was expected to be delivered. The options included in the GUI to adjust the physiological parameters were all used regularly, confirming their usefulness.

Not all results unanimously confirmed the efficacy of the program, although in each case alternative explanations must be considered. The advantages of the program over training as usual disappeared when comparing participants' HR during the simulation. The analyses revealed a very large and significant increase in HR, without any difference between the conditions. It is suspected that the HR, which was on average around 130 beats per minutes, may have been high in part because of the physical efforts required during the task. It remains possible that stress management techniques were either: (a) not practised in situations that were stressful enough for the participant's mastery of the skills to transfer adequately to very demanding stressors; (b) participants may not have applied the techniques at all during the very demanding stressor; or (c) the program was not effective. These alternative hypotheses remain to be demonstrated. But, if the program had been effective only for moderate stressors such as apprehension, the cortisol response would have been different. Given the duration of the live simulation and the high HRs, it would have most likely blunted the cortisol response and the effect of the program would not have been large and significant. As for being ineffective, this is highly unlikely given the significant difference in salivary cortisol and previous findings from the literature (Bouchard, Guitard, et al., 2012; Grossman & Christensen, 2008). Stress levels experienced in the theatre of operation can range from low (or chronic) to very high (or acute). This experiment tried to reproduce a range of level of stress and to recreate many stressful aspects of the theatre of operations. By showing the benefit of ImPACT in such conditions, it is likely that ImPACT be beneficial in theatre of operation, but the exact types and levels of stress that the military are exposed to for which ImPACT is most suitable remain to be evaluated.

The second inconsistent result was with the self-reported measure of state anxiety. The data on that measure not only suggested the program was no more effective than training as usual, but also that the simulation did not induce any anxiety. It is very difficult to lend credibility to this finding. Large and statistically significant physiological impacts were observed in hypothalamus-pituitary-adrenal neuroendocrine activity (i.e., salivary cortisol) and replicated in the autonomic nervous system (i.e, HR) during the anticipatory phases of the first aid simulation. The very low mean scores also cast doubts on the validity of the scale in the sample. Similar doubts were raised in a study conducted with the same measure and a similar sample (Bouchard, Bernier, et al., 2011). It remains to be further researched whether this inconsistent finding can be explained by participants' fear of reporting anxiety (e.g., some may be afraid that their answers could be leaked to their superiors or mentioned in their record, despite what was written in the ethics' consent form) or alexithymia (Berthoz, 2001).

The ImPACT program could also be used to complement training program used during military survival school (Taylor et al., 2011), law enforcement training (Homeland Security, 2004) or any other form of SMT. Taylor et al. (2011) provided training in arousal control to US Navy personnel enrolled in survival training and relied on participants recalling a past stressful experience to practice breathing control techniques during two sessions. Their results revealed that despite the known effectiveness of stress management (Bouchard, Guitard, et al., 2012), the participants trained with their program did not fared better at coping with a stressful simulation than the control participants who had not received the training. It is quite likely that Taylor et al.'s (2011) participants would have benefited from practice with more challenging stressors than souvenirs of past events, from coaching and supervision in the application of their stress management skills, from learning cues that would facilitate remembering to apply arousal control techniques, and from more practice than two 40-minute sessions where the available time is divided into learning four strategies instead of mastering one efficiently.

7 Conclusion

This report presented a summary of a three-year research program that investigated the potential of stressful virtual environments augmented with biofeedback to train soldiers to master their stress coping skills. A systematic literature review was first conducted to document that stress management training (SMT) represents an effective set of tools to regulate stress and anxiety (Bouchard, Guitard, et al., 2012). It revealed that SMT is indeed effective, even in cases of acute stress. Many cognitive-behavioural techniques are used in SMT, like tactical breathing (Grossman & Christensen, 2008), and is included in programs like *Programme d'entraînement à la résilience militaire* (Routhier, 2007) and Road to mental readiness (Guest & Bailey, 2011). This report also presented the feasibility of creating stressful virtual environments and the exploration of the design space of a training system. Finally, after describing a solution named Immersion and Practice of Arousal Control Training (ImPACT), an experiment evaluating the efficacy of ImPACT was presented.

For exploring the feasibility of creating stressful virtual environments, literature reviews and experiments investigated the potential of video games (VGs) and virtual reality (VR) to induce moderate stress for training. As a first step, significant stressors that lead to psychological wounds in theatre of operations were identified when examining epidemiological data from deployed Canadian and United States troops (Bouchard et al., 2010). Many of the traumatic events that are significant stressors among military personnel were found in the VGs reviewed during that process. Using VGs known as being stressful by the gaming community has proven to be an effective means to induce stress (Bernier et al., 2009; Bouchard, Bernier, et al., 2012, 2011). The first study did not find any differences in the stress inducing potential between two VGs. A future and more fruitful research approach should be to discriminate the emotional response to specific event occurring in VGs and then to identify what is more effective for training. As for the VR side, an experiment showed that low-cost recent VR technology is sufficient for inducing stress. Considering previous experimental studies, finding that the highly immersive CAVE automatic virtual environment (CAVE) was no more stressful than a large stereoscopic TV was disconcerting at first. A few factors likely explain this lack of effect. Overall, were more stressful training required, further research would be needed to better exploit stressful VGs and, as a last resort, to exploit a CAVE more efficiently. A second experiment (Bouchard, Bernier, et al., 2011; Monthuy-Blanc et al., 2011) showed that empathy caused by a realistic suffering avatar can induce stress, though using a known person is no more stressful. Near-humanlike but still imperfect avatars of known people are known to cause revulsion. Since major technological improvements are still required for solving this problem, using realistic avatar of unknown people remains the only viable option in the short-term.

Before implementing ImPACT, design options were investigated in order to tackle the complexity of modifying VGs and augmenting them with biofeedback. On the modification aspect, plenty of options are available to implement a training system in an existing VG. Yet, the openness of the VG dictates what is feasible. On the biofeedback aspect, there are many possible implementations but no straightforward recipes. The domain of biofeedback augmented VGs is still in its infancy and additional research is required to provide clearer and more optimal design principles. Nevertheless, it was still possible to propose circumscribed design guidelines.

The most recent and comprehensive stress management program developed in the United States for the military population is deeply rooted in concepts such as resilience, positive psychology and self-regulation. ImPACT training program blends well with this approach since trainees are given the opportunity to practice and master a skill that fosters emotion regulation. It is not explicitly focused on negative emotions, the prevention of mental disorders or building mental toughness. It could complement psychological resilience programs by offering the opportunity to practise under stress, which is hardly feasible otherwise. The costs are minimal (e.g. ImPACT prototype cost is less than 10k$) and the buy-in factor is strong. In addition, ImPACT is easily deployable.

The experimental assessment of ImPACT confirmed our initial hypothesis, namely that soldiers trained with ImPACT would be less stressed and perform better when exposed to a stressful situation than those who received only a 15-minute refresher briefing. This was confirmed with soldiers experiencing a smaller increase (half) in their salivary cortisol during the stressful situation, a lower hear rate (HR) increase during the apprehension phase, and a higher level of performance for completing a complex task. In addition, soldiers enjoyed their training sessions with ImPACT and, for those who received the training, they were more confident in their stress coping skills than their non-trained counterparts. Improvement in confidence is paramount since, self-efficacy being a very strong predictor of behaviour change, soldiers who received the program are more likely to apply tactical breathing in the future. No effect of the training was observed on the HR during the most stressful (acute) moments. A first explanation, the fact that the training was not efficient, is refuted by the large effect size of the statistical difference in cortisol response. Other reasons, like the lack of practice in more stressful situations and the non-use of the techniques by the participants during that phase, require additional investigations.

The experimental assessment of ImPACT measured the benefits on the short-term and in a realistic but still a simulation context. An important remaining research question is how the training effects endure and translates in a real theatre of operations like when under enemy fire or dealing with hostile reactions from civilians. Meanwhile, it would be interesting to test the outcome of the ImPACT on other training stressful situations like on shooting ranges. Another worthwhile investigation is to test if more stress during the immersion, more training sessions, or a session with a live simulated stressor would provide additional benefits. Testing the usefulness of adding practice with higher levels of stress, probably in a fourth training session, seems warranted. Scientifically, it would help clarifying some of the HR results as well as provide the behavioural measure. Clinically, the manipulations would make sense and remain consistent with one the principle behind the program, which is that behavioural skills are mastered through practice. Other lines of inquiry include testing ImPACT with a broader group of military personnel (e.g., females, officers, medics) and considering booster sessions when military personnel are deployed. Another aspect that merits attention is the possible misperception, by the public or some military instances, of horror VGs with gore scenes to train military personnel. Developing stressful scenarios in existing military training environments is an alternative that deserves consideration.

To conclude, it is doubtful that the classical approach to training in the military, which is essentially based on teaching SMT in a classroom, would be sufficient to result in significant mastery of the techniques. Practice is essential; yet it may be insufficient unless there is objective information about level of arousal and the immediate impact of the technique. Soldiers should also adhere to this strategy despite the strong masculine standards found in the military culture (Green et al., 2010; Levant & Pollack, 1995; Rosen et al., 2000). The ImPACT program provided immersions in a stressful VG, coupled with biofeedback, and induced enough stress to practice SMT and enough feedback to allow soldiers to master the technique and increase their perceived self-efficacy. The efficacy of the program was confirmed by objective results and we recommend consideration for implementation on a much broader basis in the Canadian Forces.

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Annex A Training program

Immersion and practice of arousal control training (ImPACT)

Trainer's manual for tactical breathing applied with biofeedback while stressed with a FPS – horror VG

KEY PRINCIPLES

The goal of this program is allowing military personnel master tactical breathing while stressed and receiving: (a) biofeedback about their arousal from GSR and GSR responses, and (b) guidance from an instructor.

Tactical breathing (also referred to as combat breathing, was initially proposed by Lt. Col. Dave Grossman) is a stress management technique where the user can gain control on part of the automatic stress responses created by the body. The technique appears simple at first, but is effective and has the advantage of being applicable while under acute stress. The user: (a) takes a deep abdominal breath through his or her nose for a count of four, "1, 2, 3, 4", (b) holds that breath for a count of four, "1, 2, 3, 4", (c) breaths out through his or her mouth for a count of four, "1, 2, 3, 4", and (d) holds again for a count of four without breathing at all. The procedure is repeated four times. For some users, using counts of three and / or repeating the procedure more than four times might be more appropriate. The procedure could also be shortened as the user gains experience with it.

Tactical breathing can be used in at least three types of contexts: (a) before a stressors creates a peak in stress (i.e., in moments of apprehension), (b) while stressed and performing his or her duties (i.e., with minimal intrusion on task performance), or (c) while stepping back for a task (i.e., when becoming overwhelmed by stress the "tunnel vision" could totally disrupt performance and stepping back becomes necessary to regain control). All three types of contexts must be practiced during the training program. Stepping back from the task must be presented as an extreme measure only since disengaging from the task could have severe detrimental consequences, depending on the situation (e.g., while under direct enemy fire), depending on the task and the degree of "tunnel vision" experienced by the user.

Information instructors should keep in mind:

- How to apply the technique
- Tactical breathing must be practiced in all three contexts
- In real life situations, stepping back to breathe is an extreme measure

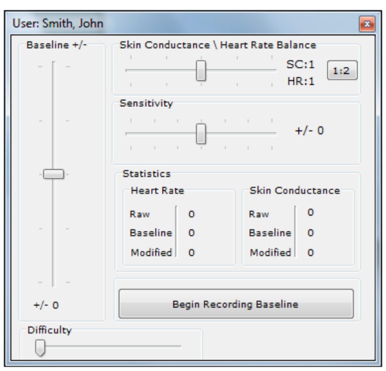
PRACTICAL APPLICATION

Soldiers will be immersed in a 3D VG that has been shown to induce moderate stress. The immersion was set-up so stress can comes from several sources, such as the mission (e.g., keep the female civilian "medic" alive), the enemies (types and numbers), the context (horror visual and audio content), the behaviour to the other teammate (the two users are playing in multiplayer mode in a network but cannot talk to each other), the difficulty level (modifications of the VG to make it more stressful), using the peripherals (for non-gamers), or user's mental state (negative self-talk and other psychological / personal factors). The source of the stress is irrelevant to the current SMT task, although the instructors could notice and report significant observations if needed (i.e., if one source of stress is especially significant for a user).

What matters is that users learn to recognize their stress level when it increases and develop confidence and proficiency in using tactical breathing. The program is based on a progressive approach, with three sessions (blocks) of 30 minutes to practice tactical breathing. Each session progressively expects more autonomy from the user.

The instructor must have to following pages printed and follow the instructions during the sessions with the users. Adjustment on timing are allowed when necessary and the instructors can communicate with each other, and with the system operators, via radios.

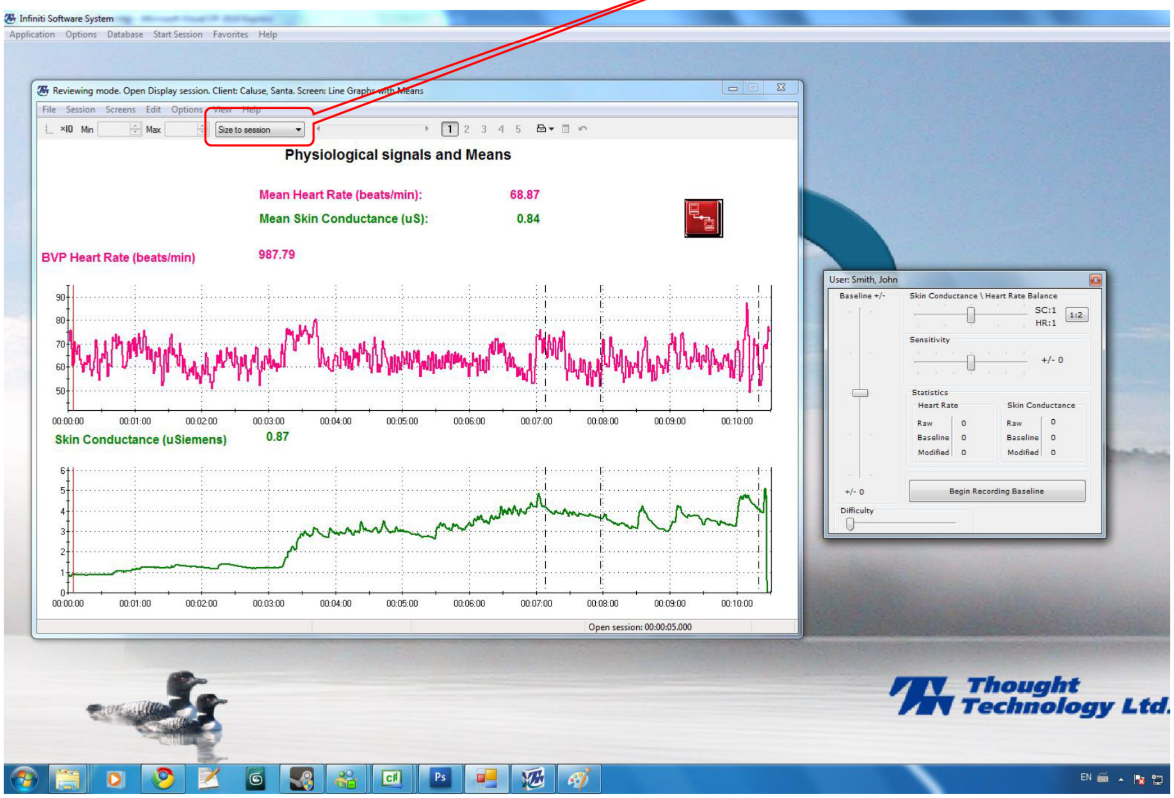
After each session with a participant, the instructor must check the "Performed Task List". Instructors can exchange among themselves if they have issues to work on about the feasibility of each tasks.



The GUI allows the instructor to: (a) modify during the session (i.e., cheat) the value used for the baseline (increasing the value by 10 raises the baseline GSR by 10); (b) give more weight to either hear rate (HR, slide to right) or GSR (SC, slide left) (if the arousal is picked-up mostly by one dimension, the instructor may want to give more weight to that dimension); and (c) sensitivity (increasing sensitivity will make smaller changes in arousal to have larger impacts in the biofeedback). Hit "Begin Recording Baseline" to start the application. Increasing the difficulty level will make the game more difficult.

The large rectangle button *Begin Recording Baseline* will launch the biofeedback application and start recording the baseline GSR and GSR, during 120 seconds. Once this is done, the appearance of the button will change to *Start the Experiment*. Clicking on this button will also mark the event in the Biograph Infinity interface (dotted vertical space bar). *Pause* and *Reset* buttons will appear once the experiment is started.

During the experiment, the laptop will display an image like the one below, with the recording from Biograph Infinity on the left and the GUI on the right. Note that to get a nice visual display the instructor should, before starting the experiment, set the size to 30 minutes (note that Size to session is not available while recording the data.



SESSION 1: LEARNING PHASE, WITH ACTIVE COACHING

- Step 1 – Brief recap of the tactical breathing technique. *2 minutes*
  - Review the technique and the contexts where it could be applied
  - Present the sequence of today's practice (see below).

- Step 2 – Guided discovery / playing without applying the technique to get familiarised with the stress response. *4 minutes*
  - User discovers the link between stress and visual / audio feedback.
  - Instructor can adjust the sensitivity of the device.

- Step 3 – Getting acquainted with biofeedback while immersed / playing with the goal of mastering the skill instead of winning[1] (active coaching). 11 *minutes*
    - User tries to apply tactical breathing to reduce stress. It does not matter if he/se does not progress in the game.
    - Instructor helps detect stress and apply technique.

- Step 4 – Practising while playing the game[1] at a slow to moderate pace (try to both self-regulate stress and win the game, while progressively exploring the map and being actively coached in applying tactical breathing). 11 *minutes*
    - User augments the pace to play more intensively the game and progress faster while practicing the technique.
    - Instructor reminds user to apply the technique, reinforces user when stress is controlled, and points-out contexts when it can be applied (e.g. during apprehension).

- Step 5 – Recap. 2 *minutes*
    - User knows the technique and feels an increase in self-efficacy
    - Instructor mentions explicitly that the technique is to be used when stressed.

Note: [1] It is important that the user understands that, right now, winning the game is not as important as acquiring the skills (i.e., play at a slow pace to practice tactical breathing in action).

Performed Task List

After each session, please check to document if the following points were addressed.

Session 1	Participant ID / number: _____	Instructor initials: _____
Reviewed the tactical breathing technique		☐
Reviewed the 3 contexts where tactical breathing could be applied		☐
Helped the user discover the link between stress and the feedback		☐
Helped detect signs of stress		☐
Helped apply tactical breathing technique		☐
Reinforced the user when he did good		☐
Showed to use tactical breathing in the different contexts		☐
Recap the key points of today's session		☐
Mentioned explicitly that the technique is to be used when stressed		☐
I needed to adjust the sensitivity of the device		☐
I needed to adjust the weight of the GSR vs HR		☐
I needed to adjust the value of the baseline		☐

SESSION 2: MASTERING PHASE, WITH ACTIVE COACHING

- Step 1 – Brief recap of when practicing the technique. 2 *minutes*
  - Review the contexts where it could be applied (in apprehension, during acute stress, when in need to step back)
  - Present the sequence of today's practice (see below).

- Step 2 – Practicing while playing the game at a moderate pace (try to both self-regulate stress and win the game[1], while exploring the map and being coached in applying tactical breathing). *12 minutes*
  - User augments the pace to play more intensively the game and progress faster while practicing the technique.
  - Instructor reminds user to apply the technique, reinforces user when stress is controlled, and points-out contexts when it can be applied (e.g. during apprehension). Show the user to practice the technique when in need to step back, even if the stress is not at maximum peak.

- Step 3 – Practicing while playing the game[1] at a rapid / natural pace (try to both win the game and self-regulate stress, with a coaching that facilitates increase in self-efficacy). *13 minutes*
  - User plays more intensively the game and progress faster while practicing the technique so the technique becomes more of a reflex.
  - Instructor reminds user to apply the technique, reinforces user when stress is controlled, and points-out contexts when it can be applied (e.g. during apprehension).

- Step 4 – Recap. 3 *minutes*
  - User knows the technique and feels an increase in self-efficacy to practice it in the three contexts.
  - Instructor mentions explicitly that the technique is to be used when stressed and when apprehending stress.

Note: [1] It is important that the user understands that, in the first part of the session, winning the game is not as important as acquiring the skills (i.e., play at a slow pace to practice tactical breathing in action). But in the second part of the session, the user is ordered to play the game at a strong pace to help him or her integrate the application of the technique as a reflex.

Performed Task List

After each session, please check to document if the following points were addressed.

Session 2	Participant ID / number: _____	Instructor initials: ______
Reviewed the 3 contexts where tactical breathing could be applied		☐
Helped detect signs of stress		☐
Helped apply tactical breathing technique		☐
Reinforced the user when he did good		☐
Showed to use tactical breathing in the different contexts		☐
Practice using tactical breathing when in need to step back		☐
Recap the key points of today's session		☐
Mentioned explicitly that the technique is to be used when stressed		☐
Mentioned explicitly that the technique is to be used during apprehension		☐
I needed to adjust the sensitivity of the device		☐
I needed to adjust the weight of the GSR vs HR		☐
I needed to adjust the value of the baseline		☐

SESSION 3: AUTOMATISATION PHASE, WITHOUT ACTIVE COACHING

- Step 1 – Done by only one instructor with both users at the same time. 2 *minutes*
  - Review both the technique and the contexts where it could be applied
  - Present today's practice (see below).
  - Set-up the sensitivity and ratio of HR and GSR if needed.
  - Participants receive the order to control their stress and not only enjoy playing.

- Step 2 - Playing the game[1] at a natural pace and using biofeedback autonomously to apply tactical breathing. *26 minutes*
  - User plays the game and practice autonomously the technique.
  - Instructors role are: (a) make sure the user does not ignore the biofeedback to play only for fun, and (b) assist user in case he or she really needs help. The goal is essentially to foster autonomy.

- Step 3 – Recap. 2 *minutes*
  - Instructor explicitly reminds users that the technique is to be used when stressed, including in each of the three contexts.

Note: [1] It is important that the user has to play the game at a strong pace to help him or her integrate the application of the technique as a reflex. Playing only for fun is unacceptable; this is a serious task, not a time for fun.

Performed Task List

After each session, please check to document if the following points were addressed.

Session 3	Participant ID / number: _____	Instructor initials: ______
Reviewed the tactical breathing technique		☐
Reviewed the 3 contexts where tactical breathing could be applied		☐
Told the user to control their stress and not only enjoy playing the game		☐
Ensured the user was not ignoring the biofeedback to play only for fun		☐
Had to help the user apply tactical breathing technique		☐
Reinforced the user when he did good		☐
Was able to let the user practice tactical breathing on his / her own		☐
Reminded the users that the technique is to be used when stressed		☐
Reminded the user that the technique is to be used during apprehension		☐
I needed to adjust the sensitivity of the device		☐
I needed to adjust the weight of the GSR vs HR		☐
I needed to adjust the value of the baseline		☐

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List of symbols/abbreviations/acronyms/initialisms

3D	Three-Dimensional
AI	Artificial Intelligence
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
BP	Blood Pressure
CAVE	Cave Automatic Virtual Environment
CF	Canadian Forces
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
ESRB	Entertainment Software Rating Board
FOV	Field of View
FPS	First-Person Shooter
GSR	Galvanic Skin Response
GUI	Graphical User Interface
HF	Heat Flux
HR	Heart Rate
IED	Improvised Explosive Device
IKM	Ignorance and Knowledge Management
KAF	Known Avatar First
KF	Killing Floor
ImPACT	Immersion and Practice of Arousal Control Training
ITQ	Immersive Tendencies Questionnaire
L4D	Left 4 Dead
R2MR	Road to Mental Readiness
ns	Not Significant
PERM	*Programme d'entraînement à la résilience militaire*
PTSD	Post-traumatic Stress Disorder
R&D	Research & Development
R2MR	Road to Mental Readiness
S&T	Science & Technology
SMT	Stress Management Training

SoS	System of Systems
SR-GEQ	Self-Reported – Gaming Experience Questionnaire
SR-SAM	Self-Reported - Self-Assessment Manikin
TAU	Training as Usual
TSST	Trier Social Stress Test
TV	Television
UAF	Unknown Avatar First
UQO	Université du Québec en Outaouais
VG	Video Game
VR	Virtual Reality
VRGL	Virtual Reality Graphics Library

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There is a strong movement in the military to implement programs that foster mental resilience and readiness. One key ingredient in these programs is stress management training (SMT). Traditional approaches to training are limited because of the lack of practice of the skills in stressful situations and of resistance with approaches related to emotion. Virtual reality (VR) and video games (VGs) can help to overcome such limitations; these technologies are appreciated by their users and their effectiveness for training is proven. This report presents the results of a three-year research project on creating and assessing the efficacy of an immersive VG-based training system augmented with biofeedback (Immersion and Practice of Arousal Control Training; ImPACT) for learning to master SMT. Aspects discussed include a review of SMT and the validation of the potential of VGs and VR to induce stress. Also presented are the possible designs for adding biofeedback to VGs. This report concludes with a randomized control trial of ImPACT. Statistical analyses of the heart rate (HR) and salivary cortisol revealed significantly less stress for soldiers trained with ImPACT than those trained as usual. In addition, soldiers trained with ImPACT performed better and were more confident in their stress coping skills. The immersion in a stressful VG, coupled with biofeedback, was shown to be more effective than training as usual and it has the additional advantage of favouring the “buy-in” of emotion management by soldiers. More studies could be conducted to refine ImPACT. In the meantime, the Canadian Forces (CF) should consider implementing this approach on a larger basis.

On note une vague de popularité dans les milieux militaires à implanter des programmes ciblant la résilience psychologique. L’utilisation de techniques de gestion de stress (TGS) demeure un concept clé dans ces programmes. Toutefois, les approches traditionnelles souffrent de l’absence de pratique dans des situations stressantes ainsi qu'une certaine aversion pour les approches liées aux émotions. La réalité virtuelle (RV) et les jeux vidéo (JV) peuvent aider à combler de telles lacunes. Ces technologies sont appréciées et ont démontré leur efficacité pour l'entraînement. Ce rapport présente les résultats d'un projet de recherche de trois ans sur la création et la validation d'une plateforme d'entraînement immersive basée sur les JV et augmentée de bio-rétroaction (Immersion and Practice of Arousal Control Training; ImPACT) afin d'enseigner les TGS. Les éléments présentés inclus une validation de l'efficacité des TGS et du potentiel de certains JV et de la RV à induire du stress suivis. Une analyse d'options sur l'extension des JV avec la bio-rétroaction est également présentée. Ce rapport conclu avec un essai clinique aléatoire d'ImPACT. Les analyses statistiques du rythme cardiaque et du cortisol salivaire ont révélé un stress significativement plus bas pour les soldats entraînés avec ImPACT en comparaison avec ceux entrainés comme d'habitude. Aussi, les soldats entraînés avec ImPACT ont mieux performé et ont développé une plus grande confiance à appliquer les TGS. L’immersion dans un jeu vidéo stressant étendu avec de la bio-rétroaction a été plus efficace que l’entraînement théorique habituel et comporte l’avantage d’être plus attrayante comme outil de régulation émotionnelle pour la population militaire. Des recherches complémentaires pourraient être effectuées pour affiner ImPACT, mais entre temps, les Forces Canadiennes se doivent de considérer l’implantation de cette approche à plus grande échelle.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS

Stress management, videogames, virtual reality, biofeedback, immersion